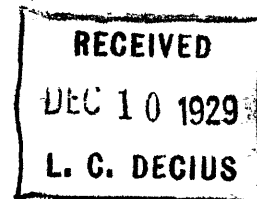


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Professional Paper 158—B



THE CONTACT OF THE FOX HILLS AND LANCE FORMATIONS

BY

C. E. DOBBIN AND JOHN B. REESIDE, JR.

Shorter contributions to general geology, 1929

(Pages 9-25)



UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1929

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THE CONTACT OF THE FOX HILLS AND LANCE FORMATIONS

By C. E. DOBBIN and JOHN B. REESIDE, Jr.

ABSTRACT

The presence or absence of an extensive unconformity at the contact between the Fox Hills and Lance formations is an important element in the problem of the Cretaceous-Tertiary boundary in the Western Interior of the United States. Proponents of the theory that an unconformity exists have rested their case primarily on a correlation of the Arapahoe and Denver formations with the Lance and Fort Union formations, the supposed absence in the northern Great Plains of the Laramie formation, the relative thinness of the Fox Hills sandstone in the northern Great Plains as compared with that in the Denver Basin, and reported angular discordances between the Fox Hills and the Lance at several localities. The present writers describe, chiefly from personal observation, the contact of the Fox Hills and Lance formations over much of the area of their occurrence and of units equivalent to these formations in areas where other names are used, paying especial attention to localities in which there are reported discordances. They advocate the view that the Laramie, Arapahoe, and Denver formations of the Denver Basin are represented in the Lance formation; that the differing thicknesses of the Fox Hills are original and not due to varying amounts of pre-Lance erosion; that each supposed angular discordance is due to some other phenomenon, such as local small faulting or cross-bedding; and finally, as a general conclusion, that there is no unconformity between the Fox Hills and Lance other than such as is found along local minor erosion planes at many horizons within both formations. The suspicion that the peculiar lithology of the Colgate member of the Fox Hills sandstone might be due to a content of volcanic ash is disproved by petrographic examination.

INTRODUCTION

Many papers have been published on the problem of the Cretaceous-Tertiary boundary in the Western Interior of the United States, but many points nevertheless remain in dispute. The relation between the Fox Hills and Lance formations, a cause of particularly wide divergence of opinion, has been of especial interest to the writers because of intimate concern with it in the field, and they have ventured here to review the matter and to present certain observations and opinions regarding it.

The field work upon which the paper is based, carried out at different times during the years 1921 to 1926, covered most of the region where the Lance occurs. It included studies of the contact of the Fox Hills and Lance formations in areas that were mapped in detail; visits to localities cited by previous investigators as showing angular discordance or other marked evidence of unconformity between the formations; and examinations of the strata in areas where beds of Fox Hills

age are present in formations known by other names and are overlain by nonmarine beds that are variously named.

For historical details and references to the literature of the subject the reader may consult recent papers by Knowlton,¹ Thom and Dobbin,² and Ward.³

QUESTIONS INVOLVED AND GENERAL CONCLUSIONS

In the northern Great Plains region the standard section of late Cretaceous and early Tertiary deposits contains the following formations, in ascending order: Pierre shale, Fox Hills sandstone, Lance formation, Fort Union formation, and Wasatch formation. The Pierre shale contains a large marine fauna, including such characteristic ammonites as *Platoniceras*, scaphites of the group of *Acanthoscaphites? nodosus*, and baculites of the large species *B. ovatus*, *B. compressus*, and *B. grandis*. The uppermost Pierre includes a group of scaphites of the genus *Discoscaphites* and certain other fossils that are more abundant in and more characteristic of the Fox Hills. The Fox Hills has a large marine fauna, of which the most distinctive fossils belong to the ammonite genus *Sphenodiscus*. At some places the uppermost Fox Hills contains brackish-water species which are found also in the lower part of the overlying Lance. The Lance also contains a great variety of fresh-water invertebrates, some reptiles, including especially the dinosaurian genus *Triceratops*, a few species of mammals, and a large flora. In a small area the upper part of the Lance contains a marine fauna similar to that of the Fox Hills but somewhat modified and without cephalopods. The Fort Union formation has yielded a small but characteristic fauna of fresh-water invertebrates, a fairly large fauna of primitive mammals, and a large flora. The Wasatch formation has yielded a small fauna of fresh-water invertebrates, a large fauna of mammals of more modern type, and a flora like that of the Fort Union formation.

It has been generally agreed that the Pierre shale and the Fox Hills sandstone are Cretaceous and that

¹ Knowlton, F. H., The Laramie flora of the Denver Basin: U. S. Geol. Survey Prof. Paper 130, pp. 3-82, 1922.

² Thom, W. T., Jr., and Dobbin, C. E., Stratigraphy of the Cretaceous-Eocene transition beds in eastern Montana and the Dakotas: Geol. Soc. America Bull., vol. 35, pp. 500-506, 1924.

³ Ward, Freeman, The Lance problem in South Dakota: Am. Jour. Sci., 5th ser., vol. 7, pp. 65-68, 1924.

the Wasatch formation is Eocene. Concerning the intermediate formations—the Lance and the Fort Union—three views have been expressed. One view is that the base of the Wasatch formation is the proper plane of division between the Cretaceous and the Eocene because the Fort Union is apparently inseparable from the Lance, which contains dinosaurs, whereas the Wasatch contains modern types of mammals, and because a pronounced discordance at many places indicates pre-Wasatch orogeny. Another view is that the contact of the Fort Union and Lance formations indicates the boundary between the Cretaceous and the Eocene because the Lance formation contains the latest known dinosaurs, the Lance invertebrates are more like those of the Cretaceous, and the marine member of the Lance, which is the final marine deposit in the whole Western Interior region, is Cretaceous in aspect, though at most places the contact with the Fort Union appears transitional. A third view is that the Lance and Fox Hills are separated by a hiatus of great magnitude, which is the first after a great unbroken sequence of Cretaceous deposits and which therefore constitutes the proper plane of division between the Cretaceous and the Eocene.

The question whether the Lance and Fox Hills formations are or are not separated by a great unconformity¹ therefore becomes an important element in the general problem, and the history of the view that such an unconformity exists will be of interest here. This view arose from a comparison of the stratigraphy in northeastern Wyoming, eastern Montana, and adjoining portions of North and South Dakota with the stratigraphy of the Denver Basin in Colorado, where the detailed studies of Emmons, Cross, and Eldridge⁴ were believed to have established the following propositions: The Cretaceous sea of the Western Interior invaded a region of low relief; there were no upward movements and no eroded areas of great size within the borders of this region until the end of Cretaceous time; there was, near the end of Cretaceous time, a passage into conditions of nonmarine sedimentation expressed by the Laramie formation; then followed an inception of mountain building over the present site of the Rocky Mountains and a period of active erosion, during which the sediments at places were stripped down to the pre-Cambrian; and a new set of deposits was then formed, resting in the Denver Basin itself on the eroded Laramie and beginning with the conglomerate of the Arapahoe formation.

The nonmarine Laramie formation was reported to contain a distinctive flora and a brackish and fresh water invertebrate fauna and to rest conformably upon the highest marine Upper Cretaceous beds in the basin, the Fox Hills sandstone. The conglomerate of the Arapahoe formation was reported to contain pebbles

derived from all the older rocks in the adjacent mountains, indicating the long period of mountain making and erosion that preceded. The succeeding Denver formation was reported to consist largely of andesitic debris not seen in the Arapahoe, a fact that implies the elapse of the time necessary for the extrusion and erosion of the volcanic materials after the deposition of the Arapahoe. The Denver and Arapahoe formations were reported to contain a distinctive flora and a dinosaurian fauna that included the genus *Triceratops*.

In early discussions⁵ the Arapahoe and Denver were referred to the Tertiary, and the Laramie was left in the Cretaceous. In the monograph on the Denver Basin, in consideration of the dinosaurian fauna and despite the great hiatus believed to exist beneath the Arapahoe, both Arapahoe and Denver were placed in the Cretaceous. In later papers, chiefly because of the evidence of diastrophism between Laramie and Arapahoe time, the Laramie was considered by Cross⁶ to be the uppermost Cretaceous and the Arapahoe and Denver formations to be Tertiary. The *Triceratops* fauna in the post-Laramie beds was considered a relic of the Mesozoic fauna that lived on into Tertiary time.

In the 20 years that followed the publication of the Denver Basin monograph the Fox Hills sandstone and overlying strata at many places in northeastern Wyoming, eastern Montana, and western North and South Dakota were examined in detail by geologists of the United States Geological Survey, who did not find a thick Fox Hills formation, a typical Laramie flora, nor a conglomerate similar to the Arapahoe of the Denver Basin. On the contrary, a *Triceratops* fauna and a flora identified as like that of the Fort Union formation, which is widely accepted as Tertiary, were found in the Lance formation, directly above the relatively thin Fox Hills sandstone, and in the sandstone was found the same distinctive Cretaceous fauna as in the Denver Basin. For some geologists the only answer to the query thus raised seemed to be that the "*Triceratops* beds" (the Lance formation) are separated from the underlying marine Fox Hills sandstone by the same great unconformity as that supposed to be marked by the conglomerate of the Arapahoe formation in the Denver Basin; that erosion was greater in the north than in the Denver Basin; and that in the north there are no strata equivalent in time to the Laramie formation and part of the Fox Hills formation. In the north, however, no suitable plane of unconformity was at first observed, owing to the absence of a conglomerate similar to that of the Arapahoe. Further search revealed local details that were interpreted by some geologists as proof of a widespread and at some

¹ See, for example, Cross, Whitman, The Denver Tertiary formation: *Am. Jour. Sci.*, 3d ser., vol. 37, pp. 261-282, 1889.

² Cross, Whitman, The Laramie formation and the Shoshone group: *Washington Acad. Sci. Proc.*, vol. 11, pp. 27-45, 1909; Are the Lance and Fort Union formations of Mesozoic time?: *Science*, new ser., vol. 53, pp. 304-308, 1921.

⁴ Emmons, S. F., Cross, Whitman, and Eldridge, G. H., *Geology of the Denver Basin in Colorado*: U. S. Geol. Survey Mon. 27, 1896.

places angular unconformity between the Fox Hills and Lance formations.

The interpretation of geologic history given above, the assignment of a great time value to the unconformity in the Denver Basin, and the evidence of the presence of a corresponding unconformity farther north have been vigorously disputed, and a list of papers contributed to the discussion is long. The strongest support for the theory of a large hiatus beneath the Lance formation lies in the supposed existence of an angular unconformity due to deformation and erosion, and no other specific explanation of some of this important physical evidence has yet been published.

In brief, then, the specific question to be considered here is whether the Lance formation rests conformably on the Fox Hills sandstone, or whether there is immediately beneath the Lance a great hiatus that represents the time required for the deposition of a considerable thickness of beds and for the occurrence of notable events in the geologic history of the Western Interior region. The writers' answer to this question is that there is nowhere in the areas considered a great unconformity between the Fox Hills and Lance formations and at most localities not even a minor one.

