STRATIGRAPHY AND PALEOECOLOGY OF THE FOX HILLS FORMATION (UPPER CRETACEOUS) OF NORTH DAKOTA

by

Rodney M. Feldmann

1972

BULLETIN 61
North Dakota Geological Survey
Edwin A. Noble, *State Geologist*

This bulletin is a condensation of a doctoral dissertation submitted to the faculty of the University of North Dakota by Rodney M. Feldmann in June 1967. In addition to the material here published, the dissertation contains a considerable amount of additional information including systematic descriptions of species and illustrative plates. The thesis is in the library at the University of North Dakota, Grand Forks, North Dakota.

CONTENTS

ILLUSTRATIONS

TABLES

ABSTRACT

The bivalve fauna of the Fox Hills Formation, Maestrichtian, of North Dakota was studied in an attempt to modernize the nomenclature of known bivalves, describe new forms, interpret the relationships of members of the formation, and establish the paleoecological setting in which the Fox Hills was deposited.

The Fox Hills Formation crops out in Logan, Emmons, Sioux, Morton, Burleigh, Kidder, Pierce, McHenry, Bottineau, and Bowman counties in North Dakota. It is best exposed along the Missouri River in south-central North Dakota. Traditionally, the formation has been subdivided into four members, all of which are exposed in the type area of the formation in north-central South Dakota. In North Dakota, however, the lowermost Trail City Member cannot be lithologically recognized and, therefore, only the Timber Lake, Bullhead, and Colgate members, in ascending order, have been recognized. Lithologically, the Timber Lake Member consists of medium- to fine-grained sandstone, which is either unconsolidated or loosely cemented. This unit becomes increasingly crossbedded toward the top. The Bullhead Member consists of a sequence of intercalated sandstone and shale which is essentially devoid of bivalves. The uppermost member, the Colgate, consists of light colored greywacke sandstone.

Forty-two species of bivalves were identified from the Fox Hills Formation in North Dakota and arranged in twenty-five genera. This number included three hitherto undescribed species. Three other species which are characteristic of the Cretaceous of the Eastern Seaboard were identified for the first time from the Midcontinent.

Using ecological data derived by studying the ecology of recent bivalves of the same genera as those collected in the Fox Hills Formation and the sedimentologic data, it was concluded that the Fox Hills Formation in North Dakota represents the littoral and shallow subtidal sedimentation unit of the retreating Cretaceous epicontinental seaway. Data from the bivalves indicated that, in general, water depth decreased from about 80 fathoms to 0 fathoms from the base of the formation to the top, an observation which is further strengthened by sedimentologic evidence. These data in conjunction with those derived from the presence of a volcanic ash bed occurring in several parts of Emmons, Sioux, and Morton counties, which transcends the member boundaries, indicate that the members were being deposited penecontemporaneously across central North Dakota. At the time that the strand line, now represented by the Fox Hills-Hell Creek boundary, occupied the area of central Sioux County, the Pierre-Fox Hills boundary would have occupied an area in central Emmons County

forty miles to the east. Deposition of the Timber Lake Member was normal marine, whereas that in the area of Bullhead deposition was apparently brackish, probably as a result of restriction caused by development of barriers in the area of the upper Timber Lake Member. The Colgate Member represents the strand line of the Fox Hills seaway.

INTRODUCTION

Purpose

This study is an attempt to unravel a portion of the history of the Fox Hills Formation in North Dakota. This unit, deposited in the last stages of marine inundation of the Midcontinent during the Cretaceous Period, represents not only a long sequence of deposition in the area of North Dakota, South Dakota, Montana, Wyoming, and Colorado, but also affords some key to the development of the Rocky Mountains, which were tectonically active during this period and shed sediments to the east, forming the Fox Hills Formation.

During the summers of 1962-64, I studied the Fox Hills Formation throughout North Dakota, visiting virtually every known outcrop of that unit in the state. The purpose of the study was to describe the bivalve fauna of the Fox Hills Formation and to determine as nearly as possible the paleoecological setting in which the Fox Hills Formation was deposited. The study entailed carefully collecting all fossils that could be found, piecing together the stratigraphic sequence, identifying the fossils, and attempting to portray, as accurately as possible, the geological setting at the time of deposition of the formation. The conclusions are, of necessity, restricted in that not all of the fossil groups represented in the formation have been studied, and in that the exposures of the Fox Hills in North Dakota, as first indicated by Leonard (1906, p. 75), are in no way extensive, resulting in considerable difficulty in piecing together a complete stratigraphic section.

ACKNOWLEDGMENTS

During the preparation of this paper, a number of people offered valuable assistance and corrective criticism and their aid is gratefully acknowledged.

Notable among them are Dr. F. D. Holland, Jr., who initially introduced me to the problem and throughout the preparation of the manuscript offered many suggestions. Drs. Robert A. Caldwell, Alan M. Cvancara, Wilson M. Laird, and George C. Wheeler served as additional members on the Ph.D. dissertation committee and carefully read the manuscript.

Dr. Wilson M. Laird, State Geologist and head of the North Dakota Geological Survey, offered financial assistance to me during the three summers that field work was done. Further assistance was given by Dr. Horace G. Richards, Curator of Paleontology at the Philadelphia Academy of Natural Sciences, who made the collections of the museum available to me and assisted in locating specimens. During the completion of the manuscript, Dr. Barry B. Miller, Assistant Professor of Geology at Kent State University, read the section dealing with stratigraphy and paleoecology and offered many valuable suggestions.

Finally, I would like to thank my wife, Barbara, who typed a portion of the original manuscript and without whose perseverance, understanding and, at times, fortitude, this work could not have been completed.

This paper is Contribution Number 22 of the Department of Geology, Kent State University, Kent, Ohio.

Location and Physiography

The outcrops of the Fox Hills Formation in North Dakota are widely scattered (Fig. 1). The most extensive area of Fox Hills exposure is in the south-central portion of the state in Sioux, Morton, Emmons, Burleigh, and Logan counties along the Missouri River. Two smaller areas in which the formation is seen, somewhat less well exposed, are the north-central portion of the state in Bottineau County and the extreme southwestern part of the state in Bowman County. In the latter two areas, however, exposures of the Fox Hills are extremely limited, no fossils were found, and only limited work was done.

The areas of Fox Hills exposure lie within three different physiographic regions of the Midcontinent. The portion surrounding the Turtle Mountains occupies a small part of what has been called (Fenneman, 1931; 1938) the Western Lake Section of the Central Lowland Province. The area adjacent to the Missouri River as well as the area of outcrop of Bowman County in the southwestern portion of the state is in the physiographic region designated as the Missouri Plateau Section of the Great Plains Province. The former area is in the

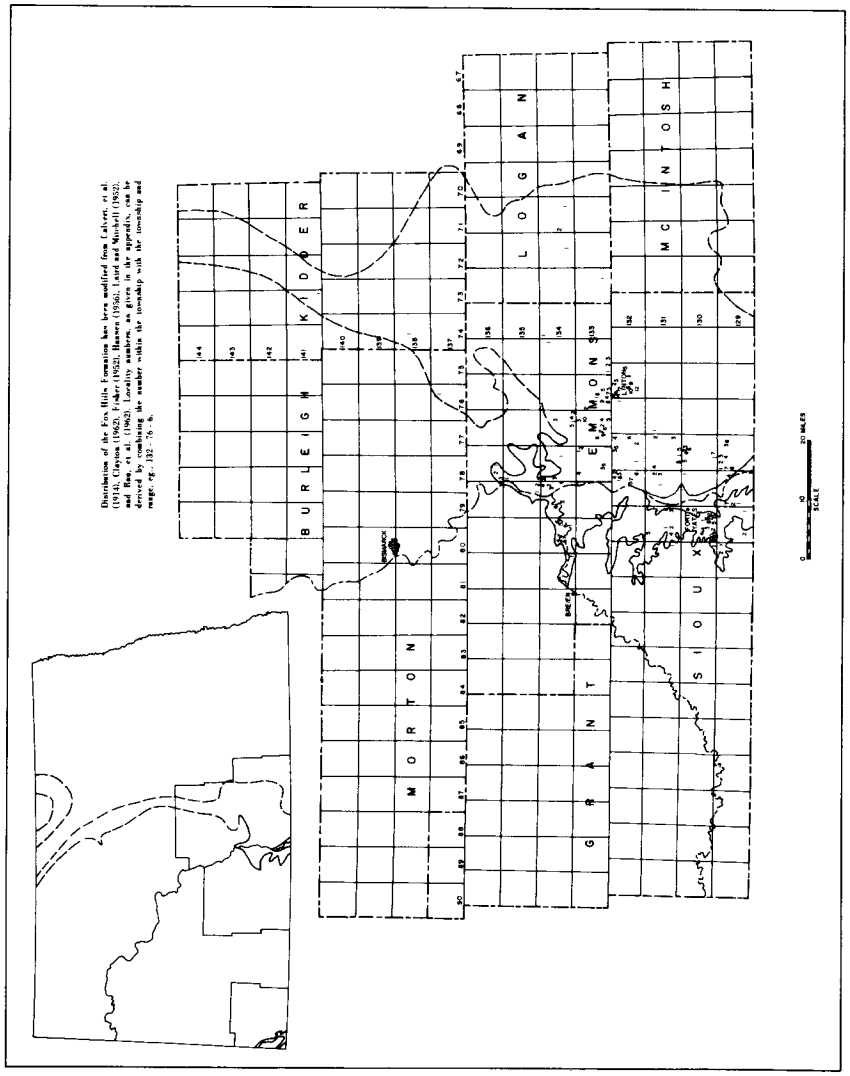


FIGURE 1. Location map showing distribution of the Fox Hills Formation in North Dakota and collecting localities in south central North Dakota.

glaciated portion of the Missouri Plateau; the latter in the nonglaciated portion of the Missouri Plateau. The physiographic expression of these various areas plays a rather fundamental role in the study of the Fox Hills Formation in that the majority of the area has been glaciated. The result is a rather subdued topographic setting in which exposures of bedrock are restricted. This cover is wide-spread enough that, in the regions surrounding the Turtle Mountains and adjacent to the Missouri River, exposures are found only along streams and highway ditches. Generally speaking, the area is given to agricultural usage and exposures of bedrock are limited to extremely small areas. The nonglaciated portion of the Missouri Plateau affords somewhat better exposures. However, the Fox Hills is considerably thinner and is apparently devoid of fossil material in this area.

The areas in North Dakota in which the Fox Hills is exposed fall into two distinct climatic zones. The areas east of the Missouri River fall within the bounds of the interior subhumid lands (Trewartha, 1941, p. 168) and are characterized by an average annual precipitation in excess of 16 inches (Bavendick, 1941, p. 1053) and a tall grass prairie flora (Wheeler and Wheeler, 1963, p. 67). The area west of the Missouri River is characterized by semiarid climate (Thornthwaite, 1941, p. 178). Here, rainfall varies between 14 and 16 inches (Bavendick, 1941, p. 1053) and the flora is characterized by mixed and short grasses (Wheeler and Wheeler, 1963, p. 67).

Historical Development

The accumulation of knowledge about the Fox Hills Formation in North Dakota and closely related areas has been sporadic and, with the exception of two periods nearly a century apart, extremely slow. Apparently the first recorded mention of the beds that were later to be called the Fox Hills Formation was that by Lewis and Clark on October 18, 1804. They noted (Thwaites, 1905, p. 198), ". . . above the mouth of the river Great numbers of Stone perfectly round with fine Grit. . . ." The stones to which they referred were large sandstone concretions in the Timber Lake Member of the Fox Hills Formation. The river mentioned had earlier been named *Le Boulet*, or Cannonball, by French trappers (Thwaites, 1905, p. 198) who had also noticed the structures.

Observations similar to those by Lewis and Clark were made by Alexander Philip Maximilian in 1833 (Thwaites, 1905, p. 338). Not only did Maximilian observe the concretionary structures, but he also

noted the dip of the units to the northwest, into what is now called the Williston Basin. The observations of Maximilian were, however, apparently nothing more than minor points of interest, and it was left for Edward Harris to make the first truly scientific observations.

Harris traveled up the Missouri River with John James Audubon in 1843 to study the birds and quadrupeds of the area. Although Harris was an agronomist, he had a remarkable ability to observe natural phenomena and made the first significant statements concerning the stratigraphy and structure of the area through which he passed. Notable among these are the following comments concerning the beds that were later termed the Fox Hills:

> About 40 miles below the Mandan Fort the shale and clay formation first noticed below the great Bend disappears below the bed of the river, the Stratum which overlies it I believe to be the brownish stone seen soon after leaving Fort Pierre, I have had no opportunity whatever of examining this Rock and cannot speak of its character. On passing the mouth of Cannon Ball river yesterday we noticed a remarkable formation of this stratum of round masses of the rock in the divisions of the strata many of them apparently perfectly spherical and from 18 inches to 30 inches in diameter, some are as perfect as cast balls and others appear to be flattened or composed of two sections of a sphere, from a smaller arc up to a hemisphere, joined together with mathematical nicety, and surrounded by a belt or zone at the junction, which zone corresponds with the line of division of two strata. (McDermott, 1951, p. 89-90.)

Unfortunately, although Harris was encouraged to publish his diary, he took no action in that direction. The first complete publication of his notes was not made until 1951 (McDermott, 1951, p. IX) and, therefore, his observations were not publicly available until long after other workers had completed far more extensive works.

Somewhat earlier than the work of Edward Harris, S. G. Morton published a paper (1839) describing several new species of organisms collected from the Cretaceous of the Midcontinent and at the same time proposed a correlation of the Cretaceous units located in the Midcontinent with those of the Eastern Seaboard. This work closely followed what has been described (Merrill, 1924, p. 117) as the first use of fossils for correlation in the United States. His earlier work, published in 1828, was a study of the Tertiary sediments of the east coast. In his work in 1839, Morton attempted to piece together the record of the Cretaceous System as it was known in the country at that time. He did so by dividing the Cretaceous into three divisions, the "upper," "medial," and "lower." The upper unit was presumed to be the "Nummulite limestone" found in Alabama. It was characterized by an absence of annomites but the presence of *Nummulites* and the cephalopod *Nautilus*. The medial Cretaceous Morton thought to be represented by deposits from Vincentown to Salem in New Jersey and correlated with the White Chalk in England and France. The medial

Cretaceous was then characterized by the fossil *Belemnites ambiguus*. The lower unit consisted of a ferruginous sand from Martha's Vineyard to South Carolina and then west across the Mississippi River into the Midcontinent. This unit Morton correlated with deposits between the "White Chalk" and the "oolite" in Europe. The lower unit was characterized by an abundance of ammonites as well as the marine reptile *Mososaurus*. Although Morton also named a number of new species in this work, by far the most significant aspect of the study involved the observation that the Cretaceous deposits along the eastern seaboard were related, at least temporally, to those in the Midcontinent. Morton did not present a stratigraphic section at this time, but his work still stands as monumental in that he had, by this time, fully demonstrated the use of fossils for correlation in the United States.

Although several other explorers, trappers, and adventurers visited North Dakota and South Dakota during this same period and made significant contributions in the fields of paleobotany and vertebrate paleontology, nothing more was done with the Fox Hills stratigraphy and paleontology until 1853. In that year James Hall, State Geologist of New York, instructed Dr. Fielding Bradford Meek and Dr. Frederick Vandiveer Hayden to travel up the Missouri River to Fort Pierre and to study and collect the Cretaceous and Tertiary fossils of that region. Although the expedition was primarily designed for the collection of vertebrate fossils (Meek, 1876, p. XXII), many invertebrates were also collected along with detailed data concerning the stratigraphy of the area. This trip, and subsequent trips by Hayden provided the nucleus of stratigraphic and paleontologic data from which was constructed the first comprehensive study of the Cretaceous and Tertiary of the Midcontinent. Their material was originally published as a series of taxonomic papers.

The first of these (Meek and Hayden, 1856) also contained the first known stratigraphic section of the beds in North Dakota and South Dakota (Fig. 2). Essentially the same section was given in 1857; however, at this time the original estimates of thickness were somewhat revised (Meek and Hayden, 1857, p. 63). These sections subdivided the Cretaceous System in the Midcontinent into five units of which the Fox Hills Formation, then referred to as Unit 5, was described as 100 to 150 feet of "grey and yellowish arenaceous clays containing great numbers of marine Molluska with a few plants" (Meek and Hayden, 1857, p. 63). This section underwent still further modification and was published in final form, for the first time, in 1861 (p. 419). At this time the units, which had previously been given numerical designations, were assigned names based on areas of typical exposure. The names Dakota, Fort Benton, Niobrara, Fort Pierre, and Fox Hills, formed the

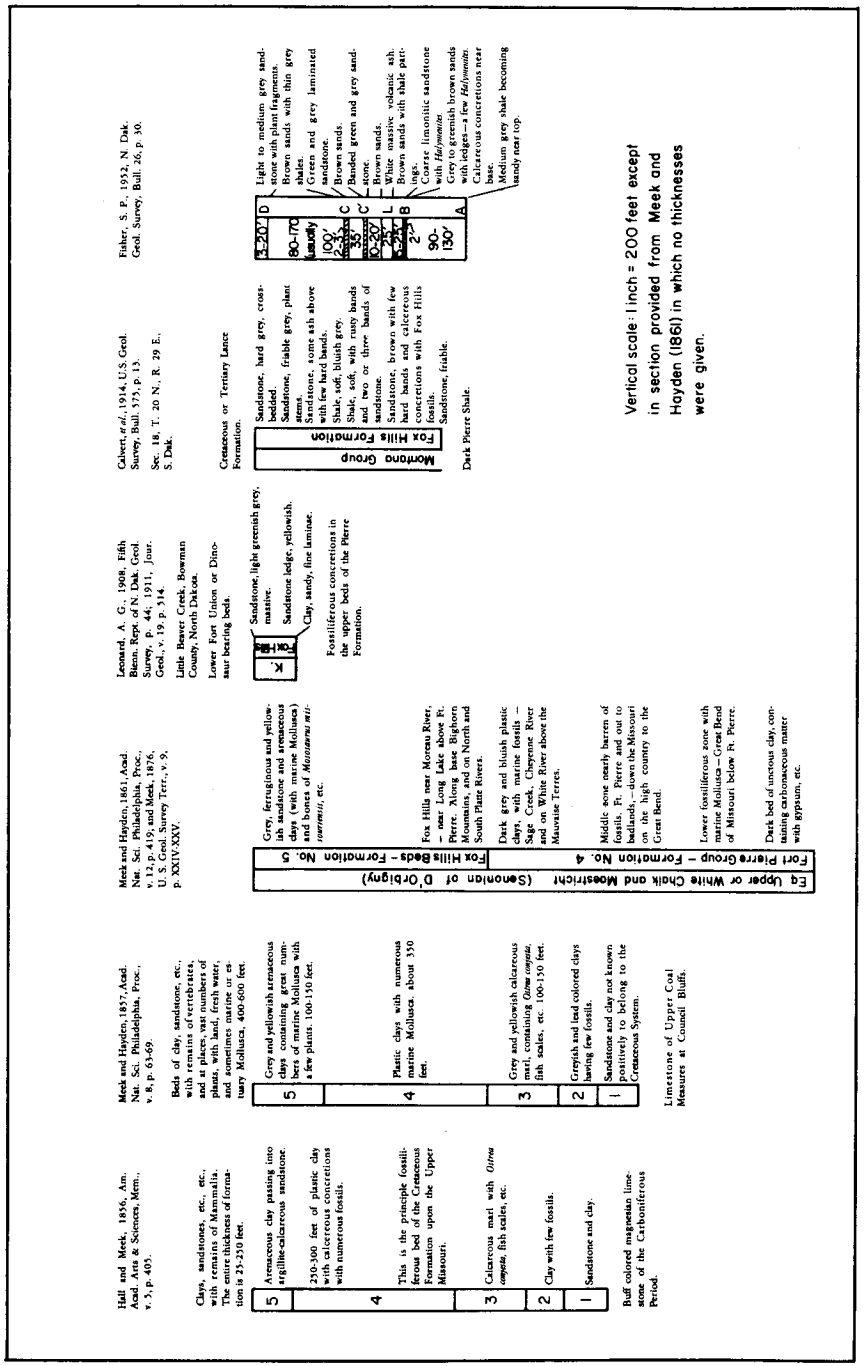


FIGURE 2. Summary of stratigraphic sections of the Fox Hills Formations in North Dakota.

framework of the standard section of the Upper Cretaceous in the Midcontinent.

