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TYPE AND REFERENCE SECTIONS FOR A NEW MEMBER OF THE FOX HILLS FORMATION, UPPER CRETACEOUS (MAESTRICHTIAN) IN THE MISSOURI VALLEY REGION, NORTH AND SOUTH DAKOTA

by

Mark C. Klett and J. Mark Erickson

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TYPE AND REFERENCE SECTIONS FOR A NEW MEMBER OF THE FOX HILLS FORMATION, UPPER CRETACEOUS (MAESTRICHTIAN) IN THE MISSOURI VALLEY REGION, NORTH AND SOUTH DAKOTA

Mark C. Klett and J. Mark Erickson
Department of Geology and Geography
St. Lawrence University, Canton, New York 13617

ABSTRACT

Field study in Emmons and Sioux Counties, North Dakota, and eastern Corson County, South Dakota has revealed a new stratigraphic unit of the Upper Cretaceous (Maestrichtian) Fox Hills Formation. Previously, workers had included this unit with the Colgate lithofacies (or member) which has its type area in Montana. Hayden clearly recognized its significance calling it "Bed Q." This is the resistant sandstone which capped Hayden's "Fox Ridge." It is probable that most of Hayden's exploration was along this ridge well into North Dakota. Recognition of the uniqueness of the unit, which we have called the Linton Member, has shed light on the meaning of much of Hayden's work.

The Linton Member consists of light olive gray to grayish brown, fine-grained, subangular, moderately to poorly sorted, indurated, siliceous sandstone containing volcanic shards. Cross-strata and flat bedding are present locally, the unit being generally massive. Analyses indicate a range of lithologic constituents which place the rock between a feldspathic arenite and subgraywacke with about 28% matrix.

Vertical roots, *Equisetum,* and *Ophiomorpha* also characterize the unit. Wood fragments are abundant in the upper beds. Thickness ranges from 0.2 to 6.0 m. A type section is designated in N½ secs. 8 and 9, T. 132 N., R. 76 W., 1 mile E. of Linton, North Dakota. Reference sections are in NE¼NW¼ sec. 28, T 130 N., R. 78 W., Emmons County, N. Dak. and 11 miles west of McLaughlin in northeastern Corson County, S. Dak. The Linton Member is interpreted as a channel sand, deposited in and along a major, wide, shallow, southward-flowing estuarine tidal river

INTRODUCTION

Purpose.—Stratigraphic description of the Fox Hills Formation in the Missouri Valley Region of North and South Dakota is intricately entwined with the history of early explorations of the Territory. A great deal of controversy has revolved around the rocks which record the transition from marine to terrestrial depositional environments. Many of these issues are resolved for such units in Wyoming, Montana, and western North Dakota, yet stratigraphic sequences and facies relationships still are not understood in the Missouri Valley, the type area of the Fox Hills Formation.

Our work is an attempt to clarify and to begin to diagnose undescribed Fox Hills strata which occur over much of Emmons County, North Dakota and which extend eastward and southward into adjacent areas (Figure 1). The present paper defines a new lithologic unit at the top of the formation. It also attempts to place this unit in proper context with respect to historic study of the Fox Hills Formation since the work of Meek and Hayden in the mid-nineteenth century. Eventually all strata east of the Strassburg Channel (Fisher, 1952, p. 26) in Emmons County, and those of Logan and McIntosh counties as well, should be thoroughly

re-examined and redefined. We begin the process herein by designating "Bed Q" of Meek and Hayden (1857) as the Linton Member of the Fox Hills Formation.

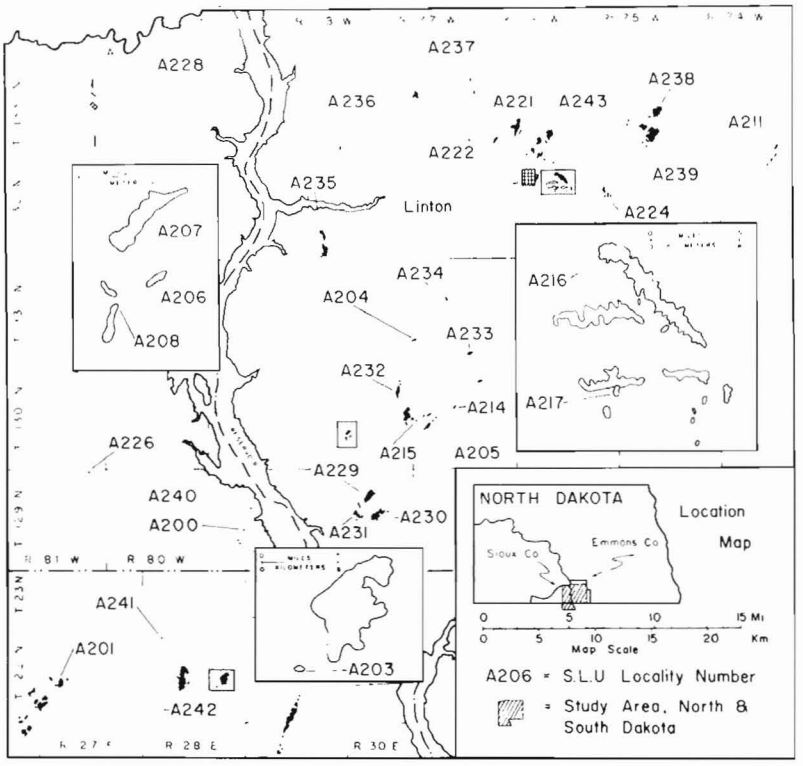

Figure 1. Map of major exposures of Linton Member with location of type (A216) and reference (A203, A206) sections.

Previous stratigraphic studies.—Formal recognition of the Upper Cretaceous (Maestrichtian) Fox Hills Formation was first made by Meek and Hayden in 1861 when the presently-used name was applied to rocks previously designated as "Unit No. 5" of the Cretaceous strata of the Missouri River Region (Meek and Hayden, 1856). Impressions of the formation and its confining beds, the Pierre below and the Hell Creek (Lance of some workers) above, upon which they based most of their discussions were developed largely from exploratory excursions conducted by Hayden along and adjacent to the Missouri River approximately between the present cities of Bismarck and Pierre. "Fox Ridge" on the divide between the Cheyenne and Moreau Rivers in South Dakota made a marked impression upon them, and the Fox Hills Formation was thought to have been named for rocks well exposed in that divide (Waage, 1968).