CRITERIA FOR SEPARATION OF THE FOX HILLS AND LANCE FORMATIONS

In a consideration of the nature of the boundary between the Lance and Fox Hills formations one must first determine what criteria shall be used for identifying the two formations and thus settle upon a means of locating the boundary between them. In general, minor individual lithologic units are not persistent in either the Fox Hills or the Lance. On the other hand, larger lithologic units, aggregations of these smaller, variable units, persist over large areas and are trustworthy features for identification. In some places, however, there is little lithologic distinction between beds that contain characteristic Lance species and others that contain characteristic Fox Hills species, and in these places the fossils must be made the chief reliance for separating the formations.

In eastern Montana, western North and South Dakota, and northeastern Wyoming the Fox Hills formation usually consists of an upper white sandstone (in eastern Montana called the Colgate sandstone member), beneath which occur alternating beds of gray, yellow, and buff sandstone and sandy shale. As noted on page 9, this formation contains a marine fauna, in part characteristic but in part similar to that found in the upper part of the underlying Pierre shale. Locally a brackish-water fauna that contains an admixture of marine forms occurs at the top of the formation. At and west of Glendive, Mont., the Colgate member contains only fossil plants, though the lower member of the formation contains a few

marine invertebrates. Here both the lithology and the marine fauna are of assistance in identification.

In central and southern Wyoming and northwestern Colorado marine forms characteristic of the Fox Hills occur in sandstones that have been interpreted at some places as part of the Lewis shale and at others as part of the overlying beds, variously named, but there is no definite, separable Fox Hills formation. The beds immediately below the horizon of these Fox Hills fossils are in part nonmarine, and the beds above are all nonmarine. Here the marine fossils alone are characteristic.

With the exception of the Cannonball marine member in a small area in North and South Dakota, the Lance formation of Montana, the Dakotas, and eastern Wyoming is of nonmarine origin. The lower part is made up of somber-colored sandy shale alternating with lenticular beds of buff or brown sandstone and thin beds of coal. The contained fossils include plants, reptiles, especially dinosaurs of the genus *Triceratops*, and a few mammals. The fact that vertebrate remains are especially abundant near the base of the Lance provides an excellent criterion for separating it from the underlying Fox Hills formation in areas where the lithology is similar, but at many places the lithology also is of great service. The upper 75 to 350 feet of the Lance usually consists of soft buff and cream-colored calcareous sandstone and shale with numerous beds of coal.

In central Wyoming the Lance formation consists of interbedded fine-grained tan sandstone, light-gray shale, and thin layers of carbonaceous shale and coal and is not conveniently divisible into members. It contains, however, the same nonmarine fossils as the Lance of the areas to the east and north.

In southern Wyoming and northwestern Colorado beds believed by the writers to be the equivalent of the Lance formation, though known by several local names, have the same lithology as the Lance of central Wyoming.

FOX HILLS AND LANCE FORMATIONS IN DIFFERENT REGIONS

In setting forth the local features on which is founded the general conclusion that there is nowhere an important unconformity between the Lance and the Fox Hills the data are presented by convenient geographic units, recognizable on Figure 1.

MOUTH OF CANNONBALL RIVER, N. DAK.

In the area near the mouth of the Cannonball River the gray-white sandstone at the top of the Fox Hills forms a variable upper part of an upper member of the formation. The remainder of the member consists of light-gray clayey sandstone and olive-colored sandy shale; the two parts together attain a thickness of 100 feet. Above the white sandstone and to all appear-

ances conformable with it are thick beds of impure lignite and carbonaceous shale of the Lance formation. (See pl. 4, A.) The lower member of the Fox Hills in this area is a thick-bedded yellowish-brown sandstone about 100 feet thick. Further details regarding the character of the Fox Hills in this area are given by

Section of parts of Fox Hills and Lance formations on south bank of Cannonball River $3\frac{1}{2}$ miles west of Solen, N. Dak.

Lance formation (basal part):		Feet
Irregular assemblage of purple and gray shale and gray sandstone	-----	60
Lignite	-----	1
Purple carbonaceous shale	-----	2

Fox Hills formation:

Sandstone, white, more resistant than inclosing beds; contains many casts of roots	-----	3
Sandstone, grayish white, soft; weathers into fluted channels; contains many layers and concretions of ferruginous brown sandstone and <i>Halymenites major</i> throughout (see pl. 4)	-----	60
Large concretions of cinnamon-brown sandstone	-----	2
Shale, olive-colored, sandy	-----	50
Sandstone, brown, thick bedded, several feet; top of lower member.		

Level of the Cannonball River.

Both members of the Fox Hills contain throughout *Halymenites major*, a fossil believed to be a usable criterion of marine origin. The lower member at the west end of the railroad cut one-third of a mile west of Solen, N. Dak., yielded, at a horizon 30 feet below the top, *Pteria nebrascana* Evans and Shumard, *P. linguaeformis* Evans and Shumard, *Tellina scitula* Meek and Hayden, and *Mastra formosa* Meek and Hayden, all of which are long-ranging species that serve only to confirm the indication of *Halymenites* that the beds are marine.

The Fox Hills near the mouth of the Cannonball River; therefore, shows two members and is apparently conformable beneath the Lance beds. Some hundreds of feet higher in the section the Cannonball marine member of the Lance appears with a large fauna so similar to that of the Fox Hills as to suggest that no long period could have intervened in addition to that during which the lower Lance sediments were being laid down.

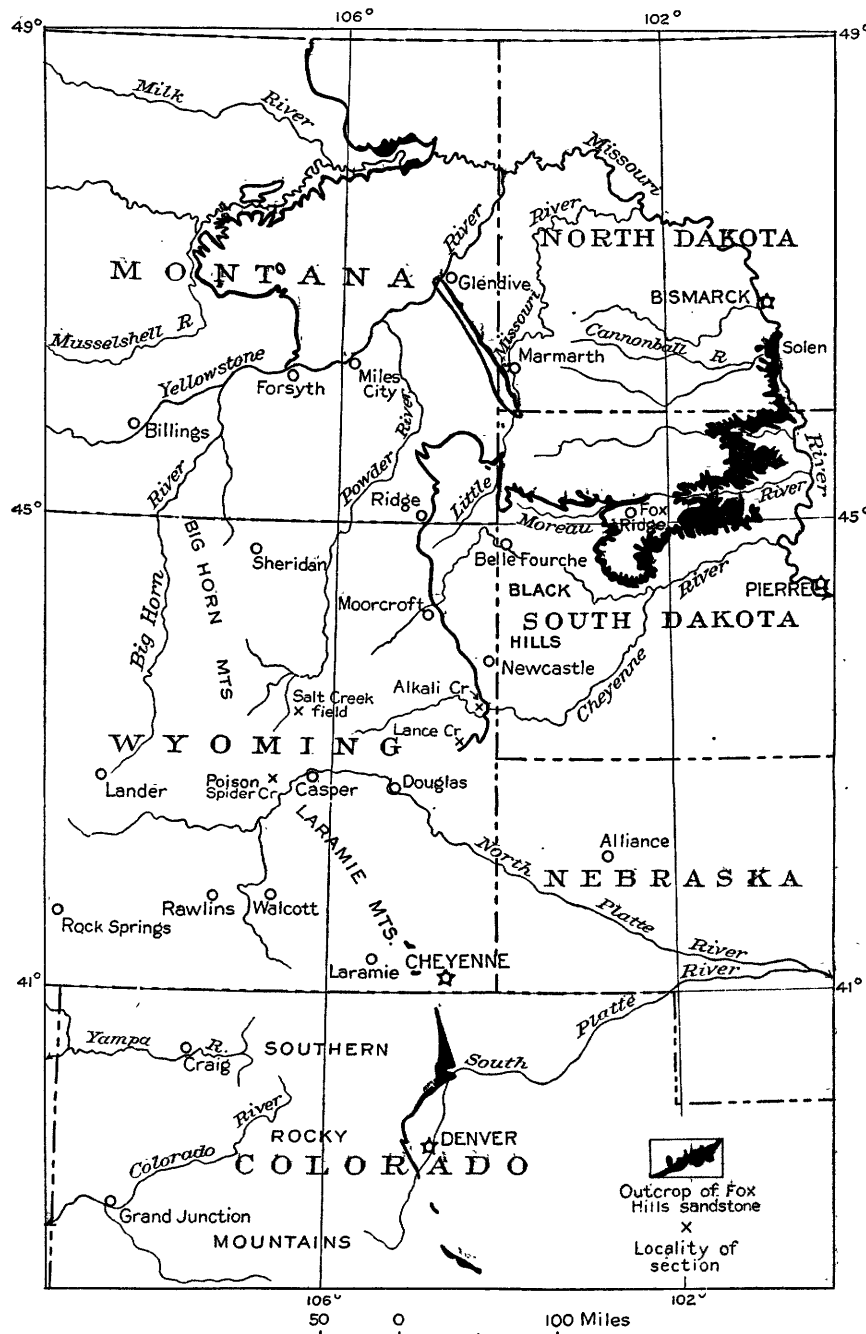


FIGURE 1.—Index map showing distribution of the Fox Hills sandstone. Certain outcrops in central South Dakota and eastern Colorado and beds of Fox Hills age included in other formations in central Wyoming and western Colorado are not shown.

Leonard.⁷ A fairly representative section of the beds exposed on the Cannonball River is as follows:

⁷ Leonard, A. G., The Cretaceous and Tertiary formations of western North Dakota and eastern Montana: Jour. Geology, vol. 19, pp. 511-514, 1911.

CANNONBALL RIVER TO FOX RIDGE, S. DAK.

Observations made by the writers between the Cannonball River and Fox Ridge, the type locality of the Fox Hills formation, are in complete accord with the

findings of Stanton,⁸ who reports that the Fox Hills exhibits much evidence of irregular deposition, channeling between beds, and variability in thickness, but that it nowhere shows evidence of a major break at its top. The occurrence at isolated localities in this area at or near the top of the Fox Hills of beds that have an irregular base and contain a fauna of chiefly brackish-water species has led to the assumption of a widespread unconformity beneath these beds and the selection of this unconformity as the "pre-Tertiary" break.⁹ The beds immediately above the "hiatus," however, contain a number of significant species of the Fox Hills fauna and preclude an interruption greater than that represented by any one of the admittedly minor erosion planes present in both Fox Hills and Lance formations. The fossils are delicate shells that would show any reworking very distinctly. Although the white sandstone of the upper Fox Hills was largely concealed along the route followed by the writers through this area, its presence locally is attested by Calvert, who says:¹⁰ "In some areas the lignite-bearing beds of the Lance abruptly change to the white marine sandstone of the Fox Hills, but in others the rocks of the two formations are very similar and no hard and fast line can be drawn between them."

Particular attention was paid to the locality on Worthless Creek (locally known as Irish Creek), in the SE. $\frac{1}{4}$ sec. 23, T. 16 N., R. 20 E., where Calvert¹¹ observed what he regarded as an angular unconformity between the Fox Hills and the Lance that is cited a number of times in the literature.¹² Calvert's description is as follows:

On Worthless Creek, in T. 16 N., R. 20 E., where exposures are especially good, the most striking example of unconformity between the Fox Hills and Lance formations was observed. On the west side of the Worthless Creek Valley, near the line between secs. 25 and 26, the "somber beds" of the Lance formation transgress across the Fox Hills sandstone, and the upper part of the Fox Hills down to the banded shale is absent. The unconformity at this locality is angular as well as erosional, for the banded shale dips 4° N., whereas the Lance is horizontal. A section of the strata 500 feet long reveals the Lance filling a channel eroded in the banded shale of the Fox Hills to a depth of 40 feet, so that the vertical amount of combined transgression and erosion is at least that amount. On the opposite side of the valley the undoubted Fox Hills is believed to be absent

and the lignitic zone of the Lance rests on a brown banded shale, which may represent the top of the Pierre or may be part of the Fox Hills. In any event, there is surely less than 25 feet of Fox Hills present at this place. In view of the fact that the Fox Hills sandstone is normally at least 150 feet thick, it seems that the time during which erosion took place was of considerable duration.