Following this short burst of activity, Hayden served as a doctor with the Union Army and Meek became involved in investigations for several state geological surveys. Further work on the Cretaceous of North Dakota was, therefore, not completed until 1876. In that year, Meek completed a monographic tome dealing with the stratigraphy and paleontology of the Cretaceous and Tertiary of the "upper Missouri country." This document, published under the auspices of Hayden's United States Geological Survey of the Territories, is a thorough, well illustrated, relatively modern treatment of all Cretaceous and Paleogene fossils known from the area to that date. It serves as a fitting tribute to Meek who died in the same year. It is still considered a standard paleontological reference for the area.

In the twenty years following the work of Meek and Hayden, little was done concerning the study of the Fox Hills in North Dakota. However, in 1879, Stevenson published a paper dealing with the Fox Hills group in Colorado, thus extending it about as far south and west as the unit had, to that point, been carried. The next work in North Dakota was that of Todd (1896). Todd studied the glacial deposits along the Coteau du Missouri and reported Fox Hills sandstone in several localities in Kidder, Burleigh, and Emmons counties. He also reported the presence of leaves collected from well cuttings in Kidder County and oysters in a coarse brown sandstone in Emmons County (1896, p. 56). Following the work of Todd, Babcock (1901) published the First Biennial Report of the North Dakota Geological Survey. In this report, Babcock discussed the occurrence of the Fox Hills Formation in North Dakota and reported it not only from the area adjacent to the Missouri but also mentioned that it could be found in the Turtle Mountains and west of Rugby, North Dakota. He further reported that it was useful as a building stone near the Turtle Mountains and near Dickinson, North Dakota. Although the Fox Hills Formation is known to have provided building stone in Emmons County, no other reference to its use in the area of the Turtle Mountains is known. Almost certainly, the material referred to near Dickinson, North Dakota, comes, not from the Fox Hills Formation, but from one of the overlying units, possibly the Tongue River Formation of Paleocene age.

In 1902, Wilder presented the first known stratigraphic section of the deposits in North Dakota. He referred to the Fox Hills "stage" of the "upper Cretaceous series" and described it as being a sandstone. His main reference to previous work is to that of Todd(1896); however, he was skeptical of this identification and stated (Wilder, 1902, p. 42) that "The reference of these elevated sandstones in Emmons, Burleigh, and

Kidder Counties to the Fox Hills may fairly be regarded as very doubtful." Leonard (1904) considered the Fox Hills Formation in about the same vein as did Wilder in that he included in the formation the beds adjacent to the Cannonball River in Sioux and Morton counties, but considered the sandstones exposed on the eastern side of the Missouri River as being Laramie in age. He further stated that in the area of the Turtle Mountains the Fox Hills would be buried at some depth, thereby indicating that the observations of Todd in 1896 were incorrect. In a later study, Leonard (1906, p. 75) summarized the knowledge of the Fox Hills Formation in North Dakota as being extremely incomplete and stated that "on account of the lack of exposures little is known of the character of the Fox Hills strata in this state." He did, however, indicate some knowledge of the geological setting of the Fox Hills in this area by stating (1908, p. 234) that the Fox Hills represented the last advance of a seaway into North Dakota. He also indicated that the relationship between the Fox Hills Formation and the overlying units is one of unconformity, having noted an erosional surface at the top of the Fox Hills along Little Beaver Creek. This, to Leonard, indicated that the overlying sediments were ". . . much younger geologically than those beneath" (Leonard, 1908, p. 234).

The publication of the last-mentioned paper represents the close of what might be considered the first stage in development of knowledge concerning the stratigraphy of the Fox Hills Formation in North Dakota. It had started essentially with the work of Meek and Hayden and at that time reached the peak of its development. From that time on, however, the unit had been restricted in lateral extent to the point that very little Fox Hills was recognized in the state by 1910.

The next publication dealing with the Fox Hills in North Dakota was that of Stanton (1910, p. 172-188) in which he discussed the uppermost Cretaceous in North Dakota, South Dakota, and eastern Wyoming. Numerous detailed stratigraphic sections were given, although none was measured within the boundary of this state. Included with the sections are rather long lists of fossil species collected from the various localities and, for the first time, an indication that the fossils in the Fox Hills Formation may be used for something other than strictly stratigraphic study. In several places Stanton indicated that the environment in which the organisms lived could be interpreted by studying the sediments and the fossil remains. He suggested (p. 178), for example, that the top portion of the Fox Hills sandstone contained not only marine but, in many places, brackish water organisms, including oysters, *Anomia* and *Corbicula* and that, therefore, the beds represented a transition between the marine unit below and the predominantly fresh-water unit overlying the formation. He also

suggested that the change in character and thickness of the unit from Colorado to North Dakota was a function of distance from source and variation in topographic expression of the source.

Sometime later, Calvert (1912) published a paper dealing with the economic implications of lignite deposits in eastern South Dakota, and, in discussing the general stratigraphy of the area, mentioned the occurrence of what he referred to as the "Colgate sandstone member of the Lance Formation." He continued by stating that this unit occupied the stratigraphic position of the Fox Hills Formation, but that information provided by plant fossil studies conducted by Knowlton indicated the age to be Tertiary rather than Cretaceous. This information coupled with the total absence of sandstone other than that which could be attributed to the Colgate Member, indicated to Calvert that the Fox Hills was definitely not present in Bowman County. Although further work with the plant fossils in the Colgate Member will be discussed below, suffice it to say here that the Colgate Member is now referred to the upper portion of the Fox Hills Formation and is considered Cretaceous in age.

Leonard (1911, 1912) summarized the fossils collected in the areas of the Cannonball River and Long Lake Creek and published what apparently was the first geologic map delimiting the extent of the Fox Hills Formation in south-central North Dakota. It is evident from the map that the earlier views mentioned by Leonard, regarding the extent of the unit, had been somewhat modified in that the majority of Emmons County in which sandstone is exposed at the surface is mapped as Fox Hills. He did, however, seem to restrict the surface exposure of the unit somewhat more than would be done today; he showed the most eastern extent of the unit as about ten miles west of Linton in central Emmons County. The unit is now known to extend as far east as the western third of Logan County.

Shortly after Leonard's map was published, Calvert, *et al.* (1914) published a report on the geology of the Standing Rock and Cheyenne River Indian Reservations in North Dakota and South Dakota. This report included an extremely detailed geologic map of the area portraying quite accurately the extent of the Fox Hills Formation. They also concluded that the Fox Hills Formation represented a shallow water unit which is gradational with the Pierre Formation below and is not separated from the overlying units by any considerable time span, thus concurring with the earlier work of Stanton. It might be noted that Calvert, *et al.* suggested two possible origins for the numerous calcareous concretions present in the formation. They suggested first that these accumulations represent natural colonies on the shallow sea floor which were formed, rather than being widely and evenly dispersed, as small groups or clusters of organisms which were

later buried and preserved. Secondly, they suggested that it is possible that these organisms represent accumulations that have been brought together by wave or current action and rolled into something resembling a mud ball. Although these concretions have been studied since that time, apparently no universally acceptable origin has yet been discovered and the two theories mentioned above seem to be as reasonable as any that have subsequently been suggested. Following the work of Calvert, nothing was published directly related to the Fox Hills Formation in North Dakota until 1937; however, several papers were published dealing with other areas of Fox Hills exposure which deserve brief mention here.

Two of these papers (Stebinger, 1914; Bowen, 1915) dealt with determining the lateral extent and stratigraphic relationships within the Montana Group, a term which had previously been coined by Eldridge (1889, p. 93) and which included the Bearpaw Shale, Judith River Formation, Claggett Formation, Eagle Sandstone in Montana, and related units in adjacent areas. Stebinger (1914, p. 67) indicated for the first time the temporal and lithologic continuity of three units: The Horsethief Formation, Lennep Formation, and the Fox Hills Formation, and indicated that they were the uppermost formations of the Montana Group.

In 1916, Knowlton published a paper dealing with the flora of the Fox Hills Formation. He dealt primarily with collections from South Dakota and Colorado. The two most significant contributions of this paper were that the flora indicated a distinct Upper Cretaceous age for the unit, and that the ecology of the flora indicated a warm, temperate climate, probably one near sea level (Knowlton, 1916, p. 87).

In 1929, Dobbin and Reeside resurrected a problem which had plagued students of the Cretaceous for some time. They concerned themselves with the contact between the Fox Hills Formation and the overlying unit which they referred to as the Lance Formation. They concluded that, contrary to the opinions held by several other workers at that time, no evidence of unconformity exists between the Fox Hills Formation and the overlying units, and that the variation in thickness of the unit from Colorado to North Dakota was original and did not represent an erosional interface. They further demonstrated that the apparent discordant bedding relationships between the beds of the Fox Hills and overlying units represented either very minor erosional scour features or cross-bedding or, in some cases, small local fault structures which again did not represent a major erosional break. They also made reference to the "Cannonball marine Member of the Lance Formation" which had been named some time earlier (Lloyd, 1914, p. 248-249). The apparent similarity of the fauna of the Cannonball and the Fox

Hills further indicated to Dobbin and Reeside that no major temporal break could have existed between the time of deposition of these two units.

By this time the usage of the term "Fox Hills Formation" was well established in the literature. The major problem that existed at this time involved determination of the precise location of the upper and the lower contacts of the unit. This problem arose for two reasons. The contact between the Pierre Formation and the Fox Hills Formation had long been recognized as transitional and deciding upon the precise position for the contact was, therefore, virtually impossible. Most workers apparently felt that the upper contact, although unconformable in local areas, did not represent any particularly long span of time. Lovering, *et al.* (1932, p. 702-703) attempted to define the boundaries of the unit and proposed the following definition of the contacts of the formation:

> **The base of the Fox Hills Formation shall be considered as the horizon below which the section is predominantly gray marine clay shales and sandy shales of Pierre age, and above which the section changes rapidly to a buff brown sandstone containing numerous large gray to brown, hard, sandy concretions. This lower concretionary member is commonly overlain by a series of light gray to brown sandstones and sandy shales.**
>
> **The top of the Fox Hills Formation shall be considered as the horizon above which the section is composed predominantly of fresh, and brackish water deposits accompanied by coals and lignitic shales, and below which it is predominantly marine.**

In a general sense, this definition is still usable today and represents the consensus of opinion regarding the upper and lower contacts of the unit.

Several other papers dealing with areas outside of North Dakota are also significant. Bartram (1937) discussed the regional setting of the Upper Cretaceous adjacent to the Rocky Mountain front, and in so doing, mentioned the Fox Hills Formation as representing the uppermost marine unit in this sequence. Although he did not discuss the Fox Hills Formation in general, he did suggest (1937, p. 910) that the term "Fox Hills" should be used in a somewhat more general sense, and that local names, such as Horsethief, Milliken, Trinidad, and Lennep should be dropped from the literature. Although this suggestion seems to bear considerable merit, the preponderance of workers since Bartram have chosen to avoid his suggestion. In the same year, Dane, Pierce, and Reeside discussed (1937) the Upper Cretaceous rocks in eastern Colorado and presented a series of faunal lists for the Fox Hills Formation. The majority of the species listed from Colorado correspond to those that have been noted in the type area of the Fox Hills Formation in South Dakota; however, some of the species

collected in Colorado, notably *Baculites grandis*, indicate that the unit in Colorado is somewhat older than that in North Dakota. This species is characteristic of the upper portion of the Pierre Formation in North Dakota and South Dakota.

Following the period from about 1910 to 1940, very little was done on the formation in North Dakota. A new surge of activity was then directed towards the study of the unit in this state. The first of these papers (Laird and Mitchell, 1942) was a study of the geology of southern Morton County and dealt, in part, with the stratigraphic relationships of the Fox Hills Formation. This work was essentially a continuation of the work by Calvert, *et al.* (1914) in Sioux County, south of Morton County. Laird and Mitchell mapped the units exposed in southern Morton County, described their stratigraphic relationships, and discussed the structure of the unit. A similar study was conducted by Fisher (1952) in Emmons County on the eastern side of the Missouri River and adjacent to the areas of Sioux and Morton counties. Fisher first applied the member terms, "Timber Lake" and "Trail City" to the lower two members of the Fox Hills Formation. Morgan and Petsch (1945) coined these terms for rocks in Dewey and Corson counties near the type area of the Fox Hills Formation in South Dakota. The mapping and stratigraphic information provided by Calvert *et al.*, Laird and Mitchell, and Fisher provides much of the basic regional information upon which the present study is based.

Several other regional studies have been conducted in North Dakota since the work of Fisher (1952) in which at least brief mention of the Fox Hills Formation has been made. These papers include Rau, *et al.* (1962), Clayton (1962), and Kume and Hansen (1965). These studies cover Kidder, Logan, McIntosh, and Burleigh counties in North Dakota. In all of these areas, a small amount of Fox Hills was noted and described and has since been restudied by the writer. Another work of regional scope is that of Lemke (1960), in which the Souris River area in north-central North Dakota was studied. He noted the presence of the Fox Hills Formation in two areas in McHenry and Pierce counties. The outcrop in McHenry County, northwest of Verendrye, is particularly significant in that it shows the relationship between the Fox Hills Formation and the next youngest overlying unit, the Cannonball Formation. In this area the Hell Creek Formation is totally absent or, if present, represents a very thin interval indicating that this location is very near the point where Fox Hills and Cannonball deposition was continuous.

The only other study concerning the Fox Hills Formation in North Dakota in recent years is that of Manz (1962) who discussed the pozzolanic properties of a volcanic ash deposit near Linton in Emmons County, North Dakota. This ash deposit, which had first been noted by

Stanton (1917, p. 80-81) has since been recognized as having certain economic as well as stratigraphic importance.

The work on the Fox Hills Formation in North Dakota in the past fifteen years has been considerably enhanced by similar studies conducted in the type area of the Fox Hills in north-central South Dakota. Waage (1961; 1968) has completed a redefinition of the type area of the Fox Hills Formation. This was prompted by a study of the unit in the type area in which he found that the original, rather vague, definition of the type Fox Hills was not adequate to thoroughly describe the complex nature of the formation. He, therefore, re-defined the type area to include portions of the Fox Hills Formation which crop out in Dewey and Corson counties in north-central South Dakota. In doing so, he has attempted to circumscribe an area in which most of the lithologic variants are exposed. Three of the members, the Trail City, Timber Lake, and Bullhead, are typically exposed in this area; whereas, the uppermost member, the Colgate, which is typically exposed in eastern Montana, occurs in this area as thin, discontinuous lenticular bodies. This work has resulted (Waage, 1968, p. 117-138) in creation of the Iron Lightning Member which includes both the Colgate and Bullhead members of other workers. Waage (1964, p. 541-563) also discussed the origin of the fossiliferous concretion zones which have been noted in the Fox Hills Formation in many areas and concluded that the concretion layers are a result of a series of mass mortalities which occurred during the time of the Fox Hills deposition.

Although the studies that have been mentioned do not include all papers which have discussed the Fox Hills Formation in North Dakota, they do serve to point out that no work has been devoted strictly to the Fox Hills Formation in North Dakota. Previous work has been one of two types, either considering the Fox Hills in regional aspect and only mentioning North Dakota occurrences in passing, or dealing with somewhat limited occurrences of the Fox Hills in North Dakota.

STRATIGRAPHY

Definition of Formation

The Fox Hills Formation was named by Meek and Hayden (1862, p. 419-427) as a unit which consisted of a sequence of silty sands and sandstone and which represented the uppermost Cretaceous marine deposits in the Midcontinent. They stated that the formation was most typically exposed in the "Fox Hills," which is the eastern end of the

divide between the Cheyenne and Moreau rivers in Ziebach and Dewey counties, north-central South Dakota. They further stated that the Fox Hills Formation could be seen in the area of Long Lake (since presumed to be general vicinity of Long Lake in Burleigh County, North Dakota) and in the areas of Sage Creek, White River, Mussel Shell River, and Milk River in Montana. The Fox Hills was also reported in the area of the North Platte River in Colorado and along the western margin of the Black Hills in Wyoming. On the basis of the enclosed fossils they correlated the unit with the "second Green Sand" in the New Jersey Cretaceous section (1862, p. 426). Prior to this time, the beds which are now called the Fox Hills, were called (Meek and Hayden, 1856, p. 63) unit "number five" in the Cretaceous section.

Meek and Hayden were rather cautious in pointing out that the contacts between the Fox Hills and the underlying Pierre Formation and the overlying unit, which they referred to in a later publication (Meek, 1876, p. XLVII) as the Judith River Group were gradational and extremely difficult to place. In regard to the lower contact Meek and Hayden (1862, p. 427) stated that

> it [the Fox Hills Formation] is not separated by any strongly defined line of demarcation from the formation below, the change from the fine clays of the latter to the more sandy material above, being usually very gradual. Nor are these two formations distinguished by any abrupt change in the organic remains, since several of the fossils occurring in the upper beds of the Pierre Group pass up into the Fox Hills beds, while at some localities we find a complete mingling in the same bed of the forms usually found at these two horizons.

They further stated that, with equal justification, the contact between the Pierre and the Fox Hills formations could be placed below the fossiliferous unit which they placed at the top of the Pierre Formation. They did not do this, however, on the grounds that the greatest sedimentological changes occur within the fossiliferous horizon. This contact has been the subject of considerable controversy since the formation was named and it has now been established, by convention, that the contact shall be picked, rather than at the horizon selected by Meek and Hayden, below the lowest fossiliferous horizon.

The upper contact was also described as being conformable and representing a more or less continuous sequence of deposition. In 1876, Meek (p. XLVII), in discussing the overlying Judith River, stated that

> at the typical locality [of the Judith River Group], it evidently rests upon well-marked Cretaceous strata belonging to the horizon of the upper part of the Fox Hills Group; and both have been upheaved together in such a manner as to show conclusively that there is no discordance of stratification or, in other words, that they are conformable.