Attempts at more detailed description of Fox Hills and related Cretaceous rocks led to a multitude of stratigraphic misinterpretations and misunderstandings which rather confused the stratigraphic relationships for more than half a century. In large part, problems were due to long-distance physical correlations and to failure to recognize lateral lithofacies relationships which had resulted from rapid regression of the Maestrichtian sea and the terrestrial deposition which followed.

Several comprehensive historical treatments of the conceptual development of the formation are available in recent literature. That of Waage (1968), given in conjunction with a redescription of the stratigraphy of the type area in South Dakota, lends itself particularly well to explanation of the intricacies of geographical locations and probable routes of the early explorations of the region. Feldmann (1972) presented an equally useful account of previous studies in North Dakota. Some recent descriptions of Fox Hills rocks and their faunas were summarized by Erickson (1974).

Our discussion of previous work now focuses upon the uppermost sandstone unit of the formation in areas adjacent to the Missouri River. These rocks are lagoonal or estuarine deposits; their lower and upper contacts are often transitional, even gradational on occasion, between marine strata below and freshwater or terrestrial strata above. The brackish-water origin of invertebrates in these rocks was recognized by Meek and Hayden. Such fossils were common in "Bed Q," a gray, indurated-to-slightly-friable sandstone reaching a thickness of 30 feet (9.0 m) which they chose as the basal unit of the overlying "Great Lignite Group" (Meek and Hayden, 1857). In their opinion, this unit also represented the first "Tertiary" deposition in the region, a decision based largely upon Newberry's identification of floras in the Great Lignite Group as Miocene, and upon the absence of ammonites from Bed Q (Waage, 1968). Thus began a long stratigraphic controversy over the position of the Mesozoic-Cenozoic boundary in the northern Great Plains.

Calvert (1912) described the "Colgate sandstone member" of the Lance Formation (=Hell Creek Fm.) from sections at Colgate Station (N.P.R.R.) near the point where the Yellowstone River crosses the northwestern nose of the Cedar Creek anticline (center, south edge T. 15 N., R. 57 E.). Here, the member was about 175 feet (52.7 m) thick, a white (brown, lower) massive sandstone containing at least two leaf-bearing horizons. Knowlton (*in* Calvert, 1912) identified a collection of these leaves as being Tertiary in age, though Calvert (1912: 195) noted that elsewhere they were associated with dinosaur remains. From 1912 onward, the term "Colgate" has provoked a wide variety of interpretations and has received an overzealous use in the literature, providing a convenient departure for stratigraphic and philosophical disagreement.

Reasons for this are at least partially historic. Presence of a sandstone unit between the recognizably marine Fox Hills and the demonstrably terrestrial (fluvial, palludal) Hell Creek above places such a unit in a critical position. Paleobotanists, limited in their studies to terrestrial beds of the Fort Union and Hell Creek, established floral indices from these younger rocks, whereas invertebrate workers derived indices from molluscan remains in the older, marine rocks. The key sand-

stone unit, by virtue of its estuarine depositional environment, contained remains of both the land plants (defined as Tertiary) and the occasional marine mollusk of Cretaceous age. Was it of Mesozoic or Cenozoic age?

In 1910, Stanton effectively summarized the rock relationships, documenting this environmental transition. He interpreted the transition from marine to terrestrial depositional environments in the type area in South Dakota, in the Little Missouri River Valley of western North Dakota, and along Lance Creek in Wyoming. In 1911, Leonard presented a brief, incomplete, yet at that time, "modern" description of the stratigraphy in North Dakota. However, it was principally Stanton's presentation which brought the relationships to realistic perspective.

Thom and Dobbin (1924) recognized the similar stratigraphic position of the sandstone between the Fox Hills and Lance in Wyoming, the "Colgate" of Calvert, and the white sandstone occurring in the type area in South Dakota. This, and the subsequent work of Dobbin and Reeside (1929), solidified regional stratigraphic concepts of the upper Fox Hills-lower Hell Creek section formulating a basis from which, intuitively and logically, the pre-1968 concept of the section in the type area was to develop. Dobbin and Reeside (1929) provided the most definitive evaluation of the contact between the Fox Hills and Hell Creek Formations as applied to its transitional and gradational character. Theirs was the first major review of the "Colgate" sandstone that described it in relationship to rocks in the same stratigraphic position in Emmons County, North Dakota, and particularly in the Linton area.

Several recent works figure in our discussion. Todd (1910) presented some cogent glimpses of the lateral variability of rocks in the South Dakota section. These were overlooked during the late 1940s when mapping at geologic quadrangle scale in and around the type area in South Dakota began earnestly. During that work, Curtis (1952) introduced the name "Colgate Member" into the type area. That term came to be used extensively for any gray, cream, or white, indurated or non-indurated sandstone holding the "key" stratigraphic position at or near the Fox Hills-Hell Creek boundary in the region. Laird and Mitchell (1942) applied the name "Colgate" to such rocks in Morton County, North Dakota. Henceforth it has become common practice to label as "Colgate" all rocks fitting the general description given above, and occupying the "key" stratigraphic position.

Waage (1968) redefined the relationships of the type area in South Dakota in a well-conceived, useful manner. Recognizing the variable stratigraphic position of the Colgate Member in South Dakota, Waage defined the Iron Lightning Member containing Colgate and Bullhead lithofacies. This redefinition took into account the ephemeral nature of the Colgate sand facies which appears in both upper Fox Hills and lower Hell Creek sections. However, his conception of rocks in the "Colgate lithofacies" produced interpretve problems (Waage, 1968:129-151, "Butte Cap Problem"). In Emmons County, North Dakota, Fisher (1952) recognized the significance of rocks in this "key" position, but skirted any nomenclatorial question because his primary concern was structural in-

terpretation. Feldmann's (1972) stratigraphic summary likewise avoided the issue by calling all such rocks Colgate. Definition of the rock unit in this position has thus continued to be a problem in recent work. The relationship of the Linton Member to this issue and its historic significance to geologic study in the Missouri Valley Region will be discussed below.