The writers visited this locality early in May, when the outcrops were not hidden by vegetation and it was possible to study the structural relations in detail. A most casual inspection under such conditions shows that the "unconformity" is due to a small fault which has displaced a carbonaceous shale bed about 20 feet, the downthrown bed dipping into the fault at an angle of about 4°. (See fig. 2.) Dinosaur bones at the base of the bluffs indicate that the beds in the exposure are Lance rather than Fox Hills, and this fact explains why Calvert failed to find Fox Hills beds on the opposite side of the valley. There is probably a second

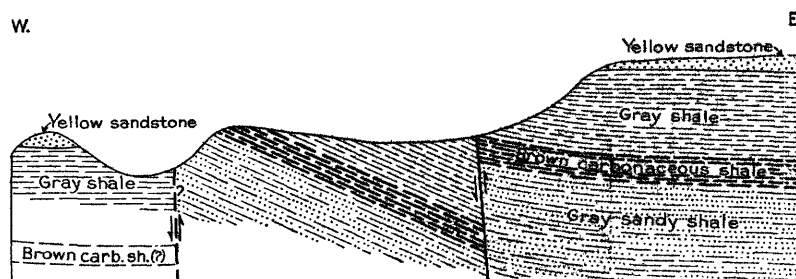


FIGURE 2.—Diagram of faulting in Lance formation on Worthless (Irish) Creek, in the SE. $\frac{1}{4}$ sec. 23, T. 16 N., R. 20 E., S. Dak. The throw is about 20 feet

small fault a few hundred feet away, though its presence is not very clearly shown.

Wilson and Ward¹³ report that the contact of the Fox Hills and Lance is transitional in the Worthless Creek district and that the lowest bed of coal or carbonaceous shale in the Lance occurs just above an oyster bed that marks the top of the Fox Hills over a rather broad area. That small faulting is common in the whole area is also evident from their work and from that of Russell.¹⁴ A small fault of the same type as the one at Worthless Creek is clearly shown on the north bank of the Moreau River about 11 miles east of Bixby, in sec. 15, T. 14 N., R. 14 E., where a throw of 35 feet introduces a local dip of 4° in beds that probably constitute the upper part of the Fox Hills. An example of irregularities of deposition is well shown on the bank of the Moreau River at Bixby. The upper part of the exposure may be Lance, but even so the relations between the irregular beds are so intricate that it is unreasonable to pick out any plane in the sequence as more significant than the rest.

⁸ Stanton, T. W., Fox Hills sandstone and Lance formation ("Ceratops beds") in South Dakota, North Dakota, and eastern Wyoming: Am. Jour. Sci., 4th ser., vol. 30, pp. 173-182, 1910.

⁹ Knowlton, F. H., Further data on the stratigraphic position of the Lance formation ("Ceratops beds"): Jour. Geology, vol. 19, pp. 362-369, 1911.

¹⁰ Calvert, W. R., and others, Geology of the Standing Rock and Cheyenne River Indian Reservations, N. and S. Dak.: U. S. Geol. Survey Bull. 575, p. 18, 1914.

¹¹ Idem, p. 18.

¹² Knowlton, F. H., Further data on the stratigraphic position of the Lance formation ("Ceratops beds"): Jour. Geology, vol. 19, p. 346, 1911; Cretaceous-Tertiary boundary in the Rocky Mountain region: Geol. Soc. America Bull., vol. 25, p. 327, 1914.

¹³ Wilson, R. A., and Ward, Freeman, The possibilities of oil in northern Ziebach County: South Dakota Geol. and Nat. Hist. Survey Circ. 13, pp. 6-7, 1923.

¹⁴ Russell, W. L., The possibilities of oil in western Ziebach County: South Dakota Geol. and Nat. Hist. Survey Circ. 20, pp. 12-23, 1925.

FOX RIDGE TO LITTLE MISSOURI RIVER, S. DAK.

From Fox Ridge westward to the Little Missouri River the contact of the Fox Hills and Lance is, as a rule, exposed only in the more or less isolated bluffs along stream valleys. Practically all outcrops of both formations near their contact show local channeling, cross-bedding, faulting, and shumping on a small scale. The Fox Hills is about 125 feet thick and consists of light-colored marine sandstone which is overlain by the basal coal-bearing beds of the Lance. No distinct or persistent division into a lower yellow sandstone and an upper white sandstone could be recognized, though it must be admitted that the outcrops are scarcely adequate.

One locality that received particular attention in the area west of Fox Ridge was that in the SE. $\frac{1}{4}$ sec. 15, T. 15 N., R. 8 E., South Dakota, 1 mile south of Govert post office, which has been reported by several writers as showing an angular unconformity between

The sandstone and conglomerate capping some of the high buttes on the divide between the Belle Fourche and Owl Rivers, northeast of Belle Fourche, S. Dak., which have been doubtfully called the Fox Hills sandstone,¹⁶ are of White River (Oligocene) age, according to Rubey,¹⁷ who has examined them in detail.

As a brief summary, it may be said that all data obtained by the writers regarding the contact of the Fox Hills and Lance in South Dakota are in accord with the findings of Ward,¹⁸ who says: "It seems plain that the evidence points consistently and convincingly to the fact that there is no sharp or well-defined break between the Fox Hills and Lance—certainly no break which would warrant a division between the Mesozoic and Cenozoic."

MARMARTH, N. DAK.

At the south end of the Cedar Creek anticline, in the vicinity of Marmarth, N. Dak., the contact of the

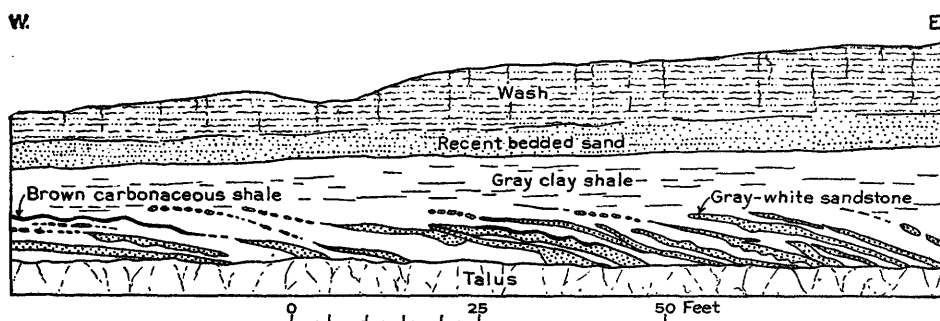


FIGURE 3.—Details of bedding of outcrop of Fox Hills sandstone (?) in the SE. $\frac{1}{4}$ sec. 15, T. 15 N., R. 8 E., near Govert, S. Dak. Length of section shown, 125 feet, drawn to scale. Part of this outcrop is shown in Plate 4, B

the Fox Hills and the Lance.¹⁵ The exposure at this locality is shown in Plate 4, B, and exhibits the following section:

Section on bank of Moreau River near Govert, S. Dak.

	Feet
Dark-colored wash and soil.....	10
Recent sand.....	6
Clay, gray.....	5
Sandstone and sandy shale with topset and foreset bedding.....	18
Talus.....	

A detailed examination of this exposure shows that the inclined bedding planes represent merely foreset bedding and are not a result of folding and erosion. The sketch in Figure 3, made to scale, gives the details of bedding not clearly visible in the photograph. No evidence could be obtained to indicate the age of the individual beds in this outcrop, and it is not possible to assign them definitely to either the Lance formation or the Fox Hills sandstone.

¹⁵ Knowlton, F. H., Further data on the stratigraphic position of the Lance formation ("Ceratops beds"): Jour. Geology, vol. 19, p. 367, 1911; Cretaceous-Tertiary boundary in the Rocky Mountain region: Geol. Soc. America Bull., vol. 25, p. 327, 1914. Calvert, W. R., and others, op. cit., p. 19.

Fox Hills and Lance exhibits all the characteristics observed farther east. On Little Beaver Creek in the SE. $\frac{1}{4}$ sec. 7, T. 132 N., R. 106 W., the transition zone between the typical Pierre shale and the basal Fox Hills sandstone is about 40 feet thick. Through this zone the rock grades upward into a soft yellowish massive sandstone about 50 feet thick, which is overlain by the grayish-white sandstone that is seen farther east and is now known in eastern Montana as the Colgate sandstone member of the Fox Hills formation. The top of the Colgate sandstone shows local channels (see pl. 5, A), which have been interpreted to indicate an unconformity.¹⁹ The section at this locality is as follows:

¹⁶ Darton, N. H., U. S. Geol. Survey Geol. Atlas, Belle Fourche folio (No. 164), p. 5, 1909.

¹⁷ Rubey, W. W., personal communication.

¹⁸ Ward, Freeman, The Lance problem in South Dakota: Am. Jour. Sci., 5th ser., vol. 7, p. 67, 1924.

¹⁹ Leonard, A. G., The geology of southwestern North Dakota with special reference to coal: North Dakota Geol. Survey Fifth Bienn. Rept., pp. 43-44, 1908. Knowlton, F. H., The stratigraphic relations and paleontology of the "Hell Creek beds," "Ceratops beds," and equivalents and their reference to the Fort Union formation: Washington Acad. Sci. Proc., vol. 11, pp. 201-202, 1906.



A. GRAYISH-WHITE SANDSTONE AT THE TOP OF THE FOX HILLS SANDSTONE IN THE SOUTH BANK OF THE CANNONBALL RIVER $3\frac{1}{2}$ MILES WEST OF SOLEN, N. DAK.



B. CROSS-BEDDING IN THE FOX HILLS SANDSTONE (p) IN THE SE. $\frac{1}{4}$ SEC. 15, T. 15 N., R. 8 E., NEAR GOVERT, S. DAK.



C. FLUTINGS IN THE WEATHERED SURFACE OF THE COLGATE SANDSTONE MEMBER OF THE FOX HILLS SANDSTONE IN THE RAILROAD CUT $3\frac{1}{2}$ MILES WEST OF MARMARTH, N. DAK.



A. LOCAL CHANNELING IN THE FOX HILLS SANDSTONE ON LITTLE BEAVER CREEK IN THE SE. $\frac{1}{4}$ SEC. 7, T. 102 N., R. 106 W., NORTH DAKOTA



B. DEVIL CREEK, IN T. 21 N., R. 32 E., MONTANA, SHOWING THE WHITE COLGATE SANDSTONE AND ASSOCIATED BEDS



C. COLGATE SANDSTONE 4 MILES SOUTHWEST OF GLENDIVE, MONT.

Section in the Fox Hills and Lance formations on Little Beaver Creek in the SE. $\frac{1}{4}$ sec. 7, T. 132 N., R. 106 W., N. Dak.