This statement, however, leaves one with some question as to whether Meek and Hayden ever truly recognized the upper contact of the Fox Hills Formation as it is presently defined. The contact which they discussed is apparently the contact between the upper part of the Claggett Formation and the lower Judith River Formation. In the area of the Judith River, in Fergus County, Montana, the Fox Hills Formation is not present; however, a relationship similar to that of the contact of the Fox Hills Formation with the overlying Hell Creek in the type area can be seen in the contact of the Claggett and Judith River formations. Although Meek and Hayden make no reference to the upper contact of the Fox Hills Formation in the Missouri Valley in North Dakota and South Dakota, it is almost certain that they must have seen the contact in that area. That this contact is conformable, and in many places gradational, has since been adequately demonstrated by Thom and Dobbin (1924) and Dobbin and Reeside (1929).

The formation has undergone some redefinition since it was originally described. Both the upper and the lower contacts have been modified since the work of Meek and Hayden. The lower contact has, in general, been moved down in the section and now generally is taken to include a good bit of the transitional sequence between typical Pierre lithology and typical Fox Hills lithology. Lovering, *et al.* (1932, p. 702-703) were perhaps the first to formalize this modification. They described the lower contact of the unit in northeastern Colorado and stated that

> The base of the Fox Hills Formation shall be considered as the horizon below which the section is predominantly 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 large gray to brown, hard, sandy concretions. (Lovering, *et al.*, 1932, p. 702.)

This definition, as emphasized by Waage (1961, p. 229), was originally intended to apply only in northeastern Colorado and has since been somewhat freely interpreted (Wilmarth, 1938, p. 767) as applying to the entire area of outcrop of the Fox Hills Formation. Although this definition cannot be used everywhere, it does not seem to be significantly at odds with the definition used for the placement of the lower boundary in either the type area of the Fox Hills Formation or in the area of Fox Hills exposure in North Dakota. The total interval of the Fox Hills Formation has been further increased at the upper boundary by the addition of the beds of the Colgate Member (Calvert, 1912). These beds, which are primarily marginal marine deposits, were, without question, included in the overlying "great lignite group" by Meek and Hayden.

Definition of Members

Careful study of the Fox Hills Formation in the past fifty years has indicated that a number of members could be subdivided and readily recognized within the Fox Hills Formation. To date, six members have been named, of which five are recognizable within the type area of the Fox Hills Formation and have been traced into North Dakota.

Trail City Member

The lowermost member of the Fox Hills Formation has been named the Trail City Member by Morgan and Petsch (1945, p. 13-14). They described (p. 13) the member 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 Member." They further stated that the member is characterized by three to five zones of dense blue limestone concretions. The lower contact of the member, and, therefore, the lower contact of the formation, was picked above the highest "bentonite" [jarosite] in the Pierre Formation and below the first layer of fossiliferous concretions. This zone is within the transitional zone between typical Pierre lithology and typical Fox Hills lithology. The zone of transition varies in thickness from three to twenty-five feet in the area of type occurrence of the Trail City Member. Morgan and Petsch did state, however, that no lithologic change could be seen within this zone, and used instead the uppermost "bentonite" as the horizon upon which the Fox Hills-Pierre contact was mapped. This contact has since been modified (Waage, 1961, p. 232) and has been placed at the lowest occurrence of jarosite in the sequence. This redefinition, then, provides a somewhat more tangible basis upon which the lower contact of the unit can be identified.

More recent work dealing with the Trail City Member (Waage, 1961, 1968) indicates that the concretionary layers noted by Morgan and Petsch can be traced over a considerable distance and consistently identified by the enclosed fossil material. Waage has subdivided the Trail City Member into several assembly zones and lithofacies. The lowermost "unit" has been named the Lower *nicolleti* Assemblage Zone. This layer, which occurs from one to eight feet above the lowermost contact of the unit, is characterized by an abundance of the cephalopod *Scaphites* (*Hoploscaphites*) *nicolleti*. The second layer, the *Limopsis-Gervillia* Assemblage Zone, is exposed about ten to eighteen feet above the lower *nicolleti* layer and is characterized by the bivalves *Limopsis striatopunctatus* and *Gervillia recta*. About fifteen to twenty feet above the *Limopsis-Gervillia* layer, the *Protocardia-Oxytoma*

Assemblage Zone is exposed. This layer is characterized by an abundance of the bivalves *Protocardia subquadrata* and *Pteria* (*Oxytoma*) *nebrascana*.

The latter two assemblage zones are occasionally separated by an accumulation of large concretions bearing *Scaphites* (*Hoploscaphites*) *nicolleti* which have been designated (Waage, 1968, p. 67) the Upper *nicolleti* Assemblage Zone. This unit is, however, distributed only over the eastern portion of the type area and is, therefore, much less extensive than the other zones.

These concretion layers are best developed near the eastern end of the divide between the Grand and Moreau rivers in the type area. As the layers are traced westward (Waage, 1961, p. 234) along the divide, the faunal assemblage of each of the zones appears to change and the characteristic fossils from which the zonal names were taken may be totally absent. As will be discussed later, this same situation seems to exist as the layers are traced northward into Sioux and Emmons counties in North Dakota. It should be further emphasized that although the names of the layers indicate an abundance of one or two particular species of organisms, these organisms may not be present in any one concretion or, indeed, may not be found over a considerable extent of the zone in question.

The upper contact of the Trail City Member was stated by Waage (1961, p. 234) to be represented by a change from sandy clay to sand. This contact is, however, not at all distinct and is perhaps best defined on the basis of a relatively widely distributed layer of glauconitic sand which occurs at the top of the Trail City Member.

Timber Lake Member

The member directly overlying the Trail City Member has been named (Morgan and Petsch, 1945, p. 15) the Timber Lake Member, and is typified by exposures in the vicinity of Timber Lake in Dewey County, South Dakota. The lower portion of the typical Timber Lake Member consists of greenish-yellow, medium-grained, uncemented quartz sandstone. This uncemented sandstone grades upward vertically into a somewhat coarser grained, brownish sand which is characterized in many places by thin layers of orange or brown, limonitic claystone stringers. In many cases this upper zone is also well cemented and forms large calcareously cemented layers, or ledges, which are generally lenticular and change abruptly in thickness and stratigraphic position as they are traced laterally.

The fauna also varies vertically in the unit. Near the base of the member, the dominant species are *Pteria linguaeformis*, a bivalve, and the large cephalopods *Sphenodiscus lenticularis*, and *Discoscaphites nebrascensis*. A fourth species, the bivalve *Cucullaea shumardi*, is also

characteristic of the lower part of the Timber Lake Member, but is not found consistently throughout the type area. The upper portion of the member is characterized by a general absence of the forms just listed, and the presence of the burrowing bivalve *Tancredia americana* and the filled tubes of the decapod crustacean *Ophiomorpha major.*

The upper contact of the Timber Lake Member is apparently not well exposed in the type area (Waage, 1961, p. 236) but is readily recognizable on the basis of the change from the sand and sandstone of the Timber Lake Member to the interbedded sandstone and shale of the overlying Bullhead Member. This contact, as well as the contact of the Timber Lake Member with the underlying Trail City Member, is gradational.

Bullhead Member

The Bullhead Member was named by Stevenson (1956) for exposures near the village of Bullhead, Corson County, South Dakota. Prior to this time, the unit had been recognized as distinguishable from the underlying and overlying units and was referred to informally as the "Banded Beds" (Searight, 1931). The unit, in the type area, consists of about 135 feet of laminated sandstone and fissile shale. The beds of sandstone are light gray, medium- or fine-grained and occasionally cross-bedded. They vary in thickness from about one to fourteen inches and are interbedded with somewhat thinner laminae of very fine-grained, gray, fissile shale. The individual laminae of shale vary in thickness from about one inch to about nine inches.

The fauna of the Bullhead Member is rather restricted, and consists (Stevenson, 1956) of a limited Timber Lake fauna near the base of the unit and, near the upper part of the member, a few scattered occurrences of oysters. Waage (1961, p. 237) also recorded the presence of the cephalopod *Discoscaphites nebrascensis* near the top of the unit.

The contact of the Bullhead Member with the overlying Colgate Member is, in many places, gradational (Waage, 1961, p. 237) although in some local areas outside the type area (Laird and Mitchell, 1942, p. 6) local channeling may be observed.

Colgate Member

The uppermost member of the Fox Hills Formation exposed in the Missouri Valley is the Colgate Member. This unit was named by Calvert (1912, p. 194) for an exposure of about 125 feet of white sandstone in the vicinity of Colgate Station on the Northern Pacific Railroad in Dawson County, Montana. The unit in this type area consists of a relatively thick sequence of massive, white sandstone with

a few layers of interbedded buff or brown sandstone, which contain fossil leaf impressions and fossil plant fragments.

In the Missouri Valley and, more specifically, in the type area of the Fox Hills Formation, the Colgate Member is considerably thinner and, although it retains its character and can be readily identified, is somewhat less well developed and not as extensive as it is in the type area of the member.

The fauna of the Colgate Member is extremely restricted and for the most part is characterized by oysters of the genus *Crassostrea* and a few less common associated bivalves and gastropods. Cephalopods of the genus *Discoscaphites nebrascensis* occasionally occur in association with the oysters (Waage, 1961, p. 237).

The contact of the Colgate Member with the overlying Hell Creek Formation is generally conformable; however, as pointed out earlier, several areas can be noted which indicate a short erosional interval between the time of deposition of the Colgate Member and the overlying Hell Creek Formation.

Milliken Member

A fifth member of the Fox Hills Formation was named the Milliken Member by Henderson (1920). This unit consists of about 100 to 150 feet of massive concretionary sandstone at the base of the Fox Hills Formation in the area of Milliken Station, Weld County, Colorado. This member would correspond approximately to the Timber Lake Member in the type area of the Fox Hills Formation, and as the term is not used in the area of North Dakota and South Dakota, it will not be discussed further.

Redefinition of the Type Area

Culmination of the redefinition of the type area of the Fox Hills Formation has resulted in a redefinition of some of the member terminology applied to the unit. This redefinition involves the combination of the Colgate and Bullhead members into a single member, the Iron Lightning Member. The Trail City Member and Timber Lake Member have been retained in the subdivision of the unit. In addition to the change of the member terminology, the three suggested members have been further subdivided into a series of lithofacies. These include the Little Eagle Lithofacies and the Irish Creek Lithofacies in the Trail City Member. The former is developed in the eastern and northern portions of the type area and probably

extends as far north as Linton, North Dakota. The Irish Creek Lithofacies represents a somewhat less fossiliferous, slightly coarser-grained equivalent of the Little Eagle Lithofacies in the western portion of the type area and has not been observed in North Dakota.

Subdivisions within the Timber Lake Member include the Rock Creek Lithofacies, which is a relatively discontinuous, thin bedded sand and shale located in the northwestern portion of the type area, and the *Tancredia-Ophiomorpha* Biofacies, which includes most of the upper portion of the Timber Lake Member. The Iron Lightning Member is subdivided into the Bullhead Lithofacies and the Colgate Lithofacies in a manner very similar to the subdivision previously used for definition of the Colgate and Bullhead members in the type area.

Complete definition and description of these units is thoroughly discussed in Waage's (1968) discussion of the type area of the Fox Hills Formation and need not be reiterated here. Suffice it to say that the redefinition is an attempt to portray the variation within the formation in a realistic manner which is not wholly inconsistent with the more classic terminology.

Fox Hills Formation in North Dakota

The general aspect of the Fox Hills Formation in North Dakota changes somewhat from that of the type area in South Dakota. The upper three members, the Timber Lake, Bullhead, and Colgate, are present in North Dakota and have the same general appearance as they do in South Dakota. The lowermost member, the Trail City Member, however, is not at all well defined in North Dakota. If the term were to be used in North Dakota, as did Waage (1961) in South Dakota, it would have to be restricted to a single outcrop in central Emmons County. Fisher (1952), therefore, subdivided the unit in North Dakota into an upper and lower sequence rather than strictly adhering to the member terminology. The writer believes that the unit can best be defined by subdividing into three members and considering the Trail City Member to be absent from the state (Pl. 1).

Pierre-Fox Hills Contact

The contact between the Pierre Formation and the overlying Fox Hills Formation in North Dakota is totally gradational, as is also true in the type area. Fisher (1952, p. 8) referred the portion of the Pierre Formation in Emmons County to the Elk Butte Member of the Pierre

and placed the contact just below the *Limopsis-Gervillia* "zone" of Waage (1961, p. 231).

The Pierre-Fox Hills contact in North Dakota is poorly exposed. However, from a study of this contact in two localities, near Linton in Emmons County and along the Little Missouri River in Bowman County, the present writer believes that a somewhat lower placement of the contact would be more consistent with the definition of the Fox Hills as used in the type area. The best exposure of the lower contact of the Fox Hills occurs in the north-facing cutbank of Beaver Creek in Seeman Park, one mile southeast from Linton, SE ¼, sec. 17, T. 132 N., R. 76 W., Emmons County, North Dakota. At this locality the Pierre Formation is represented by about 68 feet of dark bluish-black shale, which is gypsiferous and iron-stained throughout.

The Pierre becomes somewhat siltier toward the top of the unit and, in places, contains small blebs of fine-grained sand. The contact at this locality can be selected by the occurrence of the first layers, or stringers, of jarosite. At the general level of the jarosite stringers, fine-grained sand is more abundant than the silt and clay of the Pierre Formation. This level is about ten to twelve feet below the lowest concretion layer which would, therefore, be placed in the Fox Hills Formation (Fig. 3). Above the appearance of the first jarosite, the sequence changes rapidly from silty, sandy shale to fine to medium-grained buff sand with small pods of jarosite. Although the lower ten feet of the unit might well be considered lithologically similar to the Trail City Member as defined in the type area, use of the term would seem to be impractical. This part of the section can be more conveniently referred to as a transition from the Elk Butte Member of the Pierre Formation to the Timber Lake Member of the Fox Hills Formation.

This definition of the contact between the Pierre and the Fox Hills formations is consistent with the definition used by Morgan and Petsch (1945) and Waage (1961, 1968). The assignment of the lower portion of the Fox Hills in North Dakota to the Timber Lake Member is, however, somewhat at odds with the interpretation of Waage. Morgan and Petsch originally defined the Trail City and Timber Lake members on the basis of their gross lithology and mentioned the occurrence of concretionary layers only incidentally. Waage, on the other hand, seemed to regard the concretionary layers as basic components of the Trail City Member. If this usage were to be strictly followed, the gross lithology of the Trail City Member would change from brown, sandy siltstone in the type area to definite fine- or medium-grained sandstone in North Dakota. It would, therefore, seem to be more consistent with the original definition of the members to consider the concretions in this section to be enclosed in Timber Lake lithology rather than to

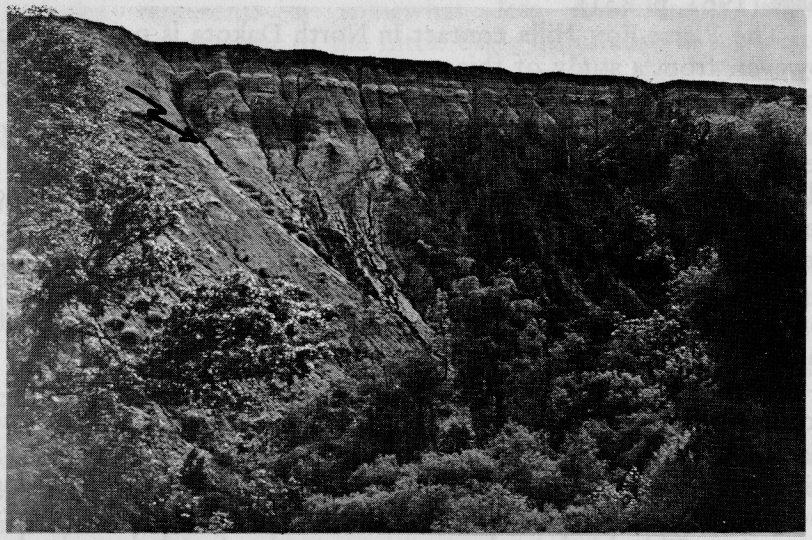


FIGURE 3. Photo of Pierre-Fox Hills contact exposed on a north-facing cutbank of Beaver Creek, Emmons County.

define the unit on the basis of presence or absence of concretionary structures. This usage would also tend to solve the dilemma, presented by Fisher (1952), in which the Trail City Member and Timber Lake Member, as he used them, were virtually indistinguishable on the basis of their gross lithology.

The foregoing remarks pertain to the Pierre-Fox Hills contact wherever it is seen in the Missouri Valley in North Dakota. The only other place in the state in which the contact is exposed is on the east flank of the Cedar Creek Anticline in Bowman County in southwestern North Dakota. The contact in this area differs in that the transition from typical Pierre lithology to typical Fox Hills lithology is somewhat more abrupt, and the fossiliferous concretionary layers noted in the Missouri Valley are absent. The only concretionary structures observed in this area are small concretions containing gypsum and cone-in-cone structure. These concretions occur within two feet of the top of the Pierre Formation (Fig. 4). The best exposure of the contact in this area is found in the NW ¼, NW ¼, sec. 4, T. 131 N., R. 106 W., in Bowman County. At this locality the Pierre Formation is represented by a dark blue shale which weathers to a light gray color. This shale, typical of Pierre Shale throughout North Dakota, contains gypsum, some jarosite,

FIGURE 4. Photo of Pierre-Fox Hills contact in Bowman County.

and the scattered concretions mentioned above. The contact between the Pierre and the overlying Fox Hills Formation is gradational through a sequence of about ten feet and represents a change from the dark blue shale to buff or yellow fine-grained sand with a few brownish shale or siltstone interbeds. Although the lower part of the Fox Hills Formation has never been assigned to any of the members of the unit, it has the general aspect of the Timber Lake Member, especially near the middle of the unit, and will be referred to as the Timber Lake Member in further discussions.

Timber Lake Member

The Timber Lake Member is the lowest member which can be definitely identified in North Dakota. It varies in thickness from as little as 42 feet in Bowman County to more than 128 feet in Sioux County. Most of the unit is composed of fine- to medium-grained lithic graywacke and subgraywacke. Microscopic inspection indicates that the sorting of the sand grains is moderate to good. Most of the grains are angular, although rarely subrounded grains are encountered. The composition of the sandstone is somewhat variable; however, the only differences that can be noted are in regard to the cement and interstitial material. The sand grains themselves are, in general, divisible into four

types. About twenty-five to thirty percent of the grains are quartz, zero to five percent are biotite, ten to fifteen percent are feldspar, and thirty-five to forty percent are rock fragments. Glauconite occurs throughout the member in minor amounts. The remaining ten to thirty percent of the rock is composed of either interstitial limonite or a combination of limonite and calcite. Although the rock fragments were counted as though they were homogeneous, three different types could be recognized. The majority of the rock fragments are small, angular chert fragments, the remainder being either fine-grained igneous rock fragments or aggregates of quartz grains.

In gross aspect, the Timber Lake Member in North Dakota consists of buff to yellowish sand which weathers to yellowish or reddish brown. The member shows little bedding near the base but becomes distinctly cross-bedded near the top. Throughout the unit discontinuous ledges or lentils of reddish brown sandstone were observed (Fig. 5). The ledges are cemented either by limonite-like material or a combination of limonite and calcium carbonate. In general, the ledges become more numerous near the top of the member. Two other features which are commonly observed in the Timber Lake Member are discontinuous stringers or layers of red or orange, brittle claystone and burrows of the decapod crustacean *Ophiomorpha* (Fig. 6). Both of these features are abundant near the top of the Timber Lake and diminish in numbers downward so that they are rarely encountered below the middle of the member.