Present field work.—Field work by Erickson in 1969 indicated that units of the Fox Hills Formation in Emmons County, North Dakota needed clarification relative to units in other areas of Fox Hills outcrop. Work in Emmons County further disclosed undescribed Fox Hills strata. Field work for this report was undertaken between late June and early August, 1973. All butte systems located in central and southwestern Emmons County were investigated, as were several buttes and outcrops in Sioux County, and related butte systems extending into northeast Corson County were examined. Fifty-four sections containing Linton strata, and 11 sections containing strata associated with the Linton Member were measured.

Where available, 7½-minute topographic maps were used to locate positions and elevations of the best exposures. However, only unedited advanced prints were available for the western one-half of Emmons County, and the lack of any topographic coverage for the eastern one-half of Emmons County necessitated other means of locating exposures. Aerial photographs were used for this purpose. Additional outcrops were located while travelling in the field.

Stratigraphic terminology in this report.—Erickson (1971) suggested the existence of an "unnamed" member at the top of the section, describing it as a blanket sandstone having an estuarine faunule. During that study, and in subsequent presentations, Erickson (1973, 1974) adopted Waage's (1968) revision of nomenclature where applicable, feeling that the Iron Lightning concept was useful in North Dakota.

We accept herein the member names Trail City, Timber Lake and Iron Lightning (with a Bullhead and Colgate lithofacies). We note that true Timber Lake sediments are scarce east of the Strassburg Channel of Fisher (1952) and suggest that Fox Hills units above the Trail City Member in that region are largely unnamed. Some Iron Lightning lithologies are present locally both east and west of the channel. The newly named Linton Member, by virtue of its butte-capping position, is at the top of the section.

DESCRIPTION OF THE LINTON MEMBER

Location and distribution.—Exposure of the Linton Member is limited in occurrence to buttes, as in Figures 3, 6, and 7, on which it forms a prominently displayed sandstone cap. Buttes are arranged in the area directly east, west, and north of Linton. In the southwestern quarter of Emmons County they form a northeast-trending, broken ridge which also appears west of the Oahe Reservoir in Sioux County where exposures of the Linton Member are found in T. 129 N., Rs. 79 and 81 W. Additional outcrops occur in the northeastern corner of Sioux County, just west of the town of Cannonball. In Corson County, South Dakota, buttes capped by the Linton Member continue the northeast trend established in

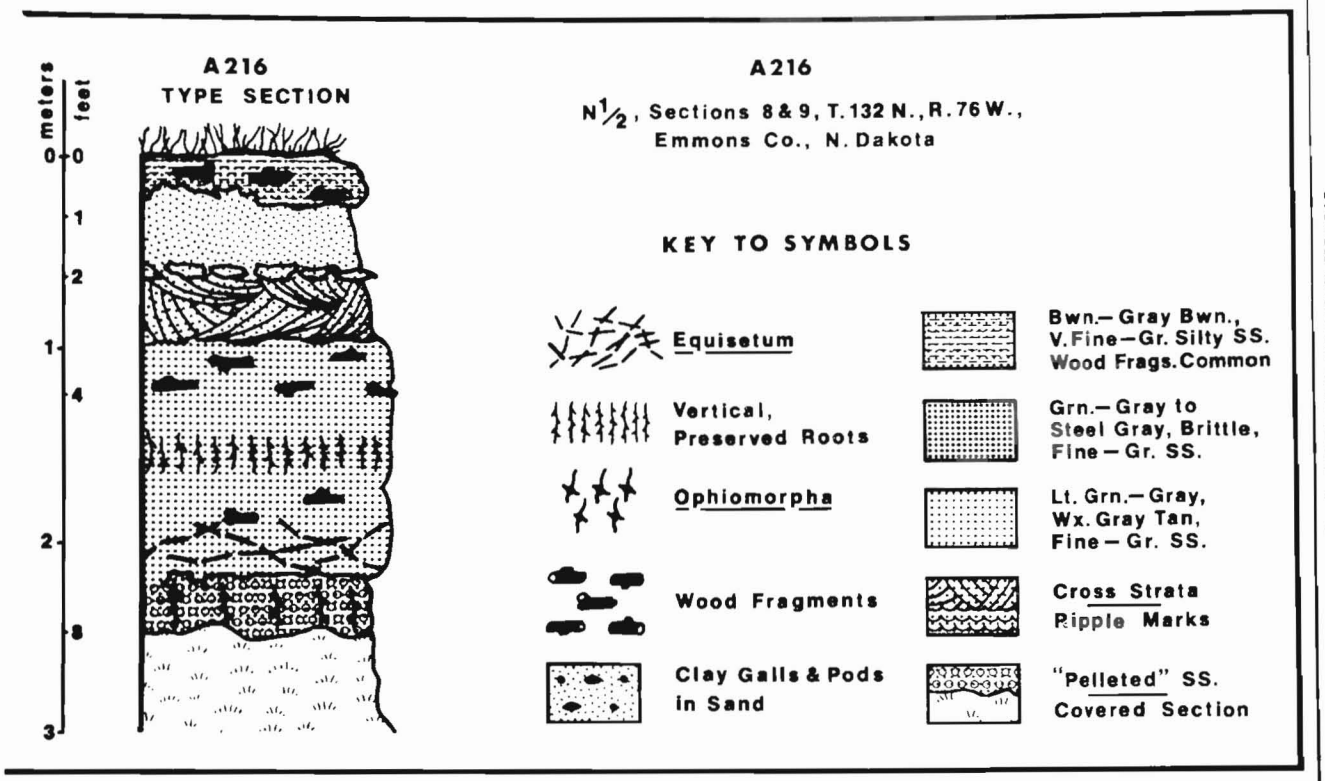

Figure 2. Schematic type section of Linton Member.

North Dakota. The unit was studied also on several buttes near McLaughlin, South Dakota.

Figure 1 shows known areas of exposure and is not a complete distribution map of Linton rocks. The unit is present well into the type area in South Dakota. It thins westward in Sioux County, although its exact lateral limits are not known; likewise the eastward extent is undescribed. Fisher traced it to the eastern edge of Emmons County where the stratigraphy became complicated by additional similiar units.

Thickness and stratigraphic position.—Exposures of Linton Member range in thickness from 0.2 m to 7 m, about 2 m being average. Although no locality offers a complete exposure due to prevalent slump blocks and hillslope talus around buttes, it is probable that 7 m approximates the maximum depositional thickness to be expected for the unit. Tops of those buttes which do not expose bare rock are covered by a soil composed of weathered glacial drift. Top and bottom contacts are not well understood because of poor exposures.