[See pl. 5, A]

Lance formation (lower part):	Feet
Sandstone, light yellowish brown, coarse grained; contains scattered fragments of carbonized wood.....	1
Sandstone, yellowish brown, soft, cross-bedded, medium grained; contains large copper-colored concretionary masses that are hard and weather out unbroken.....	15
Sandstone, shaly, and sandy shale, light gray to drab, soft; contains thin crusts of limonitic material and small limonitic concretions; cross-bedded.....	22
Sandstone, rust-colored, coarse grained, much cross-bedded; contains many siderite concretions; at some places hard, at others, soft.....	11
Sandstone, soft, light gray; contains rust-colored, iron-stained masses that are hard and contain many plant impressions.....	3
Shale, sandy, and shaly sandstone, brown, carbonaceous.....	5
Shale, black, carbonaceous.....	4
Shale, brown, carbonaceous.....	6
Sandstone, gray white, shaly, coarse grained, cross-bedded locally but otherwise massive.....	7
Shale, brown, carbonaceous, irregular.....	1
Shale, drab to light gray.....	7
Fox Hills formation:	
Colgate sandstone member (part)—	
Sandstone, light gray, soft; contains many fossil roots of plants.....	5
Shale, drab to light gray, with very irregular base.....	2
Sandstone, gray-white, and gray shale, very much cross-bedded and irregular.....	8
Sandstone, gray-white, massive to rather indistinctly bedded, shaly in places; lower 10 feet streaked with iron stains; locally contains irregular thin lenses of carbonaceous shale. <i>Halymenites major</i> throughout. Forms the smooth wall above creek level shown in Plate 5, A.....	40
Shale, carbonaceous.....	6
Creek level.	

In the railroad cut $3\frac{1}{2}$ miles west of Marmarth the Colgate sandstone is about 30 feet thick, massive, locally cross-bedded, and overlain by a carbonaceous shale bed 1 foot thick. (See pl. 4, C.) About 5 miles south of Marmarth, in the NE. $\frac{1}{4}$ sec. 32, T. 132 N., R. 106 W., the Colgate is again well exposed and contains abundant remains of *Halymenites major*. Other details regarding the Fox Hills and Lance formations in the Marmarth area are given by Stanton,²⁰ with whose conclusions the writers concur—that “it is most probable that the abrupt change from marine to fresh-water and land conditions seen near Marmarth is purely local and that the eroded surface

at the top of the Fox Hills does not represent a time interval of any geologic importance.”

MARMARTH, N. DAK., TO GLENDIVE, MONT.

In the SW. $\frac{1}{4}$ sec. 34, T. 7 N., R. 61 W., Mont., about 1 mile west of the North Dakota line, the Colgate sandstone displays a clean-cut contact with the overlying horizontal Lance beds. The sandstone is cross-bedded and channeled on a small scale, but the significance of the unconformity is minimized by the fact that at short distances away the contact is not sharp nor discordant.

Other unconformities between the Fox Hills and Lance formations, reported by Knowlton²¹ on the authority of Calvert to occur in sec. 22, T. 6 N., R. 60 E., and sec. 32, T. 7 N., R. 61 E., Montana, were not found in these sections. The writers examined every outcrop along the contact in T. 7 N. but could find no evidence of unconformity other than cross-bedding and purely local channeling of a kind present at many levels in both Fox Hills and Lance. As Knowlton was quoting Calvert, who supervised the mapping of the area by Bowen,²² it is possible that a mistake was made somewhere in the process of handing on the references and that it was intended to cite the localities as in secs. 27 and 32, T. 6 N., R. 60 E., as said elsewhere by Calvert,²³ though Bowen's map shows no Colgate in sec. 32, T. 6 N., R. 60 E. Sec. 32, T. 7 N., R. 61 E., is on the east side of the Cedar Creek anticline and not on the west side, as said by Knowlton. Published photographs²⁴ of one of these unconformities show local channeling and cross-bedding, such as characterize the upper part of the Fox Hills throughout its extent.

It has been stated that the Fox Hills and Lance are unconformable along the Cedar Creek anticline because in the Baker field the Colgate sandstone, which at the time the statement was made was considered a member of the Lance, “appears to rest directly on Pierre shale without the intervention of the lower strata so noticeable at Iron Bluff” (near Glendive).²⁵ The writers' examinations along the whole length of the anticline have convinced them that the basal brown sandstone of the Fox Hills is present throughout the greater part of the anticline, though it is replaced by gray sandy shale in a few localities, and that the upper white sandstone contains *Halymenites* at many places and is marine.

²⁰ Knowlton, F. H., Further data on the stratigraphic position of the Lance formation (“*Ceratops* beds”): Jour. Geology, vol. 19, p. 366, figs. 2, 3, 1911.

²¹ Bowen, C. F., The Baker lignite field, Custer County, Mont.: U. S. Geol. Survey Bull. 471, pp. 202-226, 1912.

²² Calvert, W. R., Geology of certain lignite fields in eastern Montana; U. S. Geol. Survey Bull. 471, p. 195, 1912.

²³ Knowlton, F. H., op. cit., p. 366.

²⁴ Calvert, W. R., Geology of certain lignite fields in eastern Montana; U. S. Geol. Survey Bull. 471, p. 195, 1912.

²⁵ Stanton, T. W., Fox Hills sandstone and Lance formation (“*Ceratops* beds”) in South Dakota, North Dakota, and eastern Wyoming: Am. Jour. Sci., 4th ser., vol. 30, pp. 182-184, 1910.

The rocks near Glendive were first studied by Leonard,²⁶ who says:

In the Glendive region there are no beds above the marine Pierre that correspond to the supposed Fox Hills clay and sandstone of Hell Creek. In fact, the line of contact between the Pierre and the overlying dinosaur-bearing beds, while not discordant so far as structure is concerned, may possibly represent a time break in which most of the upper fresh and brackish water beds of the Cretaceous are wanting.

It may be seen from this statement that all the rocks above the Pierre shale were included by Leonard in the dinosaur-bearing beds, the Lance formation. Leonard's section is as follows:

35 feet thick is 150 feet stratigraphically above Pierre shale. In the Baker field, however, this white sandstone, which Leonard states constitutes the most prominent stratum in the region, appears to rest directly on Pierre shale without the intervention of the lower strata so noticeable at Iron Bluff.

Observations made by the writers at Iron Bluff and vicinity show that the section published by Leonard and quoted by Calvert is in error. It was assumed by Leonard that the sandstone (No. 3 of Leonard's section) capping Iron Bluff (see fig. 4) dips eastward beneath the Colgate sandstone in the bluffs east of Sand Creek. It is clear, however, that the Colgate is present in Iron Bluff beneath the top of Leonard's No.

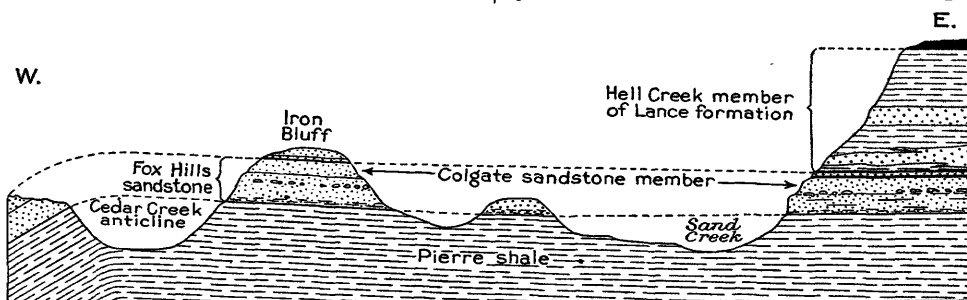


FIGURE 4.—Diagrammatic cross section across the Cedar Creek anticline at Iron Bluff, near Glendive, Mont.

Section of rocks at Iron Bluff and vicinity

	Feet
8. Coal bed, burned but probably 6 feet thick.	
7. Shale with a few thin beds of sandstone; abundant collection of fossil plants in sandstone bed 20 feet from base	150
6. Sandstone, massive, gray	40
5. Shale and sandstone; a few fossil plants at base	160
4. Sandstone, white, massive; most prominent stratum in the region	35
3. Sandstone, brown; fossil leaves in bottom part; forms summit of Iron Bluff	75
2. Shale and sandstone; fossil leaves in upper 20 feet	75
1. Shale, dark, Pierre, with limestone concretions containing abundant marine fossils; exposed to river level	100
	635

Calvert²⁷ later grouped Nos. 2, 3, and 4 of Leonard's section into the Colgate sandstone member of the Lance formation and wrote:

Although there is in the Iron Bluff section an appearance of transition from the Pierre shale into the overlying arenaceous strata, which suggests that the sandstone occupies the stratigraphic position of the Fox Hills, the evidence of fossil leaves indicates that much if not all of it is of later age.

Referring to the finding in units 2 and 3 of fossil plants that were identified by Knowlton as Tertiary species, he says:

It is certain that if the Fox Hills sandstone is present in this section it is restricted to the 70-foot interval between the location of the fossil plants and the top of the Pierre shale. * * * Southward from Iron Bluff the stratigraphy suggests even more strongly that the Fox Hills is not present. In the section near Iron Bluff, as given by Leonard, a white sandstone

3, as shown in the section on the east face of Iron Bluff given below. (See also fig. 4.) On the north face of Iron Bluff the Colgate is much discolored by brown ferruginous stain leached from the overlying rust-brown sandstone, a lens in the basal Lance which does not seem to extend eastward across Sand Creek. On Sand Creek the upper part of the lower member of the Fox Hills yielded marine fossils.

In summary, it may be said that near Glendive the Fox Hills sandstone maintains all the characteristics observed farther east, except that the Colgate member contains well-preserved fossil plants, which have been identified by Knowlton as Fort Union (Tertiary) species.²⁸

As shown in Plate 5, *B*, beds of lignite also occur in the Colgate member and in the Hell Creek member, immediately above. Sections at Iron Bluff and Sand Creek are as follows:

Section of the Fox Hills and Lance formations at Iron Bluff, southwest of Glendive, Mont.

	Feet
Lance formation (part of Hell Creek member or "sombre beds"):	
Sandstone, brown, platy; makes top of Iron Bluff	4
Concealed, probably like unit above	20
Sandstone, light gray with rusty stain locally, fairly cross-bedded	6
Concealed, probably sandstone	11
Fox Hills sandstone:	
Colgate sandstone member—Sandstone, white, fine grained, massive; deeply stained at places by material leached from the overlying ferruginous sandstone	44

²⁶ Leonard, A. G., The coal fields of parts of Dawson, Rosebud, and Custer Counties, Mont.: U. S. Geol. Survey Bull. 316, pp. 197-198, 1907.

²⁷ Calvert, W. R., Geology of certain lignite fields in eastern Montana: U. S. Geol. Survey Bull. 471, pp. 194-196, 1910.

²⁸ Calvert, W. R., Geology of certain lignite fields in eastern Montana: U. S. Geol. Survey Bull. 471, p. 195, 1912.

Fox Hills sandstone—Continued.