One of the most striking features of the lower part of the Fox Hills Formation is the presence of fossiliferous concretions. In the type area of the formation, concretions are present in both the Trail City and Timber Lake members. Although the Timber Lake Member is the only one of these two members exposed in North Dakota, the concretionary structures are no less abundant than they are in the type area. These concretions can be subdivided lithologically into two general types. Discounting the fossil fragments, one group of concretions from the lower part of the member consists of about 50% fine silt and 15% sand, the composition of which is essentially the same as that of the surrounding Timber Lake matrix, and about 35% calcium carbonate cement. These concretions are normally dense, bluish structures which show no bedding characteristics, similar to the surrounding matrix, and are enclosed in a "jacket" of sandstone. The second group of concretions is lithologically quite similar to the surrounding matrix material and is more strongly cemented by limonite. In the type area of the formation, where the unit is somewhat better exposed, the concretionary structures have been precisely zoned by Waage (1961; 1968). In North Dakota, however, exposures of the Fox Hills Formation are limited to the point that this zonation can

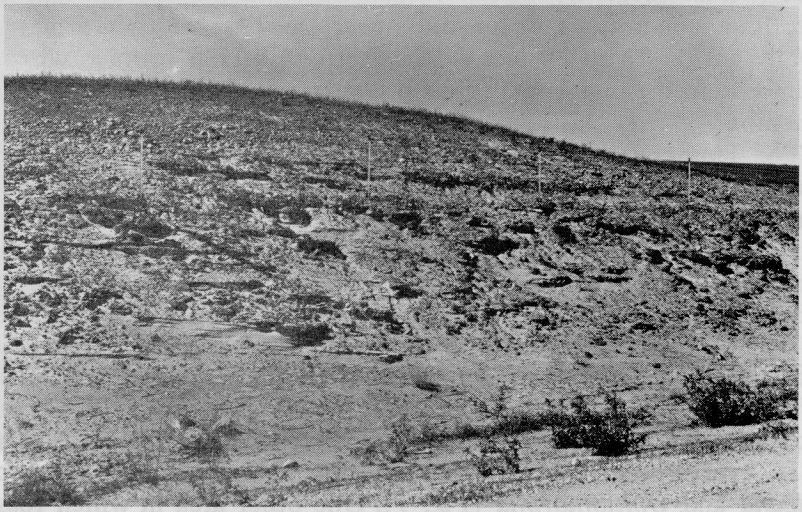


FIGURE 5. Photo of Timber Lake Member in Emmons County.

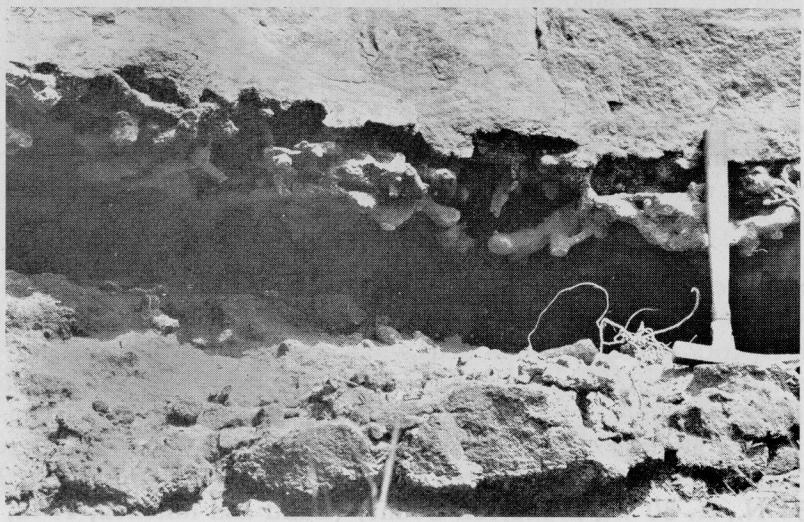


FIGURE 6. Photo of *Ophiomorpha major* burrows in Sioux County.

apparently not be accomplished without more thorough topographic coverage than presently exists. It can be stated, however, that the dense, blue concretions occur only near the base of the formation, normally within 15 to 20 feet of the Pierre-Fox Hills contact, whereas the limonite-cemented concretions occur from this level to the top of the member.

The Timber Lake is by far the most fossiliferous member in North Dakota. The majority of the fossils collected from the unit occur in the concretions mentioned above. Less commonly, fossils occur in cemented sandstone ledges and, even more rarely, fossils are found free in the matrix material. Of particular note in regard to the last mentioned occurrence is an extremely fossiliferous layer which occurs near the top of the member in Morton and Sioux counties. This layer was first mentioned by Laird and Mitchell (1942, p. 7) who described it as a "coquinite." This layer, which will be discussed in detail in a later section, has now been traced as far south as south-central Sioux County and is everywhere characterized by an abundance of *Tancredia americana* and *Ophiomorpha* (Fig. 7). One other area in which fossils occur abundantly in the matrix is in T. 132 N., R. 79 W., in Emmons County. Here, at the very top of the member, the oyster *Crassostrea glabra* and associated organisms occur in great profusion (Fig. 8). The general composition of the fauna changes markedly from the lower part of the member to the upper part, indicating a change from relatively deep water to very shallow, perhaps even intertidal, conditions near the top of the unit.

The contact between the Timber Lake Member and the overlying Bullhead Member is gradational, from the glauconitic, crossbedded sand of the Timber Lake Member to the interbedded, fine-grained sandstone and siltstone of the Bullhead Member. This gradation, where observable, takes place within a stratigraphic interval of about two to three feet.

Bullhead Member

Conformably overlying the Timber Lake Member in most areas in North Dakota is a sequence of beds which are lithologically identical to those named the Bullhead Member by Stevenson (1956). This member consists of a sequence of interbedded sand and siltstone and attains a thickness of about 97 feet in the vicinity of Redhorse Butte, SW ¼, sec. 36, T. 130 N., R. 80 W., in Sioux County and 112 feet in SE ¼, sec. 21, T. 134 N., R. 80 W., in Morton County (Laird and Mitchell, 1942, p. 6). The sand is a buff, finely laminated, fine-grained, subgraywacke which weathers into a reddish buff or buff, and often shows an irregularly cracked surface. The individual layers of sand vary in thickness from about one inch to eleven inches and are interbedded

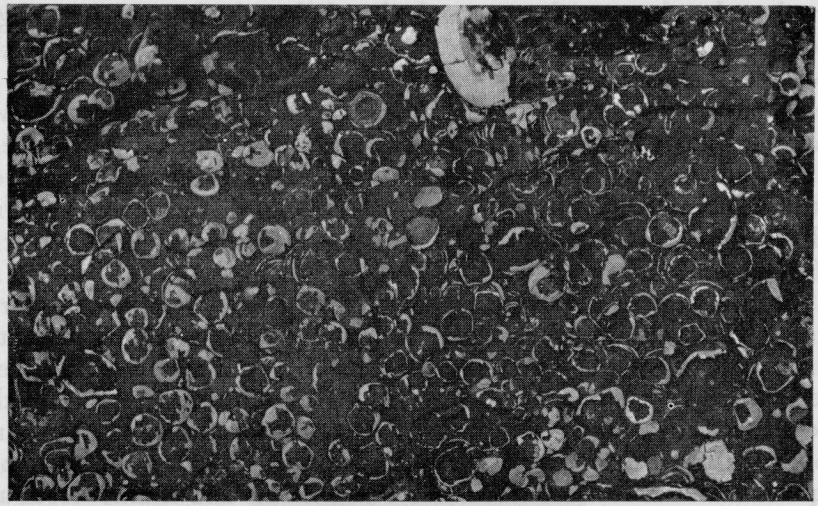


FIGURE 7. Photo of a bedding plane near the top of the Timber Lake Member in Sioux County.

FIGURE 8. Photo of oyster bed near the top of the Timber Lake Member in Emmons County.

with chocolate brown siltstone and silty shale, which weathers to light gray or buff. The shale interbeds tend to be somewhat thinner than the associated sand layers, and vary in thickness from about one inch to seven inches. The overall color of the banded beds is light, dirty brown, which vaguely resembles the overlying Hell Creek beds. The Bullhead can normally be distinguished from the Hell Creek Formation, however, on the basis of color. The Hell Creek, at least in the lower portion, tends to be a somber gray rather than the buff or brown color of the Bullhead Member.

Fossils are relatively rare in the Bullhead Member in North Dakota. The only fossils noted were plant fragments, sharks' teeth, otoliths, and oyster fragments. All of the oyster fragments that were collected are very small, broken fragments which occurred within the upper twenty-five feet of the unit. The plant fossils were found throughout the member but are not well enough preserved to afford adequate material for identification. The otoliths and sharks' teeth are extremely rare. Very thin lignite partings occur throughout the member and further indicate deposition of organic material.

The Bullhead Member varies in thickness throughout its area of outcrop. The first mention of this variation was made by Laird and Mitchell (1942, p. 6) when they correctly observed that the banded beds varied in thickness in an inverse relationship to the thickness of the overlying Colgate Member. In Bowman County, for example, in the SW ¼, sec. 13, T. 132 N., R. 107 W., in a west-facing cutbank of Little Beaver Creek, the Bullhead Member is totally absent and the Timber Lake Member is directly overlain by graywacke sandstone which can be referred to the Colgate Member. In Bowman County, the Colgate Member attains the maximum thickness observed in North Dakota, approximately 40 feet.

The contact between the Bullhead Member and the overlying Colgate Member is difficult to characterize in a general way. In places, for example, near Crowghost Cemetery, NW ¼, sec. 33, T. 134 N., R. 81 W., in Sioux County, a definite erosional interface can be noted between the two members. At this locality, about six feet of relief can be noted on the contact, suggesting that scouring took place prior to deposition of the Colgate sediments. That this disconformable relationship is, however, not general can be observed in several other localities throughout the Missouri Valley. Near the top of Redhorse Butte in Sioux County and in the SE ¼, sec. 1, T. 134 N., R. 79 W., in Emmons County, the Bullhead Member appears to be conformable with, and gradational into, the overlying Colgate sand. The conformable condition seems to be somewhat more predominant than the condition in which some scour or erosion is observed. Therefore, it can be stated

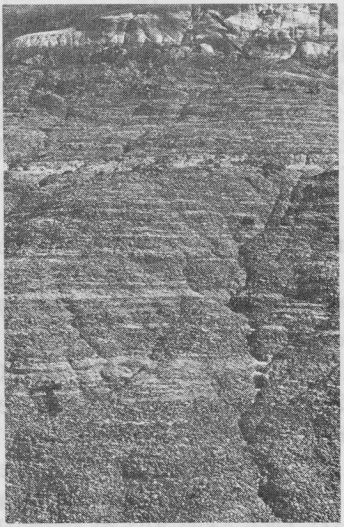


FIGURE 9. Photo of Bullhead-Colgate contact in Emmons County.

that the contact between the two members is generally gradational (Fig. 9). The erosional features observed do not suggest any long span of time.

Colgate Member

The uppermost member of the Fox Hills Formation in North Dakota is the Colgate Member. Although the term was originally coined for beds along the west flank of the Cedar Creek Anticline, it has been widely used in the Missouri Valley area since the work of Laird and Mitchell (1942). This unit presents perhaps the greatest variation in lithology of any of the members of the Fox Hills Formation in North Dakota. Near the type area, along the east flank of the Cedar Creek Anticline, in Bowman County, the unit is quite similar to that seen in the type area and consists of 36 to 40 feet of medium-grained, white, graywacke sandstone with thin scattered layers and partings of lignitic shale. The most characteristic feature of the unit in this area is the fluted surface observed on all weathered exposures. The unit can also be seen in similar aspect near Crowghost Cemetery in sec. 33, T. 134 N., R. 81 W., in Sioux County. As the unit is traced eastward and southeastward from this area, however, its character changes markedly and is normally characterized by less than ten feet of well indurated,

white to cream colored, flaggy sandstone. This condition is observable on Redhorse Butte in Sioux County in sec. 21, T. 134 N., R. 79 W., along the Cannonball River flood plain in Sioux County, as well as on many butte tops in Emmons and Logan counties.

Yet a third lithologic type, which I have referred to the Colgate Member, consists of a similar graywacke sandstone which forms the matrix of an oyster "hash" which occupies the same stratigraphic position at the top of the Fox Hills Formation. Wherever this feature is observed the unit is very thin, generally less than four feet. The occurrences of oyster fragments at the top of the Fox Hills are extremely widespread and perhaps can best be seen in secs. 16, 17, 20, and 21, T. 130 N., R. 80 W., in Sioux County, where oyster fragments festoon the surface of pasture lands. At only a few localities, for example, sec. 26, T. 133 N., R. 73 W., in Logan County and in sec. 31, T. 141 N., R. 72 W., in Kidder County, were oysters well enough preserved to allow identification (Feldmann, 1964). At the latter outcrop the oysters occur with a rather large fauna of associated brackish-water forms. Wherever the member has the same lithologic expression as the type Colgate, fossils appear to be absent, even to the exclusion of the plant fossils that have been described by Knowlton (1916) in Colorado and noted by Calvert (1912) in Montana.

Fox Hills-Hell Creek Contact

Consistent with the work of earlier workers (Laird and Mitchell, 1942; Fisher, 1952) the contact between the Fox Hills Formation and the overlying Hell Creek Formation was picked at the base of the first prominent lignite or lignitic shale occurring above the predominantly marine section below. This contact has both practical and theoretical significance in that it not only serves as an excellent marker bed upon which to separate the two units, but also marks the approximate boundary between marine and brackish water deposits of the Fox Hills Formation and the predominantly fresh water and terrestrial deposits of the overlying Hell Creek Formation. This placement of the contact has recently been substantiated by Frye (1969).

Field observations indicate that the contact may be expressed in one of two general ways. Where the contact is exposed along an essentially vertical face, the lignite at the base of the Hell Creek Formation tends to be a bit more resistant than the underlying sandstone of the Colgate Member of the Fox Hills Formation and, therefore, the Colgate forms a slight re-entrant below the lignite. In other areas, the top of the Fox Hills Formation has been stripped of all remnants of the Hell Creek and forms broad benches or flat surfaces capped by relatively resistant, flaggy Colgate sandstone. This condition

can commonly be observed in the southern half of Sioux County, and on butte tops in Emmons and Logan counties.

The contact between the two formations is, in general, conformable; however, in some local areas relief can be noted on the contact, which would indicate at least a brief erosional interval. This can perhaps best be seen near Crowghost Cemetery in Sioux County where the contact can be traced for several hundred yards and vertical relief of about six feet can be noted.

Topographic Expression of the Fox Hills

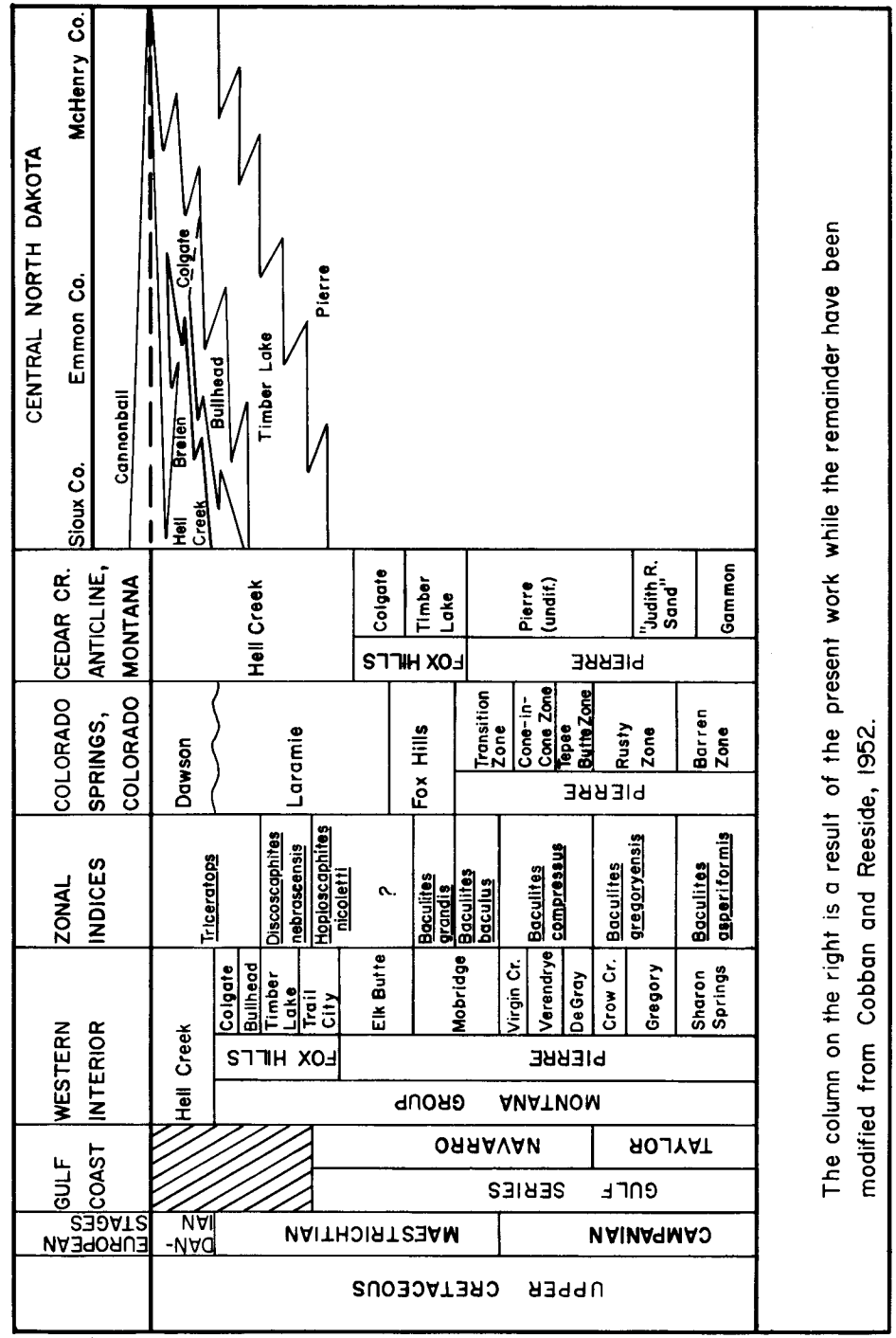
Whereas the Fox Hills Formation in its type area in South Dakota forms high ridges and caps much of the countryside, the unit in North Dakota, in response to the regional dip into the Williston Basin, generally occupies lowland areas. This results in somewhat poorer exposures than are observed in the type area. The unit does, however, cover a large area in south-central North Dakota, and, although it is not well exposed, certain general statements can be made regarding its topographic expression. Where the unit has not been deeply covered by glacial deposits, it forms gently rounded slopes; and, when viewed from some distance, tends to give the impression of forming at least two relatively flat, bench-like, surfaces. The lower surface is formed at the approximate level of the top of the Timber Lake Member and seems to be the result of abundant well-cemented sandstone ledges. This, however, should not be taken to mean that the top of the Timber Lake can everywhere be recognized on the basis of the presence of a topographic bench, but it does serve to offer a general point of reference in the field. The second bench is developed at the top of the formation on the flaggy, well-cemented Colgate Sandstone. This level is represented by rather broad benches in southeastern Sioux County and by scattered butte tops in Emmons and Logan counties. The Fox Hills, unfortunately, tends to support a relatively profuse vegetal cover by comparison with the Pierre Shale below and the Hell Creek Formation above, and, therefore, the slopes developed on the Fox Hills are frequently obscured.