The basal contact on a butte on the south side of the Cannonball River in sec. 21, T. 134 N. R. 79 W. is gradational downward through thin, orange, lignitic sands into the top of a water-laid volcanic ash. The ash here is 3 or 4 m thick and rests on sediments of the Bullhead lithofacies. Eastward, at locality A206 in Emmons County, Bullhead sediment occurs 48.6 m below the Linton, and Timber Lake-like lithology occurs 62.5 m below its base. Animal burrows and slumps reveal transient glimpses of lower units. From these, it appears that the Bullhead lithofacies thins southeastward in Emmons County where its position is occupied by a complex, unindurated silty, very fine sandstone and sandy siltstone containing clay laminae, much lignitic matter and rare cleaner, flaggy, thin-bedded sandstone having a marine fauna.

Fisher (1952:39) described these flaggy "sea-green" sandstone ledges at several localities. In the type section (A216) the upper ledge occurs 29.5 m below the base of the Linton and 19.6 m above the volcanic ash which also thickens somewhat from Sioux into Emmons County. In the region around and southwest of the town of Linton the base of the member seems to have a gradational contact with the unindurated silty sands that lie below and which represent an unnamed Fox Hills facies.

Units overlying the Linton are also poorly known. However, on the largest, northernmost butte of a system in the SE¼SW¼ sec. 21, T. 130 N., R. 78 W., 1 m of chocolate-brown lignitic shale containing some jarosite, directly overlies the silty sandstone (variety 4, Table 1) of the Linton. An additional 12.3 m of very fine-grained silty sand capped by an indurated bed overlie this lignitic shale. The shale is taken as the basal unit of the Hell Creek Formation in our study.

A similar relationship was seen in a north-facing roadcut in the NW¼SW¼ sec. 30, T. 130 N., R. 78 W. There, the lignitic shale is overlain by 4.6 m of gray and orange sands containing clay laminae which in turn are covered by 4.3 m of dark gray bentonitic clay. This overlying sediment is suggestive of Hell Creek facies and supports our interpretation of the Linton Member as the top-most Fox Hills unit in this region. The basal Hell Creek lignitic shale is very difficult to

identify throughout most of Emmons County and care should be taken not to confuse it with lignitic units in or below the Linton thereby placing the contact too low in the section.

Textural and bedding characteristics.—Four lithologic varieties comprise the sediment of the Linton Member as diagrammed in Figures 2 and 5. Many of the characteristics of these are described in Table 1 and listed in their most common stratigraphic order of occurrence. Varieties 1, 2, and 3 are locally controlled manifestations of the same basic lithology. Control of variation is more likely due to post-depositional effects of diagenesis and differential lithification in response to local paleohydrology, than it is to major change in lithology. Slight lithologic differences, primarily in silt-clay content and degree of bioturbation, were responsible, however, for subtle permeability and porosity gradients within the paleohydrologic regime. Thus, depending upon these subtleties, variety 2 may lie beneath, above, or laterally adjacent to variety 3 making sequential interpretation of these lithologies difficult or impossible.

Table 1. Characteristics of lithologic variations in the Linton Member listed by most common stratigraphic position.

	Characteristics
Variety 4	Indurated, massive, loosely packed, poorly sorted, subangular, very fine-grained, silty sandstone. Thickness 0.3 m or less. Weathered color light gray (5Y7/1); fresh color dark brown (7.5YR4/2) to dark grayish brown (10YR4/2). Waterworn wood fragments abundant.
Variety 3	Indurated, brittle, massive, moderately packed, moderately sorted, angular to subround, fine-to very fine-grained sandstone. Fractures in curved, flaggy slabs. Weathered color light gray (2.5Y7/2) to light yellowish brown (2.5Y6/4); fresh color gray (5Y6/1) to light olive gray (5Y6/2). Contacts abrupt or gradational, thickness 0.5 m to 2 or 3 m. Large-scale cross-strata sometimes present. Contains clay galls, worn wood fragments, and occasional *Ophiomorpha*.
Variety 2	Indurated, sometimes brittle, massive, moderately packed, moderately sorted, moderately permeable, subangular to subround, fine-to very fine-grained, sandstone. Weathered color grayish brown (10YR5/2) to brown (10YR5/3); fresh color light olive gray (5Y6/2) to light gray (5Y7/1); often slightly mottled with iron stain. Occasionally with large scale, trough cross-strata. Contacts abrupt or gradational. Thickness 0.5 m to 2.5 m. Contains clay galls, worn wood fragments, preserved roots and casts, *Equisetum*.
Variety 1	Semi-indurated, "pelleted" (Fisher, 1952), non-bedded, friable, loosely packed, permeable, moderately sorted, subangular, fine-grained sandstone. Weathered color light brownish gray (2.5Y6/2) to light yellowish brown (2.5Y6/4); fresh color light gray (5Y6/1). Usually basal in position, not laterally persistent, 0.3 m or less in thickness, nonfossiliferous.

Usually, the "pelleted" sandstone (variety 1, Table 1) is basal. It is often gradational into a more indurated sandstone and its texture of small aggregates of sand seems to be partially a weathering phenomenon. In contrast variety 4 is constant in its physical appearance and always occupies a position at the top of the member. It is substantially different from the other lithologies in color and in higher silt and wood content.

Compositionally, the Linton Member ranges from a subgraywacke to a feldspathic arenite as determined from preliminary analysis of 38 thin sections. Cementation, where it has occurred, is with silica. All samples contain shards of volcanic glass in the silt fraction. Quartz and feldspar grains exhibit a high degree of angularity in contrast to occasional well-rounded glauconite grains. Although the sand-sized fraction is well sorted in the fine-to very fine-sand range a promnent silt-clay component leads to a slight bimodality of distribution denoted by our use of the terms "moderately" and "poorly" sorted in Table 1. This bimodality, which gives the sediment a moderately to poorly sorted overall distribution, may result from admixure of clay during deposition, a likely explanation for the origin of the glauconite grains as well.