Lower member—	Feet
Sandstone, brown, containing many ferruginous nodules.....	11
Sandstone, soft, yellow, containing discontinuous layers of dark-brown platy sandstone.....	25
Sandstone, soft, yellow.....	9
Sandstone, light gray, fine grained, concretionary.....	1
Sandstone, soft, yellow.....	10
Sandstone, dark brown, platy and concretionary.....	1
Sandstone, dark colored, soft; weathers yellow.....	10
Sandstone, soft, shaly, light gray; weathers yellow.....	16
Shale, sandy, gray, stained with limonite.....	5
Shale, brown and gray, sandy.....	13
Total lower member.....	101
Pierre shale: Shale, gray, sandy, with many large fossiliferous concretions in upper 20 feet.	
Section of the Fox Hills sandstone on east side of Sand Creek, 1/4 miles southwest of Glendive, Mont.	
Lance formation (Hell Creek member or "somber beds").	
Fox Hills sandstone:	
Colgate sandstone member—	Feet
Sandstone, white, fine grained, massive, sugary; crops out in a prominent white bluff and contains many well-preserved fossil plants identified as Fort Union (Tertiary) species.....	7
Coal, impure.....	2
Sandstone, like that above.....	45
Total Colgate member.....	54
Lower member—	
Sandstone, concretionary, lenticular.....	5
Sandstone, brown, limonitic, slabby, grading upward into soft yellow shaly sandstone and sandy shale; contains <i>Vanikoro ambigua</i> , <i>Fusus dakotensis</i> , and <i>Anomia?</i> sp. 15 feet below top....	70
Total lower member.....	75
Pierre shale.	

NORTHEASTERN MONTANA

In western and northwestern Garfield County, Mont., the lower member of the Fox Hills consists of a massive yellow-brown coarse-grained sandstone that averages about 75 feet in thickness and makes a prominent wall along the tributaries to the Musselshell and Missouri Rivers. The white Colgate member overlies the lower member and can be seen for miles as its outcrop meanders in and out of numerous coulees. (See pl. 5, C.) The lower member is marine in this region, but no fossils were found in the Colgate member. East of Hell Creek the white Colgate member is replaced by friable yellow to brownish sandstone and sandy shale.

Channeling and cross-bedding are common in the Colgate member in this region, but during detailed mapping by Mr. Dobbin, extending over two field seasons, no evidence was found to indicate a major break at the top of the Fox Hills. This conclusion is in accord with the findings of Brown,²⁹ who says:

²⁹ Brown, Barnum, Cretaceous-Eocene correlation in New Mexico, Wyoming, Montana, Alberta: Geol. Soc. America Bull., vol. 25, pp. 357-358, 1914.

On the east fork of Crooked Creek near the old Cook ranch, on the west fork of Crooked Creek near the Gus Colin claim, and on the east fork of Hell Creek near the EE cattle camp, these marine beds (Fox Hills) have been eroded in places, sometimes to a depth of 10 feet, before the succeeding massive sandstones of the fresh-water "Lance" were deposited. The strata are, however, in all cases parallel to the bedding plane of the succeeding sandstones, and the break is evidently of local erosional character. * * * No sign of an angular unconformity has been noted between the Fox Hills and the "Lance," and I have never yet seen any geologic evidence of the "great diastrophic break" which is alleged to occur here.

The following section is typical of the Fox Hills sandstone along the Musselshell and Missouri Rivers in Garfield County:

Section of Fox Hills sandstone on Devil Creek, in the SE. 1/4 sec. 16, T. 21 N., R. 32 E., Mont.

Lance formation (Hell Creek member or "somber beds").	Feet
Fox Hills sandstone:	
Colgate sandstone member: Sandstone, white, fine grained, massive.....	30
Lower member:	
Shale, yellow, sandy, with thin beds of sandstone.....	11
Sandstone, concretionary.....	1
Sandstone, brown, hard; makes a ledge; contains <i>Lingula nitida</i> Meek and Hayden in abundance.....	2
Shale, yellow, sandy.....	5
Sandstone, yellow, fairly hard; makes a wall.....	15
Sandstone, brownish yellow.....	15
Shale, gray, sandy.....	4
Sandstone, yellow, soft, shaly at base.....	20
Total Fox Hills sandstone.....	103
Bearpaw shale (= upper Pierre).	

In T. 16 N., R. 38 E., Montana, about 60 miles north of Forsyth, Bauer³⁰ found quartzite and porphyry pebbles at a horizon considered by him the base of the Lance formation. The pebbles are half an inch to 3 inches or more in diameter and are embedded in impure limonite, which ranges in thickness from 3 to 8 inches. A detailed examination of this locality by Mr. Dobbin has shown that the conglomerate is conformable with the underlying beds in most of the exposures, though locally there are indications of channeling such as characterize the upper part of the Fox Hills throughout its extent. As the conglomerate occurs only in this small area, its presence affords little proof of the existence of a major unconformity at the contact of the Fox Hills and the Lance.

The relations between the Fox Hills and Lance formations in the region between the Missouri River and the Canadian boundary can not be satisfactorily determined, owing to the covering of late Tertiary and Pleistocene deposits. Studies by Smith,³¹

³⁰ Bauer, C. M., Quartzite pebbles at the base of the Lance formation in Montana: Am. Assoc. Petroleum Geologists Bull., vol. 9, pp. 344-346, 1925.

³¹ Smith, C. D., The Fort Peck Indian Reservation lignite field, Mont.: U. S. Geol. Survey Bull. 381, p. 42, 1910.

Beekly,³² and Collier³³ indicate that the beds tentatively called Fox Hills in this region are probably of continental origin, as shown by the lack of marine fossils and by the finding of remains of a trachodont dinosaur in a sandstone "which surely lies only a short distance above the Bearpaw" (= upper Pierre).³⁴ These remains were identified as belonging to the species *Trachodon annectens* Marsh, a form which also occurs in the Lance of the Hell Creek area. This occurrence is noteworthy in view of the fact that the Fox Hills contains marine fossils on the south bank of the Missouri River and also in Canada, only a few miles from the locality where the dinosaur remains were found.³⁵ Studies by McConnell³⁶ indicate that the Fox Hills and "Laramie" (Lance) are conformable also in the Cypress Hills, which lie but a short distance northwest of the Wood Mountain Plateau.

CENTRAL MONTANA

West and southwest of Forsyth, Mont., the Bearpaw shale (= upper Pierre) is conformably overlain by nonmarine sandy shale and sandstone, locally indistinguishable from the rest of the Lance formation. These beds are indubitably of fluvial origin, yield characteristic Lance fresh-water invertebrates, and probably represent the purely continental phase of the marine Fox Hills of the Dakotas.

SOUTHEASTERN MONTANA

The Fox Hills formation in the southeast corner of Montana is similar to the outcrops near Marmarth, N. Dak., except that locally the white Colgate member is replaced by brown sandstone. Near Ridge the Colgate member is more resistant than in areas to the north and east and makes bluffs 60 feet high. Excellent exposures at certain localities in this area fail to show any evidence of an unconformity between the Fox Hills and Lance.

RIDGE, MONT., TO LANCE CREEK, WYO.

Between the Montana-Wyoming State line and Moorcroft, Wyo., the contact of the Fox Hills and Lance could not be studied in detail, because of the lack of exposures in areas of low relief. The lower part of the Fox Hills in this area consists of brown slabby marine sandstone and sandy shale, which crop out in a pronounced escarpment that stands well

above the Pierre lowlands to the east. Rubey³⁷ has mapped this area in detail and reports that the Colgate sandstone member of the Fox Hills is either absent or present as some other lithologic facies—for example, a brown unconsolidated sandstone that occurs locally between the marine Fox Hills and the *Triceratops*-bearing Lance beds may be equivalent to the Colgate sandstone member.

On Good Lad Creek, less than a quarter of a mile below Oshoto post office, in the SW. $\frac{1}{4}$ sec. 7, T. 53 N., R. 67 W., Wyoming, sandy beds that are possibly of Fox Hills age stand vertical in a cut bank, and 400 feet upstream, directly opposite Oshoto post office, beds of brown and gray sandstone containing prominent concretions, such as characterize the Lance, dip about 5° SW. The great decrease in dip within so short a horizontal distance has been thought by some to indicate a structural unconformity between the Lance and Fox Hills. An examination of the locality by the writers showed that the exposures are too poor to reveal the structure with certainty. It is believed, however, that the abrupt change in dip is due either to sharp unsymmetrical folding or to folding and faulting on a prominent monocline, which has been mapped by Rubey³⁷ for a distance of 30 miles.

In the same area as that described in the preceding paragraph Darton and O'Harra³⁸ reported the Fox Hills to be apparently 400 to 450 feet thick and to contain vertebrate bones, fossil wood, and species of *Inoceramus*. That the record of *Inoceramus* was due to a misidentification of *Unio couesi* which caused these writers to include a portion of the Lance containing this fossil in the Fox Hills sandstone has been proved by a subsequent examination of the precise locality described. The true thickness is much less than that reported.

At 4 miles southeast of Moorcroft the Fox Hills sandstone is well exposed in a conspicuous ridge but affords no evidence of an unconformity with the Lance. The Fox Hills is about 200 feet thick at this locality.

The Fox Hills is also well exposed in the escarpment 7 miles northwest of Upton, Wyo. Its top is a white sugary sandstone overlain by a bed of purple carbonaceous shale. The white sandstone contains *Haly-menites major* and is possibly a correlative of the Colgate sandstone of southeastern Montana, though this can not be proved. Dinosaur bones were collected from the Lance beds less than 50 feet above the purple carbonaceous shale, and marine fossils were obtained in the lower member of the Fox Hills.

About 13 miles west of Newcastle the Fox Hills and Lance exhibit the following section:

³² Beekly, A. L., The Culbertson lignite field, Valley County, Mont.: U. S. Geol. Survey Bull. 471, pp. 329-330, 1912.

³³ Collier, A. J., Geology of northeastern Montana: U. S. Geol. Survey Prof. Paper 120, pp. 30-31, 1919.

³⁴ Collier, A. J., op. cit., p. 31.

³⁵ Rose, Bruce, Wood Mountain coal area, Saskatchewan: Canada Geol. Survey Summary Rept. for 1914, p. 65, 1915.

³⁶ McConnell, R. G., Report on the Cypress Hills, Wood Mountain, and adjacent country: Canada Geol. Survey Ann. Rept., new ser., vol. 1, pt. C, p. 26 c, 1885.

³⁷ Rubey, W. W., personal communication.

³⁸ Darton, N. H., and O'Harra, C. C., U. S. Geol. Survey Geol. Atlas, Devils Tower folio (No. 150), p. 5, 1907.

Section 13 miles west of Newcastle, Wyo.