Age and Correlation

The Fox Hills Formation in North Dakota represents one of the latest Cretaceous deposits in North America (Fig. 10). The unit has been correlated (Stevenson and Reeside, 1938, p. 1631; Cobban and Reeside, 1952, Chart 10b) with Maestrichtian deposits in Europe. It can, therefore, be considered a temporal equivalent of the Lennep and Horse Thief formations in Montana (Stebinger, 1914, p. 67) and the Corsicana and Kemp formations of the Navarro Group in Texas (Stephenson, 1941, p. 33). The Fox Hills is also equivalent in age to the Owl Creek Formation, Prairie Bluff Formation, and upper Ripley Formation in Mississippi, as well as the upper portion of the Monmouth Group in Maryland, Delaware, and New Jersey (Stephenson, *et al.*, 1942, Chart 9). Jeletzky (1962, p. 1009) further summarized the correlation of the Fox Hills Formation with its adjacent units as well as with standard sections in several other parts of the world.

More careful study of the faunal assemblages collected in the Fox Hills in different areas of outcrop, however, indicates that the unit is not everywhere of the same age. The majority of data used to determine the age of the Fox Hills has been based on zonation of cephalopods, a group which has not been thoroughly studied in North Dakota. Preliminary investigation, however, indicates that the cephalopods in North Dakota are primarily members of the genera *Discoscaphites* and *Sphenodiscus*. These forms are characteristic of the upper portion of the Maestrichtian. On the other hand, cephalopods collected from the northeastern portion of Colorado (Bane, Pierce, and Reeside, 1937, p. 232) include such species as *Baculites grandis* and *Baculites ovatus* as well as several species of *Sphenodiscus*. These species of *Baculites* are apparently not present in the Fox Hills Formation either in North Dakota or in the type area of the formation in South Dakota (Waage, 1961, p. 232). Rather, these forms are characteristic of the Elk Butte and Mobridge members of the Pierre Formation (Gill and Cobban, 1965, p. A4). This would indicate, then, that the Fox Hills Formation in eastern Colorado is a temporal equivalent of the Pierre Formation in central North Dakota. This interpretation is further supported by the observation that the bivalve *Inoceramus* is apparently absent from the Fox Hills Formation in North Dakota, although it has been reported from the Fox Hills in the type area (Waage, 1964, p. 549), and from the Pierre Formation and most other units that are somewhat older than the Fox Hills Formation in North Dakota (Stephenson and Reeside, 1938, Fig. 3).

The Fox Hills Formation appears to represent a littoral and sublittoral facies of the regressive Upper Cretaceous seaway in the



The column on the right is a result of the present work while the remainder have been modified from Cobban and Reeside, 1952.

FIGURE 10. Correlation chart of the uppermost Cretaceous in selected areas of the United States.

Midcontinent, whereas the Pierre Formation represents a somewhat deeper water, offshore deposit. If this relationship is indeed true, it would demand that the Fox Hills Formation in the west would have to be equivalent in age to the Pierre Formation in some adjacent area to the east. Unfortunately, the amount of time involved in this regressive phase was so slight that fossil evidence indicates only a very general picture of this regression. For the purposes of regional correlation, then, it would seem that the Fox Hills Formation in North Dakota could be considered to be essentially the same age throughout its area of outcrop.

Determination of the age of the Fox Hills by means of bivalves can be done in only a very general way. Most of the clams are restricted to the Fox Hills. Their most closely related allies can be collected in the Navarro Group in Texas and the Ripley Formation in Tennessee. Both of these units are Upper Cretaceous in age. A few Fox Hills species are closely related to species collected from Upper Cretaceous units along the Eastern Seaboard.

A few of the clams collected from the Fox Hills are members of the same species as those collected from the Cannonball Formation of Paleocene age. Stanton (1920, p. 11), for example, listed ten species of bivalves which occur in both the Cannonball and Fox Hills formations. More recent work on the Cannonball bivalves by Cvancara (1966) revealed that only six species from that unit can be referred to species known from the Fox Hills Formation in North Dakota. They are *Nucula planomarginata*, *Nuculana evansi* (*Neilonella evansi*? of Cvancara), *Pteria linguaeformis*, *Crassostrea glabra*, *Corbicula cytheriformis*, and *Dosiniopsis deweyi*. The remainder of the bivalves from the Fox Hills Formation, therefore, are restricted to the Upper Cretaceous.

PALEOECOLOGY

Boucot (1953, p. 25) defined paleoecology as an attempt, ". . . to reconstruct the total environment for the particular time and place in question, including the physical and biological factors that affect the life and relationships of organisms." Although the term "total environment" tends to pose an insurmountable limitation upon paleoecologists, the essence of the idea is sound. The task of the paleoecologist is to evaluate both sedimentologic and paleontologic data and assemble them into a coherent, logical picture of the conditions that existed at the time a particular stratigraphic unit was

deposited. Paleoecology, then, forms the link between stratigraphy and paleontology in which the factors of both the rock record and the fossil record must be evaluated in order that a complete history be written.

Several lines of evidence are available from which paleoecological interpretations can be made for the Fox Hills Formation. Foremost among these is the fossil record. The Fox Hills contains a prolific molluscan fauna and, in particular, a rich and varied bivalve fauna. The bivalve fauna is summarized in Table 1. Although only the bivalves have been studied taxonomically by this worker, the other mollusks–cephalopods, gastropods, and scaphopods–as well as the small, but interesting associated fauna of vertebrates and other invertebrates can be used to determine the paleoecological setting. In addition to the fossil criteria, details of the stratigraphic record have also been employed. The relationship of the adjacent units, sedimentary structures within the Fox Hills, and sedimentologic features such as grain size, sorting, and composition have been used wherever observable.

Several assumptions must be made when undertaking work of this sort. Many of the species of bivalves collected from the Fox Hills are generically related to species living in the modern day oceans. By assembling data on the distribution of recent forms, it is possible to suggest the environment in which the fossil forms lived. Although this information is not in itself conclusive, it forms weighty evidence when assembled with other independent sources of information.

Another assumption that I believe can be made is that the fossil suites collected from various stratigraphic positions and geographic localities within the area of outcrop of the Fox Hills in North Dakota may well represent different ecological units rather than strictly indicating evolutionary development. This application, similar to the one which caused T. H. Huxley (1862, p. XLVI) to coin the term "homotaxis," is, in part, a result of the fact that the faunal sequences in the Fox Hills Formation in North Dakota, when arranged in ascending stratigraphic order, do not seem to indicate a general evolution of forms. Rather, the organisms collected in different stratigraphic horizons seem to represent totally different faunas and, therefore, might best be considered "facies fossils" which lived at the same time, but in different environments and in different geographic localities.

The present study is in part limited by the fact that the total fauna of the unit has not been studied taxonomically. This perhaps places too great an emphasis on the bivalves, the only group thoroughly studied, and seems to reduce the significance of the other elements of the fauna. Although the remainder of the fauna have been used to aid in the definition of environments of deposition, the writer has not studied them taxonomically and no generic comparisons with recent forms have

Phylum: MOLLUSCA
Class: BIVALVIA
Order: TAXODONTA
Superfamily: NUCULOIDEA
Family: NUCULIDAE
Genus: *Nucula*
Nucula planomarginata Meek and Hayden
Nucula subplana Meek and Hayden
Nucula obsoletastriata Meek and Hayden
Nucula sp. nov.
Subgenus: *Nucula (Pectinucula)*
Nucula (Pectinucula) cancellata Meek and Hayden
Family: NUCULANIDAE
Genus: *Nuculana*
Nuculana scitula (Meek and Hayden)
Nuculana bisulcata (Meek and Hayden)
Nuculana evansi (Meek and Hayden)
Nuculana tarensis (Gardner)
Superfamily: PARALLELODONTOIDEA
Family: PARALLELODONTIDAE
Genus: *Nemodon*
Nemodon sulcatinus (Evans and Shumard)
Family: LIMOPSIDAE
Genus: *Limopsis*
Limopsis striatopunctatus Evans and Shumard
Family: CUCULLAEIDAE
Genus: *Cucullaea*
Subgenus: *Cucullaea (Idonearca)*
Cucullaea (Idonearca) shumardi Meek and Hayden
Order: ANISOMYARIA
Superfamily: MYTILOIDEA
Family: MYTILIDAE
Genus: *Modiolus*
Modiolus galpinianus (Evans and Shumard)
Modiolus sp. nov.
Genus: *Crenella*
Crenella elegantula Meek and Hayden
?Crenella elegantula Meek and Hayden
Superfamily: PTERIOIDEA
Family: PTERIIDAE
Genus: *Pteria*
Pteria linguaeformis (Evans and Shumard)
Pteria nebrascana (Evans and Shumard)

TABLE 1.–Systematic list of the species of bivalves collected from the Fox Hills Formation in North Dakota.

Family: ISOGNOMONIDAE
Genus: *Gervillia*
Gervillia recta Meek and Hayden
Gervillia subtortuosa Meek and Hayden
Superfamily: PECTINOIDEA
Family: PECTINIDAE
Genus: *Syncyclonema*
Syncyclonema halli
Superfamily: ANOMIOIDEA
Family: ANOMIIDAE
Genus: *Anomia*
Anomia micronema Meek
Superfamily: OSTREAOIDEA
Family: OSTREIDAE
Genus: *Crassostrea*
Crassostrea glabra (Meek and Hayden)
Crassostrea subtrigonalis (Evans and Shumard)
Crassostrea pellucida (Meek and Hayden)
Order: EULAMELLIBRANCHIATA
Superfamily: ASTARTOIDEA
Family: ASTARTIDAE
Genus: *Vetericardia*
Vetericardia crenalirata (Conrad)
Genus: *?Astarte*
?Astarte sp. nov.
Superfamily: SPHERIOIDEA
Family: CORBICULIDAE
Genus: *Corbicula*
Corbicula cytheriformis (Meek and Hayden)
Corbicula moreauensis (Meek and Hayden)
Superfamily: CARDIOIDEA
Family: CARDIIDAE
Genus: *Cardium*
Subgenus: *Cardium (Ethmocardium)*
Cardium (Ethmocardium) whitei Dall
Genus: *Protocardia*
Subgenus: *Protocardia (Leptocardia)*
Protocardia (Leptocardia) subquadrata (Evans and Shumard)
Family: VENERIDAE
Subfamily: SUNETTINAE
Genus: *Dosiniopsis*
Dosiniopsis deweyi (Meek and Hayden)

TABLE 1.–Systematic list of the species of bivalves collected from the Fox Hills Formation in North Dakota, continued.

Superfamily: MACTROIDEA
Family: MACTRIDAE
Genus: *Mactra*
Mactra warrenana Meek and Hayden
Mactra formosa Meek and Hayden
Superfamily: TELLINOIDEA
Family: TELLINIDAE
Genus: *Tellina*
Tellina equilateralis? Meek and Hayden
Subgenus: *Tellina (Eurytellina)*
Tellina (Eurytellina) scitula Meek and Hayden
Tellina (Eurytellina?) cheyennensis Meek and Hayden
Family: TANCREDIDAE
Genus: *Tancredia*
Tancredia americana (Meek and Hayden)
Superfamily: LATERNULOIDEA
Family: PHOLADOMYIDAE
Genus: *Goniomya*
Goniomya americana (Meek and Hayden)
Superfamily: MYOIDEA
Family: HYATELLIDAE
Genus: *Panopea*
Panopea occidentalis Meek and Hayden
Family: CORBULIDAE
Subfamily: CORBULAMELLINAE
Genus: *Corbulamella*
Corbulamella inornata (Meek and Hayden)
Subfamily: CORBULINAE
Genus: *Corbula*
Corbula monmouthensis Gardner

TABLE 1.–Systematic list of the species of bivalves collected from the Fox Hills Formation in North Dakota, continued.

been attempted. Further, the extent and size of available outcrops in North Dakota is limited by glacial and vegetal cover. This forces one to extrapolate over considerable distances, making correlation difficult.

Along the same lines, the similarity of the sediments in different parts of the Timber Lake Member is so great that, unless other information is available, it is difficult to accurately place a small, isolated outcrop in its correct stratigraphic position. This problem is further magnified by the general lack of a dependable stratigraphic marker horizon and the total absence of large-scale topographic maps. The only maps available of the area in question are North Dakota State Highway Department county road maps which have no topographic control and U. S. Army topographic maps (1:250,000). All correlation that was done between small outcrops was accomplished solely by means of a Paulin altimeter.

Faunal Assemblages

The assemblages of organisms collected from the Fox Hills can be placed in several general groups based on the stratigraphic position from which they are collected. If this is done, five groups yielding specific ecological data can be defined.

The lowermost subdivision includes the organisms collected in the basal thirty to forty feet of the Timber Lake Member. It is characterized by the bivalve genera *Crenella*, *Gervillia*, *Limopsis*, *Nemodon*, *Nucula*, *Nuculana*, and *Tellina*. These bivalves occur in association with several gastropods and a single cephalopod, *Scaphites* (*Hoploscaphites*) *nicoletti*. These organisms were collected from concretions in what Waage (1961; 1964) would refer to as the lowermost two concretionary layers of the Fox Hills Formation. The two concretionary levels have not been distinguished in North Dakota except in a single, small area in, and around, Seeman Park, southeast from Linton in Emmons County. At this locality, then, it might be possible to distinguish two distinct fossil suites; however, exposures of the lower part of the Fox Hills in the remainder of North Dakota are sufficiently obscured that this vertical zonation cannot be noted and, indeed, Seeman Park is the only locality at which *Gervillia*-rich concretions were collected. Insofar as the *Gervillia* concretions are not widespread and yield no significant ecological data, they can most conveniently be included with the organisms collected in the lower part of the unit.

The middle portion of the Timber Lake Member, up to about 50 feet from the top of the unit, is locally richly fossiliferous and contains such characteristic genera as *Corbula*, *Cucullaea*, *Dosiniopsis*, *Mactra*, *Modiolus*, *Nucula*, *Nuculana*, *Protocardia*, *Pteria*, and *Tellina*. These bivalves are normally preserved in ferruginous concretions in association with a rather small gastropod fauna, and cephalopods of the genera *Discoscaphites*, *Sphenodiscus*, and *Belemnitella*. Although these organisms have occasionally been collected as isolated specimens, they are far more commonly found in richly fossiliferous concretions. These concretionary occurrences appear to be concentrated in a relatively distinct zone but the areas of their occurrence are sufficiently scattered that this observation should be considered tenuous.

The upper portion of the Timber Lake Member is somewhat less fossiliferous than the lower two portions. In many places the upper part of the member is characterized chiefly by discontinuous ledges of cross-bedded sandstone which are apparently devoid of mollusks. In these areas the only fossils that have been collected in abundance have been burrows of the decapod crustacean *Ophiomorpha*. This fossil can truly be considered diagnostic of this horizon. In association with *Ophiomorpha*, two other fossils have been found. The first of these is a single specimen of *Hardouinia waagei*, a cassiduloid echinoid peculiar to the Fox Hills Formation (Holland and Feldmann, 1967). The other fossil collected in association with the rich *Ophiomorpha* beds is a poorly preserved, unidentified crab.

In other areas of the upper portion of the Timber Lake, generally where *Ophiomorpha* is less abundant, several other species of bivalves have been collected. Notable among these are *Panopea* and *Tancredia*. These two burrowing clams appear to be restricted to this portion of the formation. Yet a third fossil occurrence in the upper portion of the member is that of oyster banks in a few scattered outcrops in western Emmons County. These oyster beds generally consist of a network of Crassostrea shells with a smaller number of shells including *Anomia* and *Corbicula*. Several other organisms have been collected in association with the oysters, including the gastropods *Polinices* and *Fasciolaria*, sharks' teeth, otoliths, and other vertebrate remains. The oyster shells are very commonly cemented together and give every impression of having formed banks or "reefs" at these localities during the time in which they lived.

The overlying Bullhead Member contains only scattered animal remains. Among these are sharks' teeth, otoliths, and occasional oyster fragments. This is the least fossiliferous member of the Fox Hills in North Dakota, and therefore, the most difficult to define ecologically.

The uppermost unit of the Fox Hills Formation, the Colgate Member, is unfossiliferous in most areas. In some localities in Sioux

County, Logan County, and Kidder County, however, oyster banks, similar to those noted in the upper portion of the Timber Lake Member can be observed. At these localities the associations of *Crassostrea*, *Corbicula*, and *Anomia*, along with the gastropods *Polinices* and *Fasciolaria*, are essentially the same as those noted in the upper Timber Lake.

These five subdivisions seem to be separate and distinct enough that they can be considered discrete units when considering such ecological factors as water depth, type of substrate, salinity, water currents, and temperature. The bivalves in these assemblages do not appear to have been transported any significant distance. Observation of the shells indicates that only a few at any locality indicate any degree of abrasion and, in many cases, conjoined valves are prevalent. This would seem to indicate that the organisms were buried immediately or were moved only slightly following death of the organism. The only exception to this general rule is in the occurrence of *Panopea* and *Tancredia* in the upper portion of the Timber Lake Member. These two fossils are rarely found with conjoined valves and in most cases are found with the long axis of the shells parallel to the bedding planes with their concave side down indicating that they have been moved at least slightly. These shells, similar to other shells from the formation, do not show any significant amount of abrasion, although they may show some etching or pitting from chemical action which is perhaps post-depositional.

Transportation of the shells enclosed in the concretions in the lower portion of the Fox Hills Formation could have taken place only if the concretions moved *en masse* because the vast majority of the shells display conjoined valves. Waage (1964) also suggested very little, if any, transportation of the concretions.

Water Depth

Several of the fossils collected from the Fox Hills Formation offer excellent indication of the depth of water in which they lived. This is fortunate in that the sedimentological changes in the formation are slight enough that very few conclusions can be drawn from this line of evidence. In general, as one proceeds up the section through the formation, the fossils indicate progressively shallower water until, near the top, the fauna changes from a distinctly marine fauna to one characteristic of brackish water. Although this observation has been

made previously (see, for example, Waage, 1964, p. 542) it has apparently never been thoroughly documented in North Dakota.

Most of the conclusions that can be drawn concerning water depth at the time in which the Fox Hills was deposited must be made from depth records of recent analogs of the bivalve fauna collected from the formation. This information is summarized in Table 2. In addition to the information gathered from the bivalves, supplementary data concerning some of the associated fauna, notably the arthropod *Ophiomorpha* sp. and the echinoid *Hardouinia waagei*, have also been used.