The matrix of the Linton sandstones makes up nearly 30% of the rock and incorporates a volcanic shard fraction as noted above. This is distinctly unlike the Colgate lithofacies with which it has been most often confused. Dobbin and Reeside (1929) reported 66% matrix and specifically stated that volcanic material was absent from the Colgate. Our samples indicate that the Colgate may have as little as 48% matrix, still well in excess of the Linton. Likewise, the Timber Lake sandstones differ from the Linton by lack of volcanic shards, greater roundness, higher glauconite and heavy mineral content, and often by being better sorted. The Linton Member is compositionally and texturally distinct from other Fox Hills sandstone facies.

As noted earlier, nonuniform induration causes unusual weathering styles in Linton rocks and makes study of bedding features difficult. Most outcrops show no bedding. Occasionally clay pellets or galls are aligned and define bedding surfaces. More often bedding is in the form of two or three sets of large-scale trough(?) or planar cross-strata, each set being nearly 1 m thick (Figure 4). Cross-strata are common enough to give the impression that Linton deposition took place under the influence of moderately strong, persistent currents acting over a short period of time.

Ripple marks are rare in the Linton Member. Some butte caps in South Dakota, however, preserve both a thinly laminated sandstone, and unusual sets of lunate ripples indicative of uni-directional current flow. One bedding surface in Emmons County contains well preserved mud cracks. These are the only notable primary structures observed.

Fossil content.—Faunal remains are rare in the Linton Member, yet ichnofossils are rather common. Large specimens of *Ophiomorpha*, the burrow of a callianassid crustacean, can be found in most outcrops. Nowhere are these burrows clustered in thick networks as are characteristic of the upper Timber Lake sandstones, a significant difference between the two occurrences of this fossil. Trails and burrows of uncertain origin occur sporadically throughout Linton rocks and indicate the existence of an unpreserved infauna. In more southerly outcrops occasional external molds of *Tancredia americana* and, less commonly, *Cymbophora warrenana* and scaphitid ammonite fragments occur. Nowhere are these common. They do not occur in the unit in or near Linton.

Figure 3. View of northwest tip of butte containing type section, A216. Note volcanic ash bed, left middle.

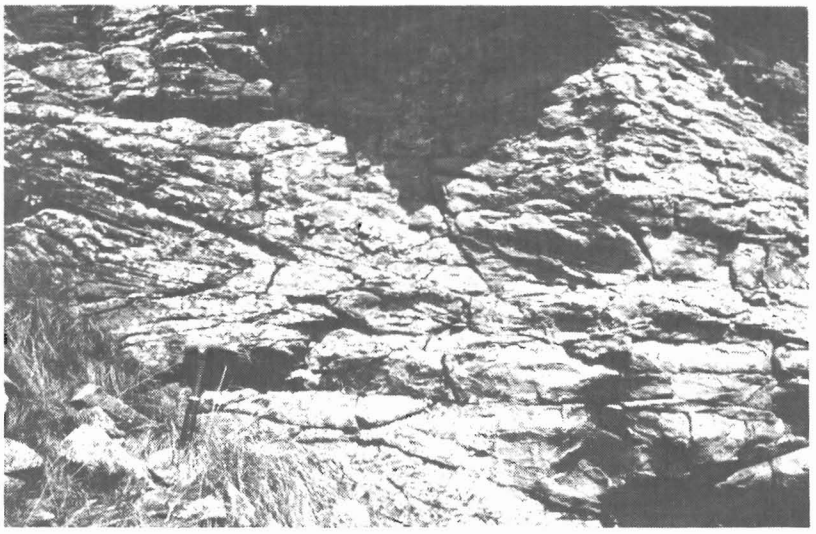

Figure 4. Remnant cross-stratification in Linton Member at A230. Hammer gives scale.

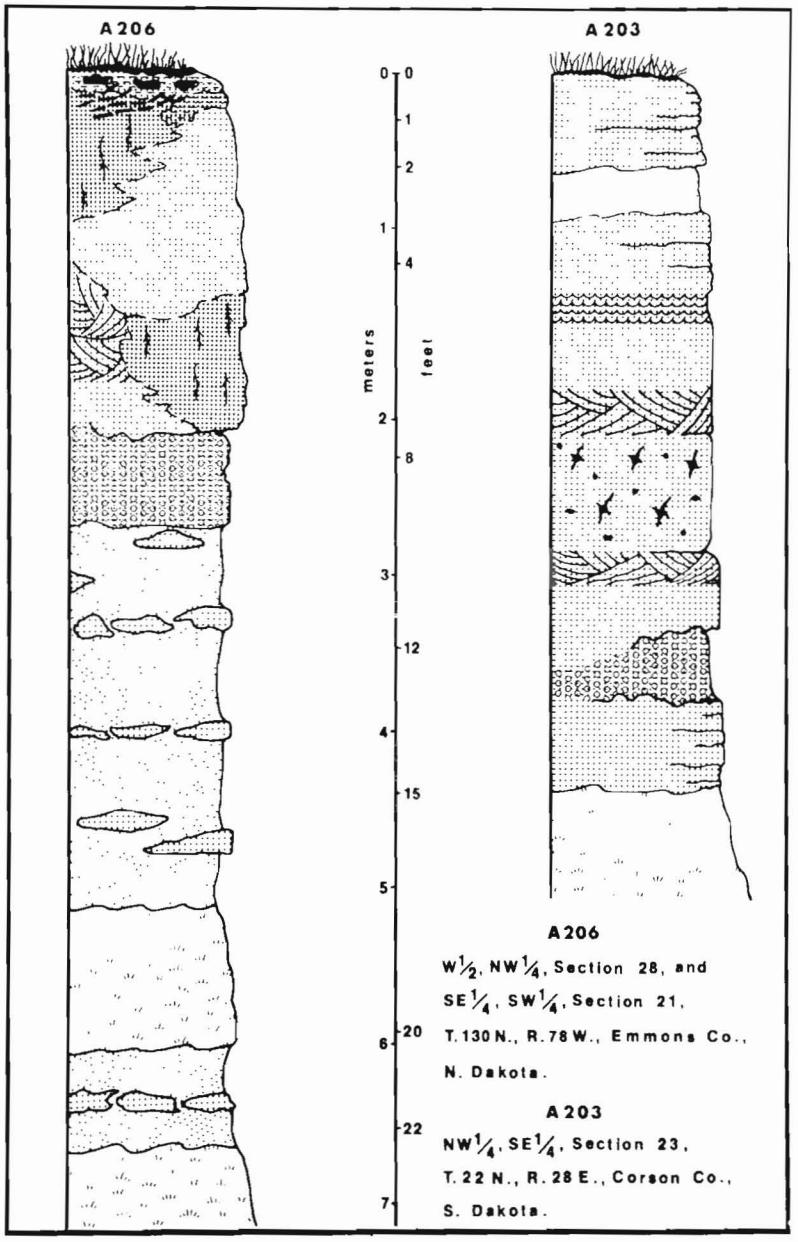

Figure 5. Schematic reference sections of Linton Member. Symbols as in Figure 2.