Lance formation (part):	Feet
Sandstone, yellow-brown, containing flat hard brown sandstone concretions; unit weathers into "toad-stools"-----	30
"Somber shale," composed of dark-gray sandy clay with small botryoidal masses of limonitic sand, brown concretions, and a little hard sandstone in thin layers; turtle and dinosaur bones at top----	50
Slope probably underlain by gray sandy clay shale.	70
Sandstone, soft, light gray, and shale, dark gray, alternating in thin layers; contains a little hard brown platy sandstone; no fossils noted, assignment arbitrary-----	30
Fox Hills sandstone:	
Sandstone, hard, platy, dark brown; forms cap rock of many small buttes-----	3
Sandstone, rather soft, yellow to light gray; weathers to a slope-----	62
Sandstone, argillaceous, very soft, slope forming; contains a few somewhat harder layers, some thin layers, and a few concretions of siderite. At 44 feet above base (U. S. G. S. locality 12833) contains <i>Crenella elegantula</i> Meek and Hayden, <i>Venilla humilis</i> Meek and Hayden, <i>Pyrifusus newberryi</i> Meek and Hayden, <i>Haminea</i> sp.; at 5 feet above base (U. S. G. S. locality 12832), <i>Serpula?</i> sp., <i>Nucula</i> sp., <i>Yoldia evansi</i> Meek and Hayden, <i>Pecten nebrascensis</i> Meek and Hayden, <i>Anomia gryphorhynchus</i> Meek and Hayden, <i>Modiola meeki</i> Meek and Hayden, <i>Crenella elegantula</i> Meek and Hayden, <i>Crassatellites subquadratus</i> Whitfield?, <i>Lunatia concinna</i> Hall and Meek, <i>Anchura americana</i> Evans and Shumard, <i>Pyrifusus newberryi</i> Meek and Hayden, <i>Fasciolaria culbertsoni</i> Hall and Meek, <i>Cinulia concinna</i> Hall and Meek, <i>Baculites ovatus</i> Say, and undetermined fish scales-----	60
Total Fox Hills sandstone-----	125
Pierre shale:	
Limestone concretions, gray, 3 to 4 feet in diameter, most of them septarian and without fossils; <i>Baculites ovatus</i> Say, <i>B. compressus</i> Say, <i>Yoldia evansi</i> Meek and Hayden seen-----	3
Shale, greenish gray, sandy, with a few small calcareous concretions-----	20
Concealed under a grassy flat, probably in part large sandy gray shale; extends eastward from Fox Hills escarpment-----	± 150
Concretions brown, calcareous, with many fossils. About a mile east of the Fox Hills escarpment (U. S. G. S. locality 12757) contains <i>Nucula</i> sp., <i>Yoldia evansi</i> Meek and Hayden, <i>Cucullaea shumardi</i> Meek and Hayden, <i>Gervillia subtortuosa</i> Meek and Hayden, <i>Inoceramus fibrosus</i> (Meek), <i>Inoceramus sagensis</i> Owen, <i>Pteria nebrascana</i> Evans and Shumard, <i>Ostrea</i> sp., <i>Pecten nebrascensis</i> Meek and Hayden, <i>Syncyclonema halli</i> Gabb, <i>Anomia gryphorhynchus</i> Meek and Hayden, <i>Modiola meeki</i> Evans and Shumard, <i>Crenella elegantula</i> Meek and Hayden, <i>Cuspidaria</i> sp., <i>Lucina</i> sp., <i>Protocardia subquadrata</i> Evans and Shumard, <i>P. borealis</i> Whiteaves, <i>Corbula</i> cf. <i>C. crassimarginata</i> Meek and Hayden, <i>Dentalium gracile</i> Meek and Hayden, <i>Lunatia occidentalis</i> Meek and Hayden, <i>Anchura</i> sp., <i>Haminea subcylindrica</i> Meek and Hayden, <i>Baculites ovatus</i> Say, <i>B. grandis</i> Hall and Meek, <i>Discoscaphites nicolleti</i> Morton, <i>D. abyssinus</i> Morton, and <i>D. conradi</i> Morton var.	

The Fox Hills sandstone has been reported,⁴⁰ on the authority of D. E. Winchester and V. H. Barnett, to be 1,040 feet thick on Alkali Creek, on the same line of outcrop as the much thinner sections reported near Newcastle and Moorcroft. This greater thickness has been interpreted as normal for the formation and the smaller thicknesses found elsewhere as representing only a remnant left by pre-Lance erosion.⁴¹ The great thickness reported is, however, incorrect, as shown by the detailed section measured by the writers and given below. The Fox Hills on Alkali Creek is thicker, it is true, than at the more northerly localities, but it reaches only the moderate thickness of 357 feet and is transitional into the overlying Lance, as described by Brown.⁴² Stanton's section at the mouth of Lance Creek,⁴³ some miles south of Alkali Creek, agrees well with that measured by the writers, though it is somewhat thicker—about 400 feet.

Section measured in sec. 18, T. 40 N., R. 61 W., and secs. 11 and 13, T. 40 N., R. 62 W., Wyo., between Alkali Creek and Robbers Roost Creek

Lance formation (part):	Feet
Shale, somber colored; contains abundant remains of turtles and dinosaurs-----	50
Shale, carbonaceous, and coal-----	3
Fox Hills formation:	
Sandstone, brown, concretionary; contains abundant remains of dinosaurs, crocodiles, and turtles near top. V. H. Barnett and D. E. Winchester ⁴⁴ reported marine fossils at a horizon 35 feet below top of this unit. The present writers did not succeed in verifying their report. This unit may belong in the Lance-----	50
Sandstone, gray, filled with shells of <i>Corbicula</i> cf. <i>C. subelliptica</i> Meek and Hayden; a brackish-water deposit that may belong to the Lance-----	23
Sandstone, gray, and soft sandy shale, inseparable in grass-covered slopes-----	74
Sandstone, yellowish, hard, capped by ripple-marked fissile concretions; contains <i>Yoldia evansi</i> Meek and Hayden, <i>Crenella?</i> sp., and <i>Haminea minor</i> Meek in basal part (U. S. G. S. locality 12586)-----	4
Shale, dark gray, and sandstone, soft, light gray, inter-laminated; contains botryoidal masses of limonite and concretions of platy brown sandstone; mass weathers into slopes like the Lance "somber beds"; contains <i>Nucula</i> sp. indet., <i>Modiola attenuata</i> Meek and Hayden, <i>Cardium speciosum</i> Meek and Hayden, <i>Tellina</i> sp. indet., 25 feet below top (U. S. G. S. locality 12585)-----	70
Sandstone, platy, hard, brown-----	1
Clay, somber-colored-----	10
Concealed; probably interlaminated gray and brown sandy shale and sandstone much like third unit above.	80

⁴⁰ Calvert, W. R., and others, Geology of the Standing Rock and Cheyenne River Indian Reservations, North and South Dakota: U. S. Geol. Survey Bull. 575, p. 12, 1914.

⁴¹ Knowlton, F. H., Cretaceous-Tertiary boundary in the Rocky Mountain region: Geol. Soc. America Bull., vol. 25, pp. 326-327, 1914.

⁴² Brown, Barnum, Cretaceous-Eocene correlation in New Mexico, Wyoming, Montana, Alberta: Geol. Soc. America Bull., vol. 25, p. 358, 1914.

⁴³ Stanton, T. W., Fox Hills sandstone and Lance formation ("Ceratops beds") in South Dakota, North Dakota, and eastern Wyoming: Am. Jour. Sci., 4th ser., vol. 30, pp. 184-185, 1910.

⁴⁴ Unpublished data.

Fox Hills formation—Continued.	
Sandstone, gray, platy; makes bench.....	10
Sandstone, brown, limonitic, hard and platy; makes the cap rock on the lowest Fox Hills escarpment....	12
Sandstone, yellow, massive, soft; contains large hard brown calcareous concretions, which yielded (U. S. G. S. locality 12584) <i>Membranipora</i> n. sp., <i>Gervillia subtoruosa</i> Meek and Hayden, <i>Inoceramus</i> (<i>Actinoceramus</i>) <i>fibrosus</i> Meek and Hayden, <i>Veniella humilis</i> Meek and Hayden, <i>Protocardia subquadrata</i> Evans and Shumard, <i>Tellina equilateralis</i> Meek and Hayden, <i>Dentalium gracile</i> Meek and Hayden, <i>Fasciolaria cheyennensis</i> Meek and Hayden?, <i>Fasciolaria galpinianum</i> Meek and Hayden, <i>Cinulia concinna</i> Hall and Meek, <i>Discoscaphites nicolleti</i> (Morton), <i>Sphenodiscus lenticularis</i> (Owen), <i>Hypson</i> sp., and <i>Centrarchites?</i> sp.....	40
Sandstone, gray, shaly but hard enough to make a prominent bench.....	23
Total Fox Hills.....	57
Pierre shale.	

In the upper Lance Creek area the Fox Hills is about 500 feet thick and is transitional into the Lance. Winchester⁴⁵ reports a thickness of 748 feet, but examination by others has not substantiated so great a thickness as this. An increase in thickness toward the southwest has been established for all the marine formations of the Montana group and for the overlying Lance and Fort Union formations and is possibly due to the fact that the chief source of the sediments lay toward the southwest. Practically all sections of the Fox Hills in this particular area contain several beds of massive white sandstone, some of which are associated with beds of coal and impure shale. The following section, given by Stanton,⁴⁶ is typical of the Fox Hills in this area:

Section on Johnson Bros.' ranch near Buck Creek	
Lance formation: Sandy shale with thin beds of coal.....	25
Fox Hills sandstone:	
Massive white sandstone with <i>Halymenites major</i>	60
Yellowish massive sandstone with brown concretions..	20
More thinly bedded brown sandstone with <i>Halymenites</i>	25
Massive white sandstone.....	75
Soft, somewhat sandy shales with thin sandstone bands containing marine Fox Hills shells.....	30
Brown shaly sandstone.....	5
Massive white sandstone.....	60
Thin-bedded brown and gray sandstone.....	130
Yellowish massive sandstone with concretions containing Fox Hills fauna.....	100
Total Fox Hills.....	505
Pierre shale.	

CENTRAL WYOMING

In the district near the Salt Creek oil field the freshwater Lance formation is 3,200 feet thick and is

⁴⁵ Winchester, D. E., The Lost Spring coal field, Converse County, Wyo.: U. S. Geol. Survey Bull. 471, p. 478, 1912.

⁴⁶ Stanton, T. W., Fox Hills sandstone and Lance formation ("Ceratops beds") in South Dakota, North Dakota, and eastern Wyoming: Am. Jour. Sci., 4th ser., vol. 30, p. 186, 1910.

underlain conformably by a series of beds designated the Lewis shale. The uppermost part of the Lewis is a pure-white sandstone 100 to 150 feet thick which bears *Halymenites* and is possibly a correlative of the Colgate sandstone of eastern Montana. Shale associated with the white sandstone contains Fox Hills fossils,⁴⁷ and the sandstone itself contains one or more coal beds, generally only a few inches thick but in some places as much as 5 feet thick. The beds through an interval of 600 feet below the white sandstone are predominantly sandy, though in at least half of this interval they contain distinctive Pierre fossils and are equivalent to the uppermost part of the Pierre shale of eastern Wyoming. Deposition of sandy beds, therefore, began earlier here than it did farther east. There are only arbitrary boundaries between representatives of the Pierre, Fox Hills, and Lance.

At Glenrock, east of Casper, the uppermost part of the Lewis shale, just under the Glenrock coal bed of the Lance, is a massive pure-white sandstone about 75 feet thick that contains *Halymenites* throughout. Under it lies perhaps 125 feet of yellow-brown massive sandstone containing many concretions of red-brown hard calcareous sandstone. Beneath this yellow-brown sandstone lies about 125 feet of shale, thin-bedded sandstone, and coal, beneath which in turn is a second yellow sandstone 70 feet thick. Barnett⁴⁸ reports the beds above the coal-bearing zone as 100 feet thick, but this figure is not quite large enough. Beneath the rocks above described, which are very likely of Fox Hills age, lie some 600 feet of interbedded sandstone and shale and, still lower, less sandy beds. These all contain a Pierre fauna and are therefore older than the Fox Hills.