If the Fox Hills is subdivided into the five units discussed above, the gradual decrease in water depth can be illustrated. The lowermost portion of the Timber Lake Member is characterized, at least in part, by three genera which are represented by species in modern oceans. The ecological data available concerning these three genera indicates that the water depth in the area in which they were deposited must have been between 30 and 80 fathoms. The three genera which were used in this determination are *Pteria*, *Crenella*, and *Limopsis*. All three of these genera are commonly found on the east and west coasts of the United States today, and some ecological data are available for them. *Pteria* apparently lives in water varying in depths from intertidal conditions to several fathoms whereas *Crenella* is typically found in water varying from 3 to 250 fathoms. The genus which is apparently most restricted in its range is *Limopsis*. Data provided by Keen (1963) indicate that the vertical range of this genus is between 30 and 80 fathoms. This depth range can then be taken as the approximate limit of depth in which the lower portion of the Fox Hills was deposited.

Higher in the section, near the middle of the Timber Lake Member, evidence for water depth is somewhat less specific although several genera are available from which the determination can be made. This portion of the section is best illustrated by the faunal suite collected in NE ¼, sec. 12, T. 131 N., R. 78 W., Emmons County, where species *Corbula*, *Pteria*, *Tellina*, *Mactra*, *Nucula*, and *Nuculana* were collected. Applying the same general procedure used in the previous determination, whereby the range of overlap of all depth data was used, one could conclude that the depth at which the organisms lived was between ten and seventy-five fathoms. The considerable overlap between this range of depth with that of the basal portion of the unit is not in itself evidence of decreasing water depth. One other observation that is, however, important is the significant increase in the infaunal component of the bivalve fauna over that of the previous portion of the section. All of the bivalves collected in SE ¼, sec. 17, T. 132 N., R. 76 W., near the base of the formation, were epifaunal, that is they lived on, or were attached to, the surface of the substrate. The

TABLE 2.–Summary of general ecological data on the bivalve genera that are found both in modern environments and in the Fox Hills Formation.

Genus	Recent Ecology	Morphological Criteria
Anomia	Intertidal or shallow, attached to stones or wood (Abbott, 1955, p. 332-477)	Byssus
Corbicula	Fresh water to .5% salt, sand or mud bottom (Sinclair and Isom, 1963, p. 12 and 13)	Pallial sinus, thick shell, strong hinge
Crassostrea	0-40 feet of water, fresh to normal salinity, most successful in brackish water (Butler, 1954, p. 479-489)	Cemented, thick shell, strong hinge
Crenella	3-100 fathoms, Arctic to North Carolina (Abbott, 1955, p. 332-477)	
Limopsis	30-80 fathoms (Keen, 1963, p. 104-108)	Strong hinge
Mactra	Intertidal to 12 fathoms (Keen, 1963, p. 104-108)	Pallial sinus, strong hinge
Modiolus	Intertidal to 40 fathoms, attached to rocks or in sand (Keen, 1963, p. 104-108)	Byssus
Nucula	Shallow to 500 fathoms, Labrador to Key West, Florida (Keen, 1963, p. 104-108)	Thick shell, strong hinge
Nuculana	3-2000 fathoms (Keen, 1963, p. 104-108) Arctic to West Indies (Abbott, 1955, p. 332-477)	Pallial sinus, strong hinge
Panopea	Intertidal, buried in about 3 feet of sand or mud (Keen, 1963, p. 104-108)	Pallial sinus, thick shell, strong hinge
Pteria	Intertidal to 5 fathoms, attached to pilings or objects in the sand (Keen, 1963, p. 104-108)	Byssus
Tellina	Intertidal to 75 fathoms, in sand or mud (Keen, 1963, p. 104-108)	Pallial sinus

organisms collected in the middle portion of the Timber Lake Member, however, were split almost evenly between infaunal and epifaunal species. At this stratigraphic position six species are definitely infaunal components, including *Corbula monmouthensis*, *Tellina scitula*, *Mactra warrenana*, *Nuculana scitula*, *Goniomya americana*, and *Nuculana bisulcata*. The remainder of this fauna, *Pteria linguaeformis*, *Pteria nebrascana*, *Nucula cancellata*, *N. planomarginata*, *N. subplana*, and *N. sp. nov.* are epifaunal organisms. Two other species of the genera *Corbulamella* and *Protocardia*, are probably best referred to the infaunal portion of the fossil suite. It is very possible that the increase in infaunal components of this suite over that of the lower portion of the unit is a response to a somewhat more vigorous, shallower environment.

Depth information concerning the upper portion of the Timber Lake Member is somewhat more varied and perhaps more thoroughly documented. Three independent sources of information are available for determination of the water depth of this particular stratigraphic position. Two rather different suites of bivalve faunas are available from which depth information may be determined. One of these, typified by deposits in Center, Sec. 26, T. 134 N., R. 71 W., Logan County, contains abundant oyster fragments of the genus *Crassostrea*. This organism is typically associated with such other forms as *Corbicula*, *Pteria*, *Modiolus*, *Tellina*, *Mactra*, and *Nuculana*. A composite of depth information concerning these genera indicates that the water was indeed very shallow if not intertidal. All of the genera mentioned are commonly collected in intertidal water with the exception of *Nuculana*, which has an upper limit in the order of magnitude of three fathoms. Again, the infaunal component of the suite exceeds that of the epifaunal, with eight species occupying the former niche, and six occupying the latter. Of the epifaunal components, four are forms which attach themselves to a substrate by means of a byssus while the two species of *Crassostrea* are forms which cement themselves to the substrate. If the same organisms were collected in a Recent marine situation there would be no doubt of their shallow water affinities.

A second faunal assemblage collected in the same general stratigraphic position is typified by fossils collected in SW ¼, sec. 26, T. 134 N., R. 80 W., Sioux County. In this type of assemblage the oysters are absent and a large geoduck, *Panopea*, is present. Again the indications of depth that are available indicate deposition in water approaching intertidal depth. At this locality six of the nine species collected are infaunal components. Of the remaining three, two were probably attached to the substrate by byssal threads while the third, *Nucula planomarginata*, is a member of the vagile benthos.

Another species of bivalve commonly collected singly or in association with other organisms at this horizon is *Tancredia americana*. Although *Tancredia* is now extinct, morphological features such as a relatively deep pallial sinus and a broad posterior gape indicate that this is also a burrowing form which probably had essentially the same habit as *Panopea*.

A totally different line of evidence indicating very shallow water conditions during the time of deposition of the upper Timber Lake Member is offered by the decapod crustacean burrow *Ophiomorpha*. Weimer and Hoyt (1964) indicated that this fossil is analogous to the recent species *Callianassa major*, which lives in intertidal and shallow neritic water along the east coast of the United States. They concluded (1964, p. 766) that the presence of *Ophiomorpha* indicates deposition in water of shallow sublittoral or littoral depth. This fossil is extremely important because it very often occurs in areas that are otherwise generally devoid of fossil material. At one locality, however, a single specimen of an echinoid was collected in association with *Ophiomorpha*. This echinoid, *Hardouinia waagei* Holland and Feldmann, is a member of the family Faujasiidae, the members of which typically occupy very shallow water. The upper part of the Timber Lake Member, then, is probably the best documented area with regard to water depth with sources of information from bivalves, decapod crustacean burrows, and echinoids.

The Bullhead Member, overlying the Timber Lake Member, is nearly devoid of fossils and, therefore, is difficult to interpret. The only fossil remains that have been thus far identified from this member include sharks' teeth, otoliths, and occasional oyster fragments. The only information that could possibly be significant in determining the depth of water in which the Bullhead Member was deposited would be the presence of very shallow, or possibly intertidal, sediments above and below the unit. This would indicate that it also was deposited in relatively shallow water.

The uppermost portion of the Fox Hills Formation, the Colgate Member, is also generally devoid of fossils. At some localities, however, faunal suites can be collected which include oysters, or oyster fragments, along with the typically brackish-water bivalve *Corbicula*. At these localities, the only genus that would offer any indication of water depth would be the oyster *Crassostrea*, which normally lives in intertidal or relatively shallow water. Further, the position of the Colgate Member between marine or brackish-water sediments below and the predominantly terrigenous sediments of the Hell Creek Formation above suggest that the member is a beach deposit.

Substrate

The character of the substrate must have varied considerably during the time of deposition of the Fox Hills Formation. Evidence for the condition of the substrate of the unit can be gathered from two independent sources, the character of the sediments and the fauna which is associated with the sediments. The basal portion of the Timber Lake Member is characterized by fine- to medium-grained sand and silty sand with either horizontal bedding or no bedding at all and probably formed a relatively firm substrate. This interpretation is further strengthened by the observation that several of the forms collected from this horizon, notably *Pteria linguaeformis*, *Gervillia recta*, and *Gervillia subtortuosa* are forms which probably attached themselves to the substrate by means of byssal threads. One would presume, then, that such an attachment would presuppose either a rocky substrate or a relatively firm, unconsolidated substrate. There is certainly no evidence for the former condition. Farther up in the member, the sediment becomes generally coarser and increasingly more cross-bedding is observed. This would tend to indicate that the substrate was somewhat less compacted and more subject to disturbances by wave and current action. This conclusion is further strengthened by the abundance of infaunal constituents and the reduction in number of forms which attach to the substrate by means of byssal threads.

The upper portion of the Timber Lake is somewhat more complex. The general presence of cross-bedding indicates that the substrate was certainly agitated; however, it is also characterized by a number of epifaunal constituents which either attached to the substrate by means of a byssus or by cementing to a relatively firm substrate. Such forms as *Crassostrea* definitely require a firm, although not rock, substrate and other forms, such as *Anomia* and *Pteria* again indicate byssal attachment and, therefore, a substrate that is somewhat firm.

In the areas in which *Ophiomorpha* is abundant perhaps a somewhat different situation existed. In these areas, one might envision the decapod burrows forming a network or framework which would tend to hold the substrate in place. Although some cross-bedding is also observed in the sequence in association with *Ophiomorpha*, it usually diminishes somewhat in the immediate vicinity of the burrows and becomes more prominent above or below the occurrence of *Ophiomorpha*. This would suggest an environment similar to that seen in the areas of the modern *Phoronopsis viridis* colonies on the California coast. In that area, the *Phoronopsis* tubes are densely packed together and form a strong enough framework that the sediment surrounding the tubes is essentially trapped. In many places it can be

observed that the surface in the areas of the colonies is elevated above the general surface surrounding them. Observations on *Callianassa major* (Weimer and Hoyt, 1964, p. 763) indicate that these organisms are restricted to ". . . the well-sorted sand in strongly wave-agitated waters." This conclusion would seem to be analogous with that drawn from other sources concerning the environment in which *Ophiomorpha major* lived.

The substrate in the area in which the Bullhead Member was deposited must have been quite variable in that the unit consists of a sequence of interbedded sand and shale. If the environment in which this unit was deposited can indeed be interpreted as estuarine or, in some other way, restricted, the presence of the two different lithologic types would presuppose two things. First, a rather distinct change in regimen would be required to explain the alternate influx of fine and relatively coarse-grained materials and second, the presence of well-developed bedding would indicate that at no time were burrowing organisms extremely abundant. The change in regimen might well be corroborated by evidence from the overlying Hell Creek Formation which consists primarily of a sequence of interbedded sands and shales also. If this unit was deposited at the same time that the Bullhead Member was being deposited in some other area, one might assume that the variation in regimen observed in one unit was the result of the same set of circumstances causing changing regimen of the other. The general absence of burrowing organisms, however, is a bit more difficult to explain. That they were absent is strongly indicated by the fact that their activity would certainly have disrupted any bedding characteristics that were formed. It is difficult, however, to locate an analogous situation in the record of recent coastal deposits. Virtually all areas known to the writer are characterized by a profusion of small burrowing organisms. In the case of the Bullhead sediments, a possible, although tenuous, suggestion could be that the alternating regimen of the environment might well have precluded establishment of a large fauna.

The sediments comprising the Colgate Member are generally cross-bedded and in most areas probably formed a rather poorly consolidated beach deposit. In the areas where oyster development has been noted, however, the substrate must have been firm enough that the oysters could attach themselves to the substrate and form successful colonies. Some of the colonies of oysters obtain a maximum thickness of three to four feet indicating that they were certainly successful, at least locally.

Salinity

In the area of deposition of the Fox Hills Formation, salinity varied considerably. All of the organisms collected from the lower and middle portions of the Timber Lake Member that have recent affinities apparently lived in water of normal salinity, that is about 34 parts per thousand dissolved solids. Near the upper portion of the member, however, the association of *Crassostrea* and *Corbicula* indicates conditions of generally reduced salinity. Butler (1954) has summarized the vast amount of literature concerning the occurrence of oysters, and concludes that although oysters tolerate salinities ranging from fresh water to 33 parts per thousand, they are most successful at a salinity of about 15 parts per thousand. This is a result of two factors. Oyster spats are most successful in areas of relatively high salinity, approaching 32 parts per thousand. During breeding, then, the majority of spats would tend to settle in water of near normal salinity and one might suppose that this would be the area of greatest concentration of oysters. The largest single decimator of oyster populations, however, is predation by other invertebrates, notably gastropods, sponges, and starfish. For this reason, the most successful oyster colonies are not found in areas of normal marine water where these predators would be abundant, but in water of somewhat reduced salinity.

On the other end of the scale, oysters can tolerate extremely reduced salinities in the order of magnitude of zero to ten parts per thousand dissolved solids for only brief periods of time, and are generally not wholly successful under these conditions. It is safe to estimate, then, that the salinity in the area of Fox Hills oyster development would have been about ten to twenty parts per thousand. That oyster predators were present during the deposition of the Fox Hills is demonstrated by the presence of *Polynices* and *Fasciolaria* in association with the oysters. These genera have been listed (Butler, 1954; Wells, 1961) as major predators in modern oyster accumulations. Several fragmented oyster shells have also been found which showed considerable boring, possibly by sponges. That these sponges would have affected the health or vitality of the organism is doubtful.

The upper portion of the Fox Hills yields far less information concerning salinity. The Bullhead Member, devoid of abundant fossils, yields little information about salinity, but the Colgate Member at the top of the formation yields information similar to that for the area of oyster accumulations in the Timber Lake Member. In the Colgate, the association of *Crassostrea*, *Corbicula*, *Fasciolaria*, and *Polynices* indicates situations analogous to those found in the area of the upper Timber Lake Member.

Currents

The only sedimentological evidence for current that has been noted in the Fox Hills is the presence of cross-bedding. It is much more prominent in the upper portion of the Timber Lake Member, increasing both in abundance and magnitude of sets toward the top of the member. In general, the evidence of cross-bedding in association with the fossil data concerning depth of water would indicate that the cross-beds were a result of submarine agitation caused by wave and current action. Generally, the cross-beds dip toward the east, indicating either wave or current source from that direction. This would indicate a general north-south trending shoreline. No detailed work on cross-bed orientation has been completed at this time. Bedding observable in the Bullhead Member would tend to indicate that some current must have been present to transport sediments over the considerable expanse of deposition at any one time, but that it was not strong enough to disrupt any bedding that had previously been formed. The only other evidence for water motion is seen in the abundant cross-bedding of the Colgate Member at the top of the unit. The orientation and general magnitude of the Colgate cross-beds is similar to that present in the Timber Lake Member below.

One other feature that might well be considered a result of some sort of current action is the abundant accumulation of fossils in concretions near the lower portion of the Timber Lake Member. These structures are characterized by an abundant and diverse fauna of mollusks and careful study of the concretions indicates that the orientation of the fossils is generally random. They do not appear to be either bedded or in living positions. This would indicate that, in one way or another, the material had been incorporated into the structure by some technique whereby the organisms were collected in small groups or piles and were later indurated into a dense mass.

The origin of the concretions is in considerable doubt. The latest attempted explanation was that they represent accumulations resulting from a series of mass mortalities (Waage, 1964). Whatever their origin, several facts emerge which are germane to the question of magnitude of currents in the area in which the organisms lived. First, the organisms collected from the concretions show very little abrasion and are very often found with both valves of the pelecypods conjoined so that if the animals were transported at all, they must have been moved over very short distances. If the concretions themselves had been transported *en masse*, one might suspect that other bedding features would also indicate this water activity. Where concretions are found, however, the bedding is usually either totally absent or confined to relatively

horizontal, undisturbed bedding. Therefore, no strong currents are indicated. Finally, depth data for the bivalves in the concretions indicate that the organisms probably lived in relatively deep water. If they were transported any great distance, one might well expect them to reflect a somewhat different ecological setting from that of the sediments in which they are enclosed. Other factors, however, indicate that the lower part of the Timber Lake Member was indeed deposited in relatively deep water and, therefore, the fossil assemblages are consistent with the available sedimentological data. Whatever the cause of their death, one might well concur with Waage (1964, p. 545-546) that the concretions are a result of selective cementation of material around fossil accumulations, precipitated by the relatively large amount of organic matter surrounding the dead organisms. In other words, the concretions were not transported along the bottom, and, therefore, do not indicate great current action.

Temperature

Only meager evidence is available to suggest the temperature of the water at the time the Fox Hills was deposited. There seems to be a general relationship between number of species and number of individuals collected from warm water as opposed to cold water. Gunter (1957, p. 177) noted that eurythermal organisms tend to be distributed such that far fewer species are found in cold water than in warm water, but each individual species in cold water may be represented by a far larger number of individuals. If this statement could then be applied to the paleontological record as Gunter suggested, it would form rather dramatic evidence that the Fox Hills was deposited in at least relatively cool water. Cursory analysis of two other well studied Upper Cretaceous faunas, the Coon Creek fauna of the Ripley Formation in Tennessee and the Navarro fauna in Texas indicates that the Fox Hills sea must have been somewhat cooler than the seas in either of these areas. Wade (1926, p. 12) reported 114 species of bivalves from a single locality in the Ripley Formation. Stephenson (1941, p. 30) reported 174 species of bivalves from the Navarro Group. These figures contrast strongly with the bivalve fauna from the Fox Hills Formation in North Dakota where only 40 species have been collected. Ecological data taken from a study of the distribution of recent organisms of the same genera as those collected in the Fox Hills is not particularly illuminating. Most of the species which have persisted since the Cretaceous are now found in diverse situations

ranging from tropical or subtropical waters to arctic water. Only two, *Corbula* and *Limopsis*, are generally found in cooler, marine water today. The remainder seem to be relatively tolerant of water temperature, at least on the generic level.

Another bit of evidence concerning water temperature is somewhat more confusing. Gunter (1957, p. 174) has summarized data accumulated by several other workers, and concludes that individuals of a given species tend to be somewhat smaller in tropical water than in temperate or cold water. This generalization is probably also true on the generic level. This information, however, cannot be readily correlated with the data collected from the Fox Hills Formation. Species of certain genera, notably *Corbula*, *Crenella*, and *Gervillia* do appear to be somewhat larger than comparable species in the Ripley and Navarro formations in the southern part of the United States. The remainder of the species, however, appear to be in the same order of magnitude of size as comparable species in these faunas. This evidence would tend to indicate that the water from which the Fox Hills was deposited was either temperate or cold.