In Emmons County the member is characterized by the common occurrence of *Equisetum* found in both upright and flattened position. This rush was growing in and adjacent to the sand deposits which formed the member and can be relied upon for recognition of the member in the type area.

A zone of vertical root tubes and casts is also indicative of the unit (Figure 2). Most often these root systems are only a few milimeters in diameter, but they may be a foot or more in length. These should not be confused with the frequent occurrences of woody (now silicified) roots which may be as much as 2 m long and, in distribution, resemble a modern, sediment-engulfed mangrove root system. These types of root development are less common in South Dakota where they are often replaced in the section by wood "hash" of water-worn fragments up to many centimeters long.

Transported plant remains are not restricted to the South Dakota outcrops. Wood chips may be found throughout the outcrop belt. A variety of leaves have also been recovered. These appear in localized deposits generally including a few deciduous species and a variety of large palmetto. None have been transported far. Leaves are not useful for recognition of the member.

Plant remains other than leaves are surprisingly consistent in occurrence. We have little difficulty understanding why Meek and Hayden chose to consider Bed Q the basal unit of the "Great Lignite Group." The influence of terrestrial biota in it is very strong though the presence of *Ophiomorpha* confirms the estuarine character of its depositional environment.

TYPE AND REFERENCE SECTIONS

The type section for the Linton Member (Figure 2) is designated as a butte cap in the N½ secs. 8 and 9, T. 132 N., R. 76W., Emmons County, North Dakota. This is the longest (1.3 km at greatest extent), northwest-trending member of a butte system 1.2 km eastward from the eastern edge of Linton. Except at the butte's edge, soil covers the uppermost unit of the Linton Member, and aerial photographs show a cultivated strip which crosses the center of the butte top. At the northwest base of the butte (Figure 3) lies a well-known volcanic ash, mined at this locality for commercial purposes. The type section offers an exposure of the Linton Member's lithologic subunits, as well as limited exposure of some commonly associated sediment below the butte cap. Detailed descriptions of the type and reference sections are in Appendix A.

Two reference sections (Figure 5) are designated from outcrops containing representative lithologies, fossils, structures, outcrop and weathering characteristics of the Linton Member. Reference section A206 occupies the southernmost butte of a four-butte system in the NE¼NW¼ sec. 28, T. 130 N., R. 78 W., Emmons County, North Dakota. Reference section A203 was measured on a small butte directly southwest of a large ridge and butte complex in the NW¼SE¼ sec. 23, T. 22 N., R. 28 E., Corson County, South Dakota. These buttes are shown in Figures 6 and 7.

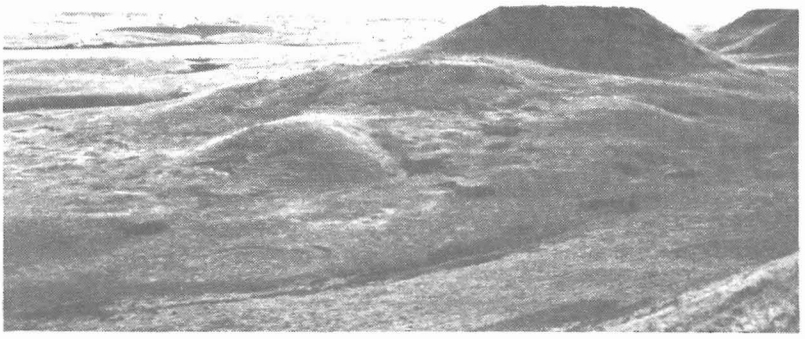

Figure 6. View, looking south, of butte containing reference section A206, Emmons Co. Buttes in distance mark southernmost exposure of the Linton Member in Emmons Co.

Figure 7. Reference section A203 caps this butte east of McLaughlin in Corson Co., S. Dak.; looking east.

HISTORICAL SIGNIFICANCE TO THE COLGATE PROBLEM

Our introductory remarks traced the literary history of the name "Colgate" from its Montana type area (Calvert, 1912) into the Missouri Valley (Curtis, 1952). No student of Fox Hills stratigraphy, with the exception of Hayden, had recognized the uniqueness of the Linton Member. Waage (1968) and Feldmann (1972) grouped these rocks under the term Colgate.

Hayden (1857) had an excellent concept of Missouri Valley stratigraphy *north* of the Grand River in South Dakota. He was intimately familiar with his Bed Q which held up "Fox Ridge." About Bed Q Waage (1968:31) wrote:

> "One other subject relating to the upper contact of the Fox Hills Formation as interpreted by Meek and Hayden concerns the nature of "Bed Q", the limiting bed marking the base of their Lignite Group. From their writings it is apparent that Meek and Hayden believed Bed Q to be a single widespread bed, but they were only slightly more fallible in picking out this unit at different localities than later geologists have been in trying to use the Colgate lithofacies as a mappable unit."

Meek and Hayden believed it to be widespread because, in fact, it is in the Missouri Valley, whereas the Colgate is not. The butte caps which remain are remnants of a more expansive unit than we presently see and easily lend themselves to Hayden's interpretation. The fluted Colgate lithofacies (Figure 8) occurs widely west of the Missouri Valley in many stratigraphic positions throughout the upper Fox Hills and lower Hell Creek as Waage demonstrated, and is a subdued, slope-forming lithology with no noteworthy butte-capping capability. Bed Q has little of this time-transgressive character.