In the Poison Spider district, 35 miles west of Casper, the Lewis shale is about 800 feet thick and consists of alternating beds of sandstone, shale, carbonaceous shale, and coal; the upper beds contain a distinctive Fox Hills fauna with *Sphenodiscus*, etc., and the lower beds an upper Pierre fauna. There are alternations of marine and nonmarine beds, and the entire section can be interpreted only as showing a gradual change from marine to continental conditions. A section illustrative of this district follows:

Section at the center of T. 33 N., R. 83 W., Wyo., 3 miles southwest of the Poison Spider oil field

Lance formation (basal part): Shale, sandy, gray, with carbonaceous shale, thin coal beds, and concretionary sandstone; forms a prominent scarp. This unit is the lower part of the coal-bearing zone of the Lance formation.....	154
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⁴⁷ Wegetmann, C. H., The Sussex coal field, Johnson, Natrona, and Converse Counties, Wyo.: U. S. Geol. Survey Bull. 471, p. 445, 912; The Salt Creek oil field, Wyo.: U. S. Geol. Survey Bull. 670, p. 23, 1918.

⁴⁸ Barnett, V. H., Possibilities of oil in the Big Muddy dome, Converse and Natrona Counties, Wyo.: U. S. Geol. Survey Bull. 581, p. 114, 1915.

Lewis shale:

	Feet
Sandstone, yellow, calcareous, concretionary; breaks into irregular pieces and contains <i>Halymenites</i>	1
Sandstone, gray-white, soft.....	80
Shale, gray to brown, sandy.....	65
Sandstone, brown, concretionary, limy; contains fossil plants in upper part (U. S. G. S. locality 7508), including <i>Taxodium occidentale</i> Newberry, <i>Ficus cockerelli</i> Knowlton?, <i>Rhamnus salicifolius</i> Lesquereux?, and <i>Ficus</i> sp.; also <i>Ostrea glabra</i> Meek and Hayden in lower 6 inches (U. S. G. S. locality 10708).....	5
Shale, sandy, gray; contains thin lenses of papery sandstone.....	75
Shale, brown, sandy, grading upward into a prominent concretionary sandstone that contains a Fox Hills fauna, including <i>Nucula</i> sp., <i>Glycimeris wyomingensis</i> (Meek), <i>Pteria linguiformis</i> Evans and Shumard, <i>Pteria nebrascana</i> Evens and Shumard, <i>Ostrea</i> cf. <i>O. glabra</i> Meek and Hayden, <i>Tancredia americana</i> ? Meek and Hayden, <i>Cardium speciosum</i> Meek and Hayden, <i>Callista nebrascensis</i> Meek and Hayden, <i>Tellina scitula</i> Meek and Hayden, <i>Turritella</i> sp. undescribed, <i>Pyrifusus newberryi</i> ? Meek and Hayden, <i>Sphenodiscus lenticulare</i> (Owen) (U. S. G. S. locality 10707).....	25
Shale, gray, sandy.....	40
Lignite and brown carbonaceous shale.....	3
Sandstone, gray, fairly hard; contains much carbonaceous debris.....	5
Shale, gray, sandy.....	10
Coal.....	1
Shale, sandy, grayish white; contains thin lenses of yellow concretionary sandstone.....	90
Sandstone, gray, platy, concretionary.....	1
Shale, sandy, gray and brown, soft.....	80
Shale, gray, and carbonaceous shale, sandy shale, and concretionary sandstone; appears to be nonmarine.....	70
Sandstone, brown, hard; makes a small ridge.....	3
Shale, gray, carbonaceous.....	25
Sandstone, soft, carbonaceous; contains several hard layers.....	6
Shale, sandy, gray and brown.....	30
Shale, some sandy and some carbonaceous.....	1
Sandstone, gray, carbonaceous.....	8
Sandstone, white; contains many gray cannon-ball concretions as much as 3 feet in diameter.....	62
Shale, sandy, brown; occupies a low valley.....	66
Sandstone, gray and brown, with many large dark-brown concretions; contains in upper part a large Pierre fauna including <i>Baculites compressus</i> Say, <i>B. ovatus</i> var. <i>baculus</i> Meek, and <i>Scaphites nodosus</i> Owen (U. S. G. S. localities 10705, 10706).....	100
Shale, gray, marine, sandy, grading upward into overlying brown sandstone; <i>Baculites compressus</i> Say (U. S. G. S. locality 10709).....	200

Mesaverde formation: Teapot sandstone hogback.

SOUTHERN WYOMING

In southern Wyoming the marine Lewis shale is succeeded by beds formerly called the Laramie formation but now designated "Laramie" or Medicine Bow formation. There is complete transition from marine to nonmarine deposits, and the transition beds are generally assigned to the succeeding formation because they are sandy and hence more like it in lithology than the underlying Lewis shale.

About 10 miles west of Rawlins, just north of Stanton station on the Union Pacific Railroad, good exposures of Lewis and overlying beds show the transition from marine to nonmarine beds through strata that are undoubtedly of Fox Hills age but here, as in the Casper region, are not separable except arbitrarily from the beds above and below. The following section illustrates the sequence:

Section 10 miles west of Rawlins, Wyo.

"Laramie" formation (part):	Feet
Shale, sandy, brown, with thin carbonaceous shale beds and concretionary sandstone; contains <i>Unio priscus</i> Meek and Hayden, <i>Campeloma multilineata</i> Meek and Hayden, <i>Tulotoma thompsoni</i> White, and <i>Goniobasis tenuicarinata</i> Meek and Hayden 140 feet below top (U. S. G. S. locality 12507); <i>Unio priscus</i> Meek and Hayden 165 feet below top (U. S. G. S. locality 12507); and <i>Unio holmesianus</i> White 40 feet above base (U. S. G. S. locality 12505).....	280
Sandstone, brown.....	6
Shale, sandy, brown, with a few concretionary sandstone lenses. Fragment of undeterminable dinosaur bone 85 feet below top; ceratopsian remains 300 feet below top.....	385
Sandstone, brown, concretionary; contains many <i>Halymenites</i> ; highest marine horizon noted.....	9
Shale, brown, sandy, with thin platy sandstone.....	21
Coal.....	3
Sandstone, brown, concretionary; gray sandy shale; and several carbonaceous shale beds 2 to 4 feet thick.....	40
Sandstone, brown, concretionary; gray sandy shale; and carbonaceous brown shale. At about the middle of this unit and half a mile south of the base of the section (U. S. G. S. locality 10722) were found <i>Nucula</i> sp., <i>Yoldia evansi</i> Meek and Hayden, <i>Barbatia</i> ? sp. undescribed, <i>Ostrea</i> sp., <i>Cardium</i> (<i>Ethmocardium</i>) sp. undescribed, <i>Macra nitidula</i> Meek and Hayden, <i>Cuspidaria</i> aff. <i>C. moreauensis</i> Meek and Hayden, undetermined crab, and <i>Echidnocephalus</i> ? sp.....	110
Shale, brown, sandy.....	38
Shale, carbonaceous.....	3
Sandstone and gray shale.....	33
Coal.....	2
Sandstone and gray shale.....	15
Shale, carbonaceous; contains at the middle (U. S. G. S. localities 10720, 12503) <i>Ostrea glabra</i> Meek....	6
Shale, gray, sandy, with brown concretionary sandstone and beds of carbonaceous shale. From a soft sandstone 20 feet below the top <i>Nucula</i> sp., <i>Anomia gryphaeiformis</i> Stanton, <i>Unio subspatulatus</i> ? Meek and Hayden, <i>Unio danus</i> ? Meek and Hayden, <i>Unio</i> sp., <i>Campeloma multilineata</i> ? Meek and Hayden, and <i>Viviparus</i> sp. (U. S. G. S. localities 102504, 10721); and <i>Rhamnus willardi</i> Knowlton, <i>Quercus</i> sp., <i>Viburnum</i> sp., and <i>Oreodaphne</i> ? sp. (U. S. G. S. locality 7510).....	140
Sandstone, brown, concretionary, marine; <i>Halymenites</i> abundant and fragments of shells.....	6
Shale, gray, sandy.....	28
Shale, carbonaceous.....	1
Shale, gray, and concretionary sandstone.....	10
Shale, carbonaceous.....	4

"Laramie" formation (part)—Continued.	Feet
Shale, gray, and concretionary sandstone.....	96
Coal.....	2
Shale, gray.....	40
Coal.....	3
Shale, gray.....	8
Coal.....	2
Shale, sandy, gray, and thin platy sandstone.....	70
Shale, carbonaceous; contains <i>Ostrea glabra</i> Meek and Hayden (U. S. G. S. locality 12502).....	6
Shale, gray, sandy, with numerous discontinuous ferruginous concretionary beds.....	140
Sandstone, dark brown, massive to platy; contains <i>Ostrea</i> sp., <i>Cardium speciosum</i> Meek and Hayden, <i>Baculites</i> sp. (U. S. G. S. locality 12501).....	6
Shale, sandy, dark brown.....	82
Shale, sandy, gray, with a few sandstone lenses.....	71
Sandstone, brown, concretionary, contains macerated plant remains.....	10
Shale, dark gray; weathers light colored.....	28
Sandstone, platy, calcareous.....	4
Shale, gray, sandy.....	112
Sandstone, brown, concretionary; contains <i>Ostrea</i> sp., <i>Cardium speciosum</i> Meek and Hayden, and <i>Corbula undifera</i> Meek (U. S. G. S. locality 12500).....	4
Sandstone, gray, platy.....	53
Shale, sandy, dark gray; weathers light colored.....	55
Sandstone, grayish brown, concretionary.....	2
Lewis shale: Shale, gray, with minor thin beds of sandstone and calcareous concretions; contains Pierre fossils. Thickness not measured.	

E. E. Smith and M. W. Ball⁴⁹ collected at other localities in this area distinctive Fox Hills fossils from strata comparable to the uppermost marine beds of this section, and there is no doubt that the higher marine beds are of Fox Hills age. The lower beds are definitely of upper Pierre age. Plants collected from the nonmarine beds above the highest marine beds have been ascribed to the Laramie flora and given an age assignment older than that of the Lance beds, but an abundant invertebrate fauna is identical with that of the Lance of northeastern and central Wyoming. At no place in the sequence, either in the part described here or in considerable thicknesses above and below it, is there a plane suggesting an important interruption.