Facies Relationships

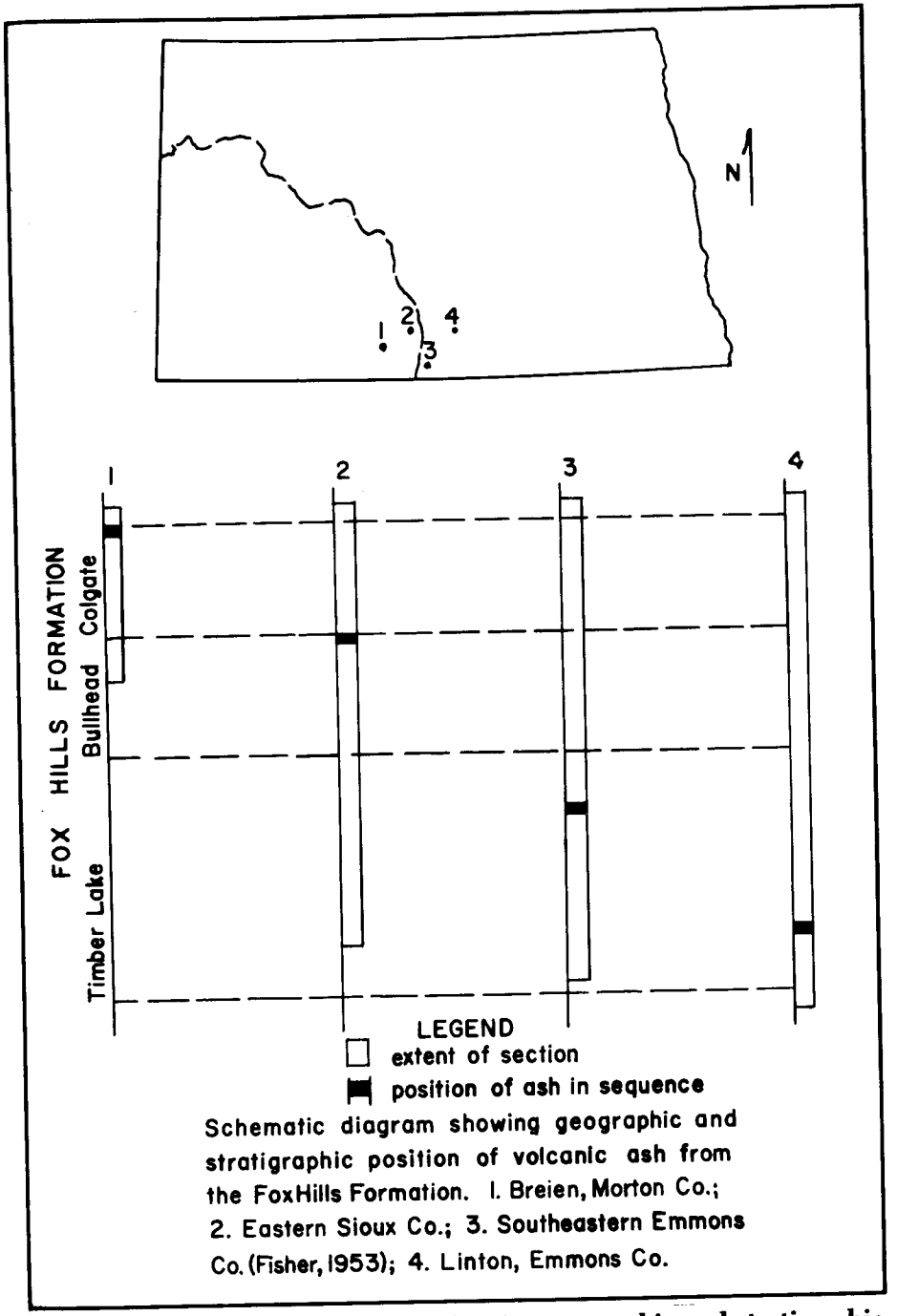
Throughout the study of the paleoecology of the Fox Hills, one recurrent theme seems to predominate over all other observations. This is the striking change from essentially normal marine conditions near the lower part of the Timber Lake Member to increasingly more shallow water, brackish conditions near the top of the Timber Lake and persisting through the Bullhead and Colgate members. The combination of this evidence along with the gradational nature of the contacts between the various stratigraphic units suggests that the members of the Fox Hills Formation as well as the overlying Hell Creek Formation and underlying Pierre Formation were being deposited at the same time in different areas and that they represent facies of one another.

One small bit of evidence, not yet conclusive, suggests that there may be sufficient evidence not only to establish definite facies relationships between the units of the Fox Hills but also to place them in lateral perspective. This evidence involves the distribution of volcanic ash in the Fox Hills Formation. T. W. Stanton (1917, p. 80-81) first recorded the presence of volcanic ash in the Fox Hills Formation. The exposure which he studied is located in the center of T. 133 N., R. 76 W., just north of Linton in Emmons County. At this locality the ash is extremely well developed and attains a maximum thickness of about 25

feet. Here, as in other areas where the ash has now been located, it is an extremely fine-grained massive unit and contains from 80-90% volcanic glass shards. Just north of Linton, the base of the ash is about 45 feet above the contact of the Pierre Formation (Fisher, 1952, p. 15) and if traced eastward into sec. 6, T. 132 N., R. 75 W., it rests upon sediments which appear to be very near the base of the formation. Fisher (1952, p. 15) indicated that he traced the bed to the southwestern corner of Emmons County where it lies about 15 feet above the top of the lower Fox Hills or the Timber Lake Member. This area is now heavily covered by vegetation and the outcrop is obscured. The ash, however, has been located in Sioux and Morton counties at several localities. An excellent exposure of the ash can be seen in the northwest corner of sec. 21, T. 134 N., R. 79 W., at the top of a small butte overlooking the Cannonball River in Sioux County. It can also be observed just across the river in Morton County, in sec. 4, T. 135 N., R. 79 W. At these two localities, the ash is enclosed in sediments of the Bullhead Member. Still farther west in sec. 31, T. 134 N., R. 81 W., southeast of Breien, the ash is present at the contact between the Fox Hills and Hell Creek formations.

Petrographic study of the ash by the writer at the locality north from Linton and in the northeast corner of Sioux County indicates that there is very little, if any, difference in the lithology except that the ash in Sioux County is somewhat coarser than that in Emmons County. The ash is thickest near Linton and becomes thinner both to the east and to the west, thinning to about 4 feet in eastern Emmons County and in Sioux County near Breien. As the ash is traced from its easternmost extent toward the west, it appears to progress steadily up section in the Fox Hills (Fig. 11).

Two possible interpretations emerge from these data. The first is that the various ash beds represent a series of at least four separate ash falls during the time of depositon of the Fox Hills. The second interpretation is that all of the ash beds represent the same ash fall and, therefore, form a time marker within the unit. Very little evidence supports the first of these hypotheses. Ash is neither repeated in the section nor are deposits of ash randomly distributed in the formation. Rather, they progress steadily up section from east to west. At present, then, it would seem most likely that the ash beds represent accumulations of debris from one event of volcanism and that the discontinuity of the beds is a function primarily of area of deposition. Without more careful mineralogical investigation and, perhaps, subsurface tracing, the hypothesis would have to be considered somewhat tenuous. It does, however, lead to some rather interesting speculation in that, if the assumption of penecontemporaneity is true, one has an accurate means of determining the lateral extent of each of



Schematic diagram showing geographic and stratigraphic position of volcanic ash from the FoxHills Formation. 1. Breien, Morton Co.; 2. Eastern Sioux Co.; 3. Southeastern Emmons Co. (Fisher, 1953); 4. Linton, Emmons Co.

FIGURE 11. Schematic diagram showing geographic and stratigraphic position of volcanic ash from the Fox Hills Formation.

the facies of the Fox Hills Formation. At the time when the ash fall occurred, the strand line marking the contact between the terrigenous sediments of the Hell Creek and the marine and brackish-water sediments of the Fox Hills would have been located in the vicinity of Breien and the lower contact of the Fox Hills would have been in the area of eastern Emmons County so that the total width of deposition of Fox Hills-type sediments would have been about 40 to 50 miles.

Synthesis

The Fox Hills Formation would appear to represent a sequence of beds deposited in the littoral and sublittoral zone of a regressive seaway. It is intimately related to the deposition of the Hell Creek and Pierre formations with the Hell Creek representing alluvial deposits of the coastline bordering the Cretaceous seaway and with the Pierre Formation representing somewhat deeper water deposition adjacent to the area of deposition of the Fox Hills (Fig. 12). The maximum water depth suggested by fossils near the base of the Fox Hills Formation was about 30-80 fathoms whereas fossils near the top of the Timber Lake Member and in the Colgate Member suggest deposition in either littoral or very shallow, sublittoral conditions.

The general picture that emerges concerning the environments in which the various members of the Fox Hills were deposited is as follows: The Colgate Member seems to represent intertidal or very shallow water, perhaps a beach deposit, which in various localities supported a very profuse oyster growth. Farther offshore, the Bullhead Member was deposited in what must have been a rather brackish-water lagoonal, or estuarine environment. Presence of oysters in both the Colgate Member and the upper part of the Timber Lake Member would tend to support this suggestion.

Restriction of water circulation in the area in which the Bullhead Member was deposited was effected by the presence of an off-shore bar which is presently represented by the shallow water deposits of the upper Timber Lake Member. Presence of *Ophiomorpha* as well as *Hardouinia* and abundant oyster deposits suggest the shallow water conditions. Cross-bedding in this same part of the stratigraphic section suggest moderate wave and current action.

The remainder of the Fox Hills Formation, the lower part of the Timber Lake Member, was deposited in increasingly deeper, less agitated water, indicated by the gradual disappearance of cross-bedding and the general decrease in grain size toward the bottom of the section.

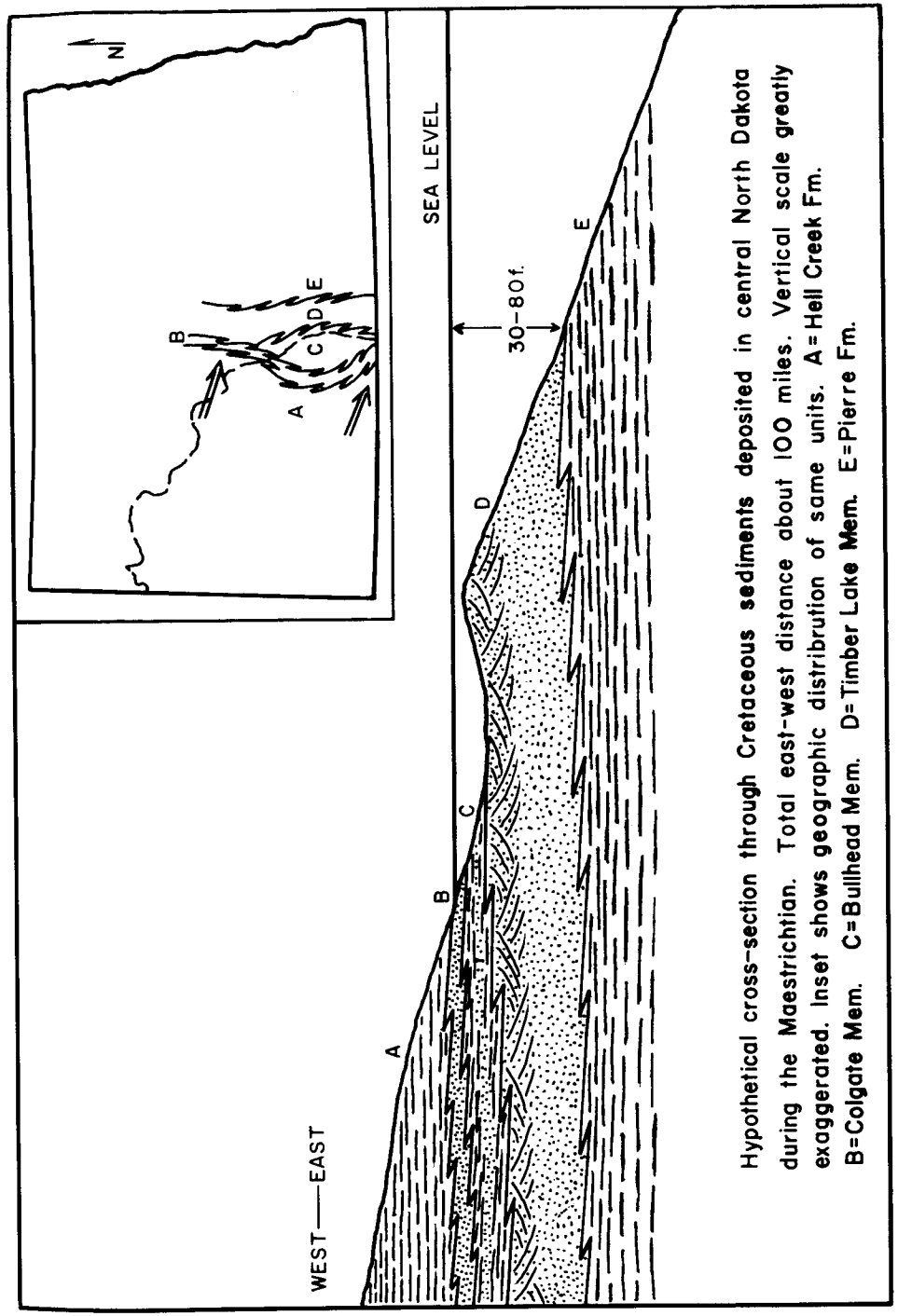


FIGURE 12. Hypothetical cross-section through Cretaceous sediments deposited in central North Dakota during the Maestrichtian.

Finally, near the base of the Fox Hills, the sand which had been transported from the adjacent coastline was winnowed out and the finer grained silt and clay sediments were deposited as Pierre sediments.

The lagoonal situation represented by the Bullhead Member is not everywhere observed. In the western part of the state, along the Cedar Creek Anticline, no such beds were observed, and one might infer that in this case the Colgate Member represented beach and sub-beach deposits, and the Timber Lake sediments again represent offshore and gradually deepening conditions.

As the margin of the seaway progressed eastward and the seaway retreated, sediments of the various environments of deposition overlapped one another, yielding the stratigraphic section now observable. The only indication of the greatest extent of retreat of the Fox Hills seaway can be seen in the area of Verendrye, North Dakota, where Lemke (1960, p. 24) suggested that the Fox Hills Formation can be found directly underlying the Cannonball Formation. If this interpretation is true, one might then suggest that the Fox Hills sea retreated as far northeastward as north-central North Dakota at which time the minor transgression of the Cannonball sea, of Paleocene age, began. Considerable careful study of the subsurface relationships of these two units in the area of Verendrye must be undertaken, however, before a definite statement in this regard can be made.

Although no evidence is available which would indicate the total length of time in which Fox Hills deposition took place in North Dakota, it must have been relatively brief. Study of the fossils in vertical section through the unit indicates very little, if any, evolutionary change in forms, but rather indicates changes in environments of deposition. The extinction of organisms and evolution of new species that can be observed are found when the Fox Hills is traced to the west into Wyoming and Colorado. Sufficient time for evolutionary change was apparently not available during the time of Fox Hills deposition in North Dakota.

CONCLUSIONS

Based on the present work on the Fox Hills Formation in North Dakota, the following conclusions can be drawn:

1. The Fox Hills Formation crops out in Logan, Emmons, Sioux, Morton, Burleigh, Kidder, Pierce, McHenry, Bottineau, and Bowman counties, but is well exposed only in Emmons, Sioux, and Morton counties in south-central North Dakota.

2. The formations can be subdivided into three members in North Dakota, the Timber Lake, Bullhead, and Colgate Members. The lowermost member of the formation in the type area in South Dakota, the Trail City Member, cannot be distinguished on the basis of lithology in North Dakota.

3. Study of the Bivalvia and Cephalopoda of the Fox Hills confirms the Maestrichtian age of the formation in the state. The Fox Hills correlates with the upper portion of the Navarro Group in Texas, the upper part of the Ripley Formation in Mississippi, and the upper part of the Monmouth Group in New Jersey. Cephalopods collected from the Fox Hills in Colorado indicate a somewhat greater age for the unit in that area, probably lowermost Maestrichtian. The formation, therefore, becomes significantly younger to the east.

4. The bivalve fauna of the Timber Lake Member probably lived in normal marine water that varied in depth from intertidal to about 80 fathoms. Increase in abundance and magnitude of cross-bedding and presence of extremely shallow-water bivalves and arthropods near the top of the member indicates that the water depth decreased progressively from the base of the member to the top.

5. The Bullhead Member, which normally yields a rather sparse fauna, consists of a sequence of interbedded sandstone and shale. The unit was probably deposited in extremely shallow, brackish water, possibly in an estuary or lagoon.

6. The Colgate Member, which locally yields a large oyster assemblage, probably represents a beach deposit separating the predominantly marine Fox Hills Formation from the overlying predominantly non-marine Hell Creek Formation.

7. The fossils collected from the Fox Hills were, in many cases, taken from concretions which were probably formed at, or very near, their present positions and probably represent calcareous accumulations around organic centers.

8. A volcanic ash bed has been identified in Emmons, Sioux, and Morton counties and, if contemporaneous throughout, indicates that the three members of the formation identified in North Dakota were deposited penecontemporaneously over a lateral distance of about 40 miles. Further petrological and geochemical work will have to be done before the continuity of the ash can be absolutely demonstrated.

9. The paleoecology of the Fox Hills Formation in North Dakota indicates that it represents the littoral and sublittoral facies of a regressive Upper Cretaceous seaway which retreated to the north and east. The regression probably terminated in the area of Pierce County in central North Dakota by the end of the Cretaceous. A single, minor transgression is suggested by the Breien Member of the Hell Creek Formation. Following the retreat of the Fox Hills sea into central

North Dakota, a major advance occurred which resulted in the deposition of the Cannonball Formation of Paleocene age.

10. Forty-two species of bivalves assigned to twenty-five genera were identified from the Fox Hills Formation in North Dakota. Of this number, three species appear to be previously undescribed.

REFERENCES

Abbott, R. T., 1955, American seashells: New York, Van Nostrand, 541 p.

Babcock, E. J., 1901, Report of the Geological Survey of North Dakota: N. Dak. Geol. Survey First Biennial Rept., 1903 p.

Bartram, J. G., 1937, Upper Cretaceous of Rocky Mountain area: Am. Assoc. Petroleum Geologists Bull., v. 21, no. 7, p. 899-913.

Bavendick, F. J., 1941, Climate of North Dakota: U. S. Dept. of Agriculture, Yearbook, p. 1045-1054.

Boucot, A. J., 1953, Life and death assemblages among fossils: Am. Jour. Sci., v. 251, p. 25-40.

Bowen, C. F., 1915, The stratigraphy of the Montana Group with special reference to the position and age of the Judith River Formation in north-central Montana: U. S. Geol. Survey Prof. Paper 90-I, p. 95-153.

Butler, P. A., 1954, Summary of our knowledge of the oyster in the Gulf of Mexico: U. S. Bureau of Fisheries Bull., v. 89, p. 479-489.

Calvert, W. R., 1912, Geology of certain lignite fields in eastern Montana: U. S. Geol. Survey Bull. 471, p. 187-201.

Calvert, W. R., and others, 1914, Geology of the Standing Rock and Cheyenne Indian reservations, North and South Dakota: U. S. Geol. Survey Bull. 575, 49 p.

Clayton, Lee, 1962, Glacial geology of Logan and McIntosh counties, North Dakota: N. Dak. Geol. Survey Bull. 37, 84 p.