To Hayden, Bed Q (the Linton Member) and the buttes it capped were the most outstanding features of the region. Fox Ridge *was* that system of buttes *as Hayden conceived of it.* Hayden (1857:113-114; *in* Waage, 1968) described the Fox Hills Formation where it crossed the Missouri River north of the North Dakota-South Dakota border as follows, with Waage's accompanying remarks:

> "In describing his Formation No. 5 at the point where its outcrop crosses the Missouri north of what is now the South Dakota-North Dakota state line, Hayden (1857, p. 113-114) wrote.
>
> > 'Here it forms an extension of what is called Fox Ridge, a series of high hills having a northeast and southwest course, crossing the Missouri River into Minnesota at this point. Its northeastern limits I have not ascertained. In its southwestern extension it continues for a considerable distance nearly parallel with the Missouri, crosses the Moreau River about thirty miles above its mouth, then forms a high dividing ridge between the Moreau and Shyenne Rivers, at which locality it *first* took its name.' [italic's ours]
>
> This description is part of the text accompanying Hayden's first geologic map of the Upper Missouri country. On the map the words "Fox Ridge" extend northeastward across the Cheyenne-Moreau and Moreau-Grand divides."

Hayden obviously extended the use of the local name "Fox Ridge" to include the entire butte system held up by the Linton Member. The "high hills" to which he

referred are those buttes, rather than the Timber Lake tableland in the Cheyenne-Moreau Divide as Waage (1968) suggested. For this and other reasons, it is deemed most probable that the historic type area of the Fox Hills Formation as Meek and Hayden knew it began about at the mouth of the Grand River in South Dakota and extended northward into North Dakota perhaps to the mouth of Long Lake Creek in Emmons County. Failure to recognize the historical significance of the Linton Member is responsible for serveral misconceptions regarding Hayden's geologic interpretations.

In Emmons County, Feldmann (1972:31-32) included the Linton Member in his definition of Colgate as quoted below:

> "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."

Furthermore, Feldmann did not adequately define Fox Hills facies east of the Strassburg Channel. He presented only one stratigraphic section from Emmons County (Plate 1, section 6), an erosionally truncated section ending in rocks of Timber Lake-like lithology. Fisher (1952) gave detailed sections of these rocks, but, as noted earlier, he made no attempt to formally define units within them. His unit "D" is equivalent to the Linton Member.

The term "Colgate" should be restricted to the white to light gray, very poorly sorted, generally unindurated, lenticular sand bodies with fluted weathering and few fossils. This rock may have 45-65% clay matrix and contains no volcanic shard component. It weathers to a very diagnostic fluted surface as seen in our Figure 8, as shown by Dobbin and Reeside (1929, Plate 4, c), and as noted by Feldmann (quoted above) for the Colgate in its type area.

Linton Member sandstones are light green to gray, poorly sorted, subangular in grain shape, moderately-to-well indurated, contain up to 40% matrix (usually about 28%), and have a substantial volcanic shard component. They never weather to a fluted surface and have a well defined *Ophiomorpha-Equisetum* fossil component. In contrast to a typical Colgate outcrop as seen in Figure 8, the Linton Member appears as in Figures 4 and 9.

Figure 8. Characteristic weathered appearance of Colgate lithofacies to be compared with Figures 4 and 9 of Linton Member. Fence gives scale.

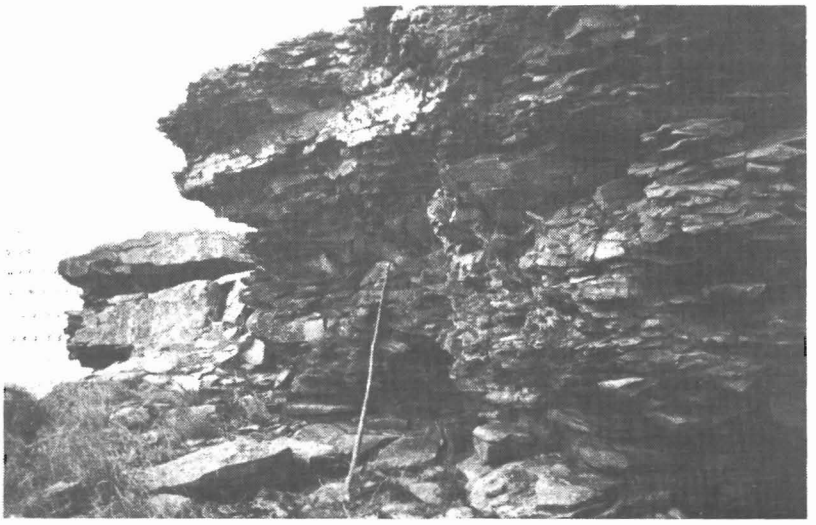

Figure 9. General outcrop appearance of Linton Member. Staff length is five feet.

The distinctions made above are sufficient to define sandstones here placed in the Linton. Such definition should aid in interpretation of the historic concept of the Fox Hills Formation and in future paleoenvironmental studies and geologic mapping of the formation.

PALEOENVIRONMENTAL INTERPRETATIONS

The *Equisetum* flora and mangrove-like root systems indicate that the sediment surface was at or slightly above the highwater line of the Maestrichtian sea. This is corroborated by the presence of large, sparsely distributed *Ophiomorpha*, a characteristic of *Callianassa* occurrences in estuarine environments today (Land, 1972). The waters were more brackish to the north where no marine bivalves occur, and more marine to the south where *Tancredia* and *Cymbophora* are found in the Linton.

Sandstone was deposited either as large shoals, somewhat analogous to point bars, in an estuarine, tidal river or deltaic distributary, or as a series of shoreline shoals along a narrow, north-trending, estuarine embayment. Source of sands was largely from reworking of previous Fox Hills deposits including the Timber Lake, Colgate, and the Emmons and Sioux County ash beds. The sea probably retreated south-southeastward from the local area at which time lignite-producing swamps flourished locally. This relationship became more complex eastward in McIntosh County.

Similar deposits in Wyoming have been described by Land (1972). He defined an estuarine channel sandstone with characteristics very similar to those of the Linton Member. Channels were marked by scour and lag deposits of gravel and oyster shells at their base. The base of the Linton Member is not sufficiently exposed in most areas to interpret analogous conditions. We do feel that they occur in some oyster hashes in Sioux County, but such relationships are not yet firm. The oysters may have been deposited in tidal channels tributary to the main estuarine river here described or in such channels meeting the estuarine shoreline along which sandy shoals of the Linton Member were forming.

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APPENDIX A

Type Section (A216)
Linton Member, Fox Hills Formation

Composite section beginning on NW tip of butte, extending to exposure on center of N side of butte, N½ secs. 8 and 9, T. 132 N., R. 76 W., Emmons Co., N. Dak.