In the Hanna Basin⁵⁰ the change from marine to nonmarine beds—from Lewis shale to Medicine Bow formation—is exactly parallel to the change near Rawlins from Lewis to "Laramie." A typical example is the section 5 miles north of Walcott, Wyo. Here massive light-gray to brown sandstone 270 feet thick rests on several thousand feet of marine Lewis shale. Upon the sandstone lies about 300 feet more of shale, poorly exposed but probably marine and included in the Lewis by Bowen; then 550 feet of shale, soft gray to brown sandstone, and some hard dark-brown sandstone, which is not very fossiliferous

but yields a few oysters and scattered plant remains and forms the basal part of the Medicine Bow formation. Next above is a thin zone of hard brown concretionary sandstone with Fox Hills fossils, including *Yoldia evansi* Meek and Hayden, *Yoldia* sp., *Ostrea* sp., *Anomia* sp., *Modiola* sp. undescribed, *Anatina* aff. *A. doddsi* Henderson, *Pholadomya subventricosa* Meek and Hayden, *Thracia subgracilis* Whitfield, *Cardium speciosum* Meek and Hayden, *Tellina scitula* Meek and Hayden, *Legumen planulatum* Conrad, *Mastra* cf. *M. warrenana* Meek and Hayden, *Dentalium* sp., *Lunatia concinna* Hall and Mee⁵¹, *Haminea* sp., *Anisomyon*? sp., and *Sphenodiscus lenticulare* (Owen) (U. S. G. S. locality 10723). At a horizon 15 feet higher (U. S. G. S. locality 10724) occur *Ostrea glabra* Meek and Hayden, *Anomia gryphorhynchus* Meek, and *Corbicula* sp.—a brackish-water fauna—and at 15 feet higher still (U. S. G. S. locality 10725) *Ostrea glabra* Meek and Hayden and *Corbicula* sp. Above these only plant remains were found in a hasty search, though fresh-water invertebrates are abundant at many places in the formation in adjacent sections. The flora of the Medicine Bow formation has been identified with that of the Laramie of the Denver Basin and has been considered pre-Lance in age. The same zone of marine beds as that noted at Walcott, or at least a very similar one, well above the base of the Medicine Bow formation, was noted by Stanton⁵¹ at several other places in the Hanna Basin, and there seems to be little doubt that a fairly thick transition zone of alternating marine and nonmarine deposits is widespread. A misinterpretation of the stratigraphy of this area⁵² by some of the earlier students led to the concept of the presence here of a very great unconformity comparable to the supposed pre-Lance and pre-Arapahoe unconformities, but the careful restudy of the region by Bowen and others has shown that the only great unconformity in the section is at a much higher stratigraphic plane, the base of the Wasatch.

In this same general area the writers, with J. B. Eby, examined and measured the section on Muddy Creek near Dad, Wyo. Here is found essentially the same unbroken sequence from Lewis up into "Laramie."

For southern Wyoming as a whole the beds called "Laramie" or Medicine Bow are identical in lithology with those a short distance to the north, beyond the Sweetwater Mountains, which are accepted as Lance by everyone who has examined them; the same large nonmarine fauna occurs in both sets of beds and also the same *Triceratops* fauna; both succeed conformably

⁴⁹ Stanton, T. W., personal communication.

⁵⁰ Veatch, A. C., Coal fields of east-central Carbon County, Wyo.: U. S. Geol. Survey Bull. 316, p. 250, 1907. Knowlton, F. H., Further data on the stratigraphic position of the Lance formation ("Ceratops beds"): Jour. Geology, vol. 19, pp. 359-362, 1911; Cretaceous-Tertiary boundary in the Rocky Mountain region: Geol. Soc. America Bull., vol. 25, p. 328, 1914.

⁴⁸ Unpublished data.

⁵⁰ For a general description see Bowen, C. F., Stratigraphy of the Hanna Basin, Wyo.: U. S. Geol. Survey Prof. Paper 108, pp. 227-235, 1913.

a zone containing the *Sphenodiscus* fauna of Fox Hills age. The only discordant note is that the flora of the Lance beds is said to be a Fort Union flora, whereas the flora of the "Laramie" or Medicine Bow formation is said to be a Laramie flora and older than Lance. Hares⁵³ some years ago expressed the opinion that the Lance of the Casper region and much of the Medicine Bow ("Lower Laramie") of southern Wyoming are equivalent, an opinion which the writers believe to be substantially correct.

YAMPA VALLEY, COLO.

An area of especial interest as being the farthest west in Colorado at which a typical Fox Hills fauna is known is in the Yampa Valley in the vicinity of Craig. The section here includes a shale formation designated the Lewis shale, overlain by a formation still known, as are the similar beds in parts of southern Wyoming, by its old name "Laramie," originally applied because the upper part of it contains Laramie plants.⁵⁴ The "Laramie" in Yampa Valley begins with a massive sandstone, above which lie thin beds of shale and sandstone that include a coal bed and zones of marine and brackish-water fossils. These fossils, including *Sphenodiscus*,⁵⁵ belong to the Fox Hills fauna and range as high as 350 feet above the base of the "Laramie," as the formation was originally identified and as the name is applied now for convenience in mapping. Above the marine beds are shale, sandstone, and thin beds of coal, an assemblage much like that which in Wyoming is called Medicine Bow and Lance, though it is much thinner. The upper boundary of the "Laramie" has been drawn beneath a conglomerate that marks the beginning of the "post-Laramie" formation—a unit that has a flora of Fort Union aspect and a lithology somewhat different from that of the "Laramie." There is no evidence of unconformity in the section except the presence of the conglomerate—evidence of somewhat doubtful value.

NORTHEASTERN COLORADO AND THE DENVER BASIN

The Fox Hills sandstone has been interpreted in this general region as including a series of sandstones and sandy shales with a conspicuous sandstone at the top, the whole assigned a thickness stated by some geologists to be as much as 2,000 feet, though by others only 800 to 1,000 feet, the difference being due in part, perhaps, to difference in choice of basal boundary, in part to differences in calculation of thickness. The sandstone at the top was designated by Henderson⁵⁶ the Milliken

sandstone, and the suggestion was made that its base would have been chosen as the logical plane of subdivision of the Montana group had the group been first studied in Colorado. The lower Fox Hills, taken in the usual sense as including beds well below the Milliken sandstone member, contains neither the fossils most characteristic of the Fox Hills nor those most characteristic of the Pierre, but it does contain a fauna of species that occur in both Fox Hills and upper Pierre; the Milliken sandstone itself contains the distinctive ammonite *Sphenodiscus*. It seems to the writers that only the Milliken and possibly any marine beds above it should be considered strictly as of Fox Hills age and comparable to the typical Fox Hills, though the grounds for this opinion are chiefly negative and therefore weak. Even if the Fox Hills is conceded to be very thick, the value of this thickness as proof of erosion in other areas is reduced by the fact that the underlying Pierre shale has in this area an astonishingly great thickness, in comparison with which even the great thickness of the Fox Hills would not be disproportionate.

According to Henderson⁵⁷ the Milliken sandstone consists of

massive, rather soft, usually greenish-yellow sandstone, from 100 to 150 feet in thickness, almost entirely free from shales except a few 1-inch bands in the lower part. The sandstone contains many large brown concretions and bands, more or less ferruginous and calcareous and usually highly fossiliferous. The more gentle slopes above are occupied by alternating shales and soft sandstones, containing marine fossils and not sharply separated from the overlying Laramie shales and sandstones. The Laramie is not well exposed in this region, owing largely to the absence or weakness of the massive thick white sandstone, which is such a conspicuous and persistent feature of the lower Laramie in Boulder County.

In the Denver Basin the Milliken sandstone is overlain by two grayish-white sandstones, each about 60 feet thick, separated by about 4 feet of lignitic shale, which passes into coal in some places. A third and much whiter sandstone, about 10 feet thick, occurs 60 feet higher in the section and is a good marker in coal exploration because all workable beds in the lower part of the Laramie formation of the Denver field occur below it.⁵⁸

The rock sequence as thus described might suggest that the Milliken sandstone is to be correlated with the basal brownish sandstone of the northern Fox Hills; that the coal-bearing white sandstones of the basal Laramie of the Denver Basin and northeastern Colorado are to be correlated with the Colgate sandstone member of the Fox Hills as developed in eastern Wyoming, eastern Montana, and the Dakotas; and that the Laramie clays are equivalent to the Hell Creek member of the Lance. Such long-range correlations on lithology alone are very uncertain, but it

⁵³ Hares, C. J., Correlation of some of the Cretaceous and Eocene formations of central Wyoming [abstract]: Washington Acad. Sci. Jour., vol. 5, pp. 328-330, 1915.

⁵⁴ Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, pp. 72-74, 1910.

⁵⁵ Hancock, E. T., Geology and coal resources of the Axial and Monument Butte quadrangles, Moffat County, Colo.: U. S. Geol. Survey Bull. 757, p. 22, 1925.

⁵⁶ Henderson, Junius, The Cretaceous formations of northeastern Colorado: Colorado Geol. Survey Bull. 19, p. 22, 1920.

⁵⁷ Henderson, Junius, op. cit., p. 23.

⁵⁸ Emmons, S. F., Cross, Whitman, and Eldridge, G. H., Geology of the Denver Basin in Colorado: U. S. Geol. Survey Mon. 27, pp. 73-74, 1896.

is on other grounds as nearly certain as such matters can be that the Milliken is equivalent to some part of the typical Fox Hills. The view that the Laramie clays are of the same age as the Hell Creek member of the Lance is supported, as Stanton long ago pointed out, by the invertebrate fauna and by the recent finding in the Laramie beds near Briggsdale, Colo.,⁵⁹ of several horn cores identified as probably *Triceratops*. The differences cited between the fossil floras of the Laramie and the Lance are no more impressive than those cited between the floras of the Denver and the Lance or Fort Union, both assigned to the Eocene by Knowlton.

No one has ever reported any evidence of unconformity between the Fox Hills and Laramie, and this fact, with the assignment of a great thickness to the Fox Hills, has been used as an argument that the Laramie and most of the Fox Hills were removed by pre-Lance erosion at places outside of the Denver Basin where no Laramie, as such, is recognized and the accepted Fox Hills is thin. If, however, the Laramie-Arapahoe unconformity represents a short interval, comparable to some of those represented by the admittedly minor unconformities within both Fox Hills and Lance formations, the Laramie, Arapahoe, and Denver with their *Triceratops* fauna become a logical equivalent for some part of the Lance, and the sections in the Denver Basin and in the northern plains match. Hay⁶⁰ and Stanton⁶¹ long ago expressed the opinion that the unconformity noted between the Laramie and Arapahoe formations is not of stratigraphic importance—an opinion with which the writers fully agree.

The emphasis that has been laid by some writers on the importance of the unconformity between the Laramie and the Arapahoe rests, as stated on page 10, upon the propositions (1) that in the Rocky Mountain region the Cretaceous sea was unbroken by any islands and undisturbed by any regressions from its entrance into the region in early Upper Cretaceous time until its withdrawal in late Upper Cretaceous time and (2) that the conglomerate of the Arapahoe contains pebbles derived from near-by exposures of practically all the pre-Arapahoe rocks—a necessary corollary being that between the deposition of the last Cretaceous beds and the beginning of the Arapahoe there must have occurred the elevation and erosion of the whole preceding section of some 12,000 feet. The first proposition would certainly not be accepted by students of the Interior Cretaceous to-day. The second appears to the writers highly debatable. Even if the identification of the pebbles as pre-Cambrian, "Red Beds," Dakota, Niobrara, Laramie, etc., is

granted—which appears not beyond some doubt, considering the types of rocks concerned—it is still a gratuitous assumption that they had to come from sources near enough to exclude any possible areas of Cretaceous erosion. The demand for a post-Laramie time interval long enough to permit elevation and erosion of the whole thickness