Cobban, W. A., and Reeside, J. B., Jr., 1952, Correlation of the Cretaceous formations of the Western Interior of the United States: Geol. Soc. America Bull., v. 53, p. 1011-1044.

Cvancara, A. M., 1966, Revision of the fauna of the Cannonball Formation (Paleocene) of North and South Dakota: Univ. Mich., Mus. of Paleontology Contr., v. 20, no. 10, p. 277-374, 9 pls.

Dane, C. H., Pierce, W. G., and Reeside, J. B., Jr., 1937, The stratigraphy of the Upper Cretaceous rocks north of the Arkansas River in eastern Colorado: U. S. Geol. Survey Prof. Paper 186-K, p. 207-232.

Dobbin, C. E., and Reeside, J. B., Jr., 1929, The contact of the Fox Hills and Lance Formations: U. S. Geol. Survey Prof. Paper 158, p. 9-25.

Eldridge, G. H., 1889, On some stratigraphical and structural features of the country about Denver: Colorado Science Soc. Proc., v. 3, p. 86-118.

Feldmann, R. M., 1964, Preliminary investigation of the paleontology and structure of Sibley Buttes, central North Dakota: Compass, v. 41, no. 2, p. 129-135.
Fenneman, N. L., 1931, Physiography of western United States: New York, McGraw-Hill, 534 p.
Fenneman, N. L., 1938, Physiography of eastern United States: New York, McGraw-Hill, 714 p.
Fisher, S. P., 1952, The geology of Emmons County, North Dakota: N. Dak. Geol. Survey Bull. 26, 47 p.
Frye, C. I., 1969, Stratigraphy of the Hell Creek Formation in North Dakota: N. Dak. Geol. Survey Bull. 54, 65 p.
Gill, J. R., and Cobban, W. A., 1965, Stratigraphy of the Pierre Shale, Valley City and Pembina Mountain areas North Dakota: U. S. Geol. Survey Prof. Paper 392-A, p. 1-20.
Gunter, Gordon, 1957, Temperature, *in* Treatise on marine ecology and paleoecology, vol. 1 - Ecology: Geol. Soc. America Mem. 67, p. 159-184.
Hall, James, and Meek, F. B., 1856, Description of new species of fossils from the Cretaceous formations of Nebraska, with observation upon *Baculites ovatus* and *Baculites compressus*, etc.: American Acad. Arts Mem., new ser., v. 5, p. 379-411.
Hanson, Miller, 1956, Geologic Map of North Dakota: Grand Forks, N. Dak. Geol. Survey.
Henderson, Junius, 1920, The Cretaceous formations of the northeastern Colorado plains: Colo. Geol. Survey Bull., v. 19, p. 7-57.
Holland, F. D., Jr., and Feldmann, R. M., 1967, A new species of cassiduloid echinoid from the Fox Hills Formation (Upper Cretaceous) of North Dakota: Jour. Paleontology, v. 41, no. 1, p. 252-255, 1 text-fig.
Huxley, T. H., 1862, Anniversary address: Geol. Soc. London, Quart. Jour., Proc, v. 18, p. xl-liv.
Jeletzky, J. A., 1962, The allegedly Danian dinosaur-bearing rocks of the globe and the problem of the Mesozoic-Cenozoic boundary: Jour. Paleontology, v. 36, no. 5, p. 1005-1019.
Keen, A. M., 1963, Marine molluscan genera of western North America: Stanford, California, Stanford Univ. Press, 126 p.
Knowlton, F. H., 1916, The flora of the Fox Hills Sandstone: U. S. Geol. Survey Prof. Paper 98, p. 85-93.
Kume, Jack, and Hansen, D. E., 1965, Geology and ground water resources of Burleigh County, North Dakota, Part 1 - Geology: N. Dak. Geol. Survey Bull. 42, 111 p.

Laird, W. M., and Mitchell, R. H., 1942, The geology of the southern part of Morton County, North Dakota: N. Dak. Geol. Survey Bull. 14, 42 p.
Lemke, R. W., 1960, Geology of the Souris River area North Dakota: U. S. Geol. Survey Prof. Paper 325, 138 p.
Leonard, A. G., 1904, Geological formations of North Dakota: N. Dak. Geol. Survey Third Bienn. Rept., p. 140-180.
Leonard, A. G., 1906, Stratigraphy of North Dakota clays: N. Dak. Geol. Survey Fourth Bienn. Rept., p. 63-94.
Leonard, A. G., 1908, The geology of southwestern North Dakota with special reference to the coal: N. Dak. Geol. Survey Fifth Bienn. Rept., p. 27-114.
Leonard, A. G., 1908, The geological history of North Dakota: N. Dak. Geol. Survey Fifth Bienn. Rept., p. 227-245.
Leonard, A. G., 1911, The Cretaceous and Tertiary formations of western North Dakota and eastern Montana: Jour. Geology, v. 19, no. 6, p. 507-547.
Leonard, A. G., 1912, The geology of south central North Dakota: N. Dak. Geol. Survey Sixth Bienn. Rept., p. 21-99.
Lloyd, E. R., 1914, The Cannonball River lignite field, Morton, Adams, and Hettinger counties, North Dakota: U. S. Geol. Survey Bull. 541, p. 243-291.
Lovering, T. H., and others, 1932, Fox Hills Formation, northeastern Colorado: Am. Assoc. Petroleum Geologists, v. 16, p. 702-703.
McDermott, J. F., (editor and annotator), 1951, Up the Missouri with Audubon; the journal of Edward Harris: Norman, Oklahoma, Univ. Oklahoma Press.
Manz, O. E., 1962, Investigation of pozzolanic properties of the Cretaceous volcanic ash deposit near Linton, North Dakota: N. Dak. Geol. Survey Rept. Inv. 38, 42 p.
Meek, F. B., 1876, A report on the invertebrate Cretaceous and Tertiary fossils of the upper Missouri country: U. S. Geol. Survey Terr., v. 9, 629 p., 45 pls.
Meek, F. B., and Hayden, F. V., 1856, Descriptions of twenty-eight species of Acephala and one gasteropod, from the Cretaceous formation of Nebrasca Territory: Acad. Nat. Sci. Philadelphia Proc., v. 8, p. 81-87.
Meek, F. B., and Hayden, F. V., 1856, Descriptions of new species of Acephala and Gasteropoda, from the Tertiary formations of Nebrasca, etc.: Acad. Nat. Sci. Philadelphia Proc., v. 8, p. 111-126.
Meek, F. B., and Hayden, F. V., 1856, Descriptions of new fossil species of Mollusca collected by Dr. F. V. Hayden, etc.: Acad. Nat. Sci. Philadelphia Proc., v. 8, p. 265-286.

Meek, F. B., and Hayden, F. V., 1857, Descriptions of new species and genera of fossils, collected by Dr. F. V. Hayden in Nebrasca Territory, etc.: Acad. Nat. Sci. Philadelphia Proc., v. 9, p. 117-148.

Meek, F. B., and Hayden, F. V., 1861, Descriptions of new Lower Silurian (Primordial), Jurassic, Cretaceous, and Tertiary fossils, etc.: Acad. Nat. Sci. Philadelphia Proc., v. 13, p. 415-447.

Merrill, G. P., 1924, The first one hundred years of American geology: New Haven, Yale Univ. Press, 773 p.

Morgan, R. E., and Petsch, B. C., 1945, A geological survey in Dewey and Corson counties, South Dakota: S. Dak. Geol. Survey Rept. Inv. 49, 45 p.

Morton, S. G., 1839, Description of some new species of organic remains of the Cretaceous Group of the United States: with a tabular view of the fossils hitherto discovered in this formation: Acad. Nat. Sci. Philadelphia Jour., v. 8, pl. 1, p. 207-227, pls. 10 and 11.

Rau, J. L., and others, 1962, Geology and ground water resources of Kidder County, North Dakota; Part 1 - Geology: N. Dak. Geol. Survey Bull. 36, 70 p.

Searight, W. V., 1931, The Isabel-Firesteel coal area: S. Dak. Geol. and Nat. History Survey Rept. Inv. 10, 35 p.

Sinclair, R. M., and Isom, B. G., 1963, Further studies on the introduced Asiatic clam (*Corbicula*) in Tennessee: Nashville, Tennessee, Tennessee Dept. of Public Health, 78 p., 14 pls.

Stanton, T. W., 1910, Fox Hills Sandstone and Lance Formation ("*Ceratops* beds") in South Dakota, North Dakota, and eastern Wyoming: Am. Jour. Sci., 4th ser., v. 30, p. 172-188.

Stanton, T. W., 1917, A Cretaceous volcanic ash bed on the Great Plains in North Dakota: Washington Acad. Sci. Jour., v. 7, p. 80-81.

Stanton, T. W., 1920, The fauna of the Cannonball marine member of the Lance Formation: U. S. Geol. Survey Prof. Paper 128, 61 p.

Stebinger, Eugene, 1914, The Montana Group of northwestern Montana: U. S. Geol. Survey Prof. Paper 90-G, p. 61-68.

Stephenson, L. W., 1941, The larger invertebrates of the Navarro Group of Texas: Univ. Texas, Pub. 4101, 641 p., 95 pls.

Stephenson, L. W., and Reeside, J. B., Jr., 1938, Comparison of Upper Cretaceous deposits of Gulf region and Western Interior region: Am. Assoc. Petroleum Geologists Bull., v. 22, no. 12, p. 1629-1638, 3 figs.

Stephenson, L. W., and others, 1942, Correlation of the outcroping Cretaceous formations of the Atlantic and Gulf Coastal Plain and trans-Pecos Texas: Geol. Soc. America Bull., v. 53, no. 3, p. 435-448.

Stevenson, R. E., 1956, Geology of the Bullhead Quadrangle: S. Dak. Geol. Survey, Geol. Quadrangle.

Thom, W. T., Jr., and Dobbin, C. E., 1924, Stratigraphy of Cretaceous-Eocene transition beds in eastern Montana and the Dakotas: Geol. Soc. America Bull., v. 35, no. 3, p. 481-505.

Thornthwaite, C. W., 1941, Climate and settlement in the Great Plains: U. S. Dept. of Agriculture, Yearbook, p. 177-187.

Thwaites, R. G., 1904, Original journals of the Lewis and Clark Expedition, 1804-1806, volume 1: New York, Antiquarian Press, 374 p.

Todd, J. E., 1896, The moraines of the Missouri Coteau and their attendant deposits: U. S. Geol. Survey Bull. 144, 71 p.

Trewartha, G. T., 1941, Climate and settlement of the subhumid lands: U. S. Dept. of Agriculture, Yearbook, p. 167-176.

Waage, K. M., 1961, The Fox Hills Formation in its type area, central South Dakota: Wyoming Geol. Assoc., 16th Ann. Field Conf. Guidebook, p. 229-240.

Waage, K. M., 1964, Origin of repeated fossiliferous concretion layers in the Fox Hills Formation *in* Symposium on cyclic sedimentation: Kansas Geol. Survey Bull. 169, p. 541-563.

Waage, K. M., 1968, The type Fox Hills Formation, Cretaceous (Maestrichtian), South Dakota: Peabody Museum of Natural History, Bull. 27, 175 p., 12 pls.

Wade, Bruce, 1926, The fauna of the Ripley Formation on Coon Creek, Tennessee: U. S. Geol. Survey Prof. Paper 137, 272 p., 72 pls.

Weimer, R. J., and Hoyt, J. H., 1964, Burrows of *Callianassa major* Say, geologic indicators of littoral and shallow neritic environments: Jour. Paleontology, v. 38, no. 4, p. 761-768.

Wells, H. W., 1961, The fauna of oyster beds with special reference to the salinity factor: Ecol. Monographs, v. 31, no. 3, p. 239-266.

Wheeler, G. C., and Wheeler, Jeanette, 1963, The ants of North Dakota: Grand Forks, North Dakota, Univ. of N. Dak. Press, 326 p.

Wilder, F. A., 1902, Geologic report on the lignite area: N. Dak. Geol. Survey Second Bienn. Rept., p. 33-55.

Wilmarth, M. G., 1938, Lexicon of geologic names of the United States: U. S. Geol. Survey Bull. 896, 2396 p.

-1-
SW 1/4 sec. 13, T. 132N, R. 107W

Top of hill

Hell Creek Fm.

Buff, massive sandstone

Interbedded dark, lignitic shale and sandstone

Lignitic shale, dark brown

80

60

Colgate Member

White, "dirty" sandstone with lignitic shale partings. Weathers to fluted surface

40

Timber Lake Member

Sandstone, well-indurated, cross-bedded, with iron cemented sandstone concretions and small "ironstone" nodules

Level of Little Beaver Creek

-2-
NW 1/4, NW 1/4 sec. 4, T 131 N., R. 106 N. to Center, sec. 32, T. 132 N., R. 106 W.,

Top of Fox Hills

80

Colgate Member

White, massive, "dirty" sandstone, medium-grained with lignitic shale partings. Weathers to fluted surface.

40

Timber Lake Member

Sand, similar to below but with cross-bedding. Some discontinuous ferrugenous sandstone ledges.

Shale as below but with small ferrugenous nodules

Fine-grained, buff to yellow sand with chocolate brown shale interbeds

Pierre Fm.

Shale, dark blue weathering to grey. Small gypsum crystals and jarosite. Scattered concretions.

-3-
NW 1/4 sec 21, T 134N., R. 79W.,

Top of butte

Tan, flaggy sandstone

Cgl

White, massive sand

Perlite ash

160

140

Interbedded chocolate brown, silty shale and brownish sand which weathers to buff or brown. Individual beds are 6"-18" thick.

120

Bullhead Member

Sand as below

Reddish sandstone ledge- locally prominent

80

Buff to yellowish sand weathering to yellowish brown with little bedding near base becoming Cross-bedded near top. Discontinuous ledges of Reddish brown sandstone becoming more prominent near top. Ophiomorpha abundant near top and rare near base

60

40

Timber Lake Member

Cannonball River floodplain

-4-
SW 1/4 sec 36, T. 130N., R. 80W.,

Top of Red Horse Butte

200

White to cream, flaggy sandstone

180

160

Interbeds of buff to chocolate silty shale and reddish brown, medium-grained sand

140

Bullhead Member

100

80

Covered

60

40

20

Massive, calcareous sandstone

20 feet

columnar sections

county map insets 20 miles

SCALE

-5-
Center, sec 27, T 130N., R. 80W.,

Top of section at top of hill

120

Sand, as below, but with minor cross-bedding and Ophiomorpha

100

Ferrugenous, fossiliferous concretions

Sand, as below, but with Ophiomorpha and ferrugenous nodules

Blocky, calcareous sandstone

80

60

Sand, medium- to fine-grained, buff to reddish, massive, with some pods or layers of reddish, brittle claystone becoming more common near top

Some shale stringers near base

40

Timber Lake Member

Buff sand with grey pods of silty shale

-6-
SE 1/4 sec. 17, T. 132 N., R. 76 W.,

Top of cutbank

Timber Lake Member

Sand as below

Calcareously cemented concretions

Fine- to medium-grained sand with jarosite

Concretions in silty sand

Jarosite rich, brown, sandy shale, weathers grey

First jarosite

Shale, as below, but with increasing silt and sand

60

Shale, as below, but with very fine sand and silt

Shale, dark bluish black, weathers to grey, fissile, gypsiferous, iron stained on joints

40

Pierre Formation

Covered

20

Top of roadway on dam

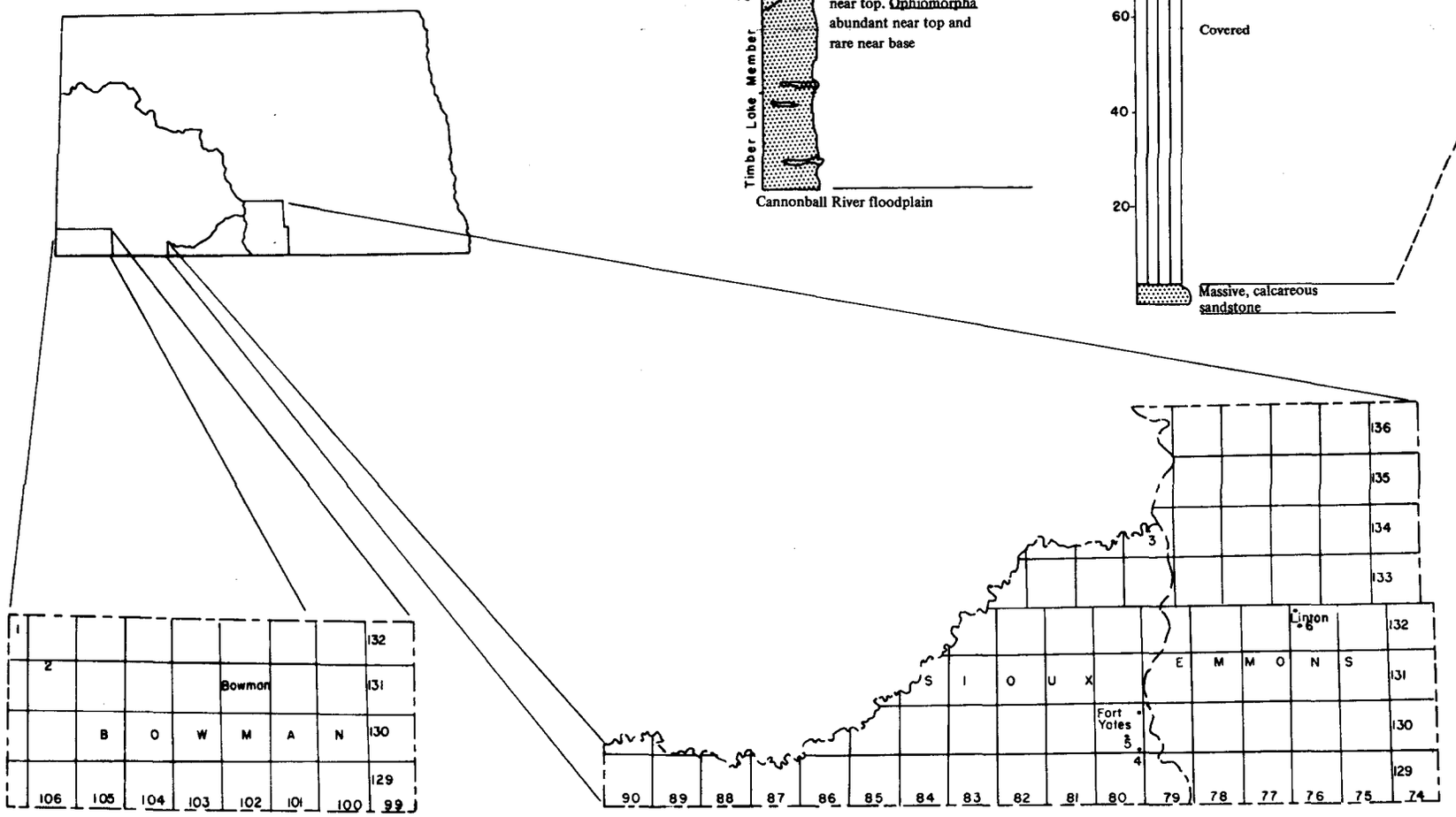


Plate 1. Columnar Sections and Correlation of Members of the Fox Hills Formation in North Dakota