Fox Hills Formation
Linton Member

Unit		Thickness (feet)
20.	Sandstone, silty, fine-grained, brown-gray brown, weathers gray brown; abundant plant fragments; 1.5 ft. maximum thickness.	0.8
19.	Sand, fine-grained, gray-tan; contains poorly indurated, fine-grained, sandstone pods above cross stratified beds.	2.2
18.	Sandstone, fine-grained, gray to gray-green, weathers gray-tan and brown-rust on fractures; massive; vertical preserved roots, some over 3 feet long; wood fragments, increasing towards top half of unit; *Equisetum* in lower half.	4.0
17.	Sandstone, fine-grained, gray, pelleted appearance; weathers gray-tan with some orange-rust color; weathers into BB-size pellets; vertical preserved roots; some thin clay laminae.	1.0
	Total thickness, Linton Member	8.0 (2.4 m)

Fox Hills, Undifferentiated

16.	Covered section.	90
15.	Sandstone, very fine-grained, sea green, weathers dark green-gray with some rusty laminae; thin bedded; fossils *Tancredia americana, Tellinimera scitula, Nucula, Cymbophora warrenana, Protocardia,* a scaphitid ammonite, *Ophiomorpha,* unidentified fish scales; fossils preserved in battered condition, spotty exposure.	7
14.	Covered section.	20
13.	Sandy silt, very fine-grained sand, tan; fossils *Euspira subcrassa, Goniocylichna bisculpturata?, Tancredia americana;* poor exposure.	1.5
12.	Sandy clay, very fine-grained sand, dark gray fissile.	1
11.	Sandy silt, very fine-grained sand, gray-tan, weathers tan with some rust color.	6
10.	Sandy silt, semi-indurated, very fine grained sand, gray-light tan with rusty sand laminae; bedded; gradational contact with unit below.	3
9.	Sandy silty shale, dark brown, weathers gray; lignitic; finely parted; few rusty sand laminae.	1.5
8.	Sandy silt, very fine-grained sand, gray-white, weathers gray-tan, bedded, some rusty laminae of sand; gradational contact with unit below.	2
7.	Sandy silty clay, tan-gray, irregular partings; rust colored sand filling burrow tubes; few laminae of lignitic material; may contain volcanic ash.	5
6.	Covered section.	3
5.	Silty shale, gray, weathers light gray-white; fecal pellets abundant; small wood fragments present; contains clay pods and volcanic ash.	1
4.	Covered section.	1
3.	Sandstone, green-gray, like unit 15 above; wood fragments, clay galls, *Ophiomorpha*; poor exposure.	20
2.	Covered section.	22
1.	Volcanic ash, white-light gray.	188 (56.6 m)
	Total thickness, Fox Hills undifferentiated	196 (59.0 m)
	Total thickness measured	

Reference Section (A206)
Linton Member, Fox Hills Formation

Section measured beginning on the southernmost butte of a four-butte system, extending downward to exposure in small valley directly SE of butte base, W½ NW¼ sec. 28, T. 130 N., R. 78 W., Emmons Co., N. Dak.

Fox Hills Formation
Linton Member

Unit		Thickness (feet)
16.	Silty sandstone, fine-grained, tan-gray, abundant angular wood fragments, some 2 inches × 3¼ inches; gradational contact with unit below.	0.6
15.	Sandstone, fine-grained, steel gray, weathers rust colored from iron stain; brittle, breaks in curved fracture; vertical preserved roots to 2 feet in length; *Equisetum* in horizontal position; thin laminae of wood fragments at top; grades laterally wtih unit below.	2.2
14.	Sandstone, fine-grained, gray-green to gray-tan, weathers in blotchy pattern; vertical preserved roots; shows textural variations, grades to more friable cross-bedded sandstone below, and grades laterally to fine-grained, steel gray sandstone, weathering rust colored; brittle with curved fracture; vertical preserved roots like in unit 16 above.	4
13.	Sandstone, fine-grained, gray to gray-tan; friable, weathers to small pellets; gradational contact with unit below.	2
	Total thickness measured, Linton Member	8.8 (2.7 m)

Fox Hills, undifferentiated

12.	Sand, fine-grained, gray-tan; contains semi-indurated ledges of fine-grained sandstone.	8
11.	Covered section.	3
10.	Sand, fine-grained, orange-tan to gray with green tinge; some rusty ledges of fine-grained sand and clay.	2
9.	Covered section.	10
8.	Sand, fine-grained, orange-tan, green tinge, scattered small pieces of indurated fine-grained sand and clay.	1
7.	Sand, very fine-grained and silt, gray-tan.	1
6.	Covered section.	95
5.	Silty clay, brown-gray, poor bentonitic "popcorn" weathering.	1
4.	Covered section.	40
3.	Sandy, silty, clay, very fine-grained sand, gray-brown, bentonitic "popcorn" weathering.	2.5
2.	Covered section.	45
	Total thickness Fox Hills undifferentiated	208.5 (62.8 m)

Timber Lake Member (?)

1.	Sand, fine-grained, orange with green cast; glauconitic; one rust-brown indurated ledge of calcareous cement containing *Ophiomorpha;* small concretions containing poorly preserved shells and small wood fragments; base covered.	7
	Total Fox Hills measured	215.5 (65.5 m)

Reference Section (A203)
Linton Member, Fox Hills Formation

Section taken from small butte, directly southwest of a large ridge and butte complex approximately 11 miles E. of McLaughlin, NW¼ SE ¼ sec. 23, T. 22 N., R. 28 E., Corson Co., S. Dak.

Fox Hills Formation
Linton Member

Unit		Thickness (feet)
5.	Sandstone, fine-grained, gray-tan, flaggy.	2
4.	Covered section.	1
3.	Sandstone, fine-grained, green-gray with "salt and pepper" appearance; weathers to pitted surface in places due to presence of clay pods and galls; *Ophiomorpha;* cross-strata, ripple marks; some massive blocks have slumped down butte side; gradational contact with unit below.	9
2.	Sandstone, fine-grained, green-gray, pelleted surface; unit not persistent.	1
1.	Sandstone, fine-grained, like unit 3 above; more flaggy; base covered.	2
	Total thickness measured, Linton Member	15 (4.5 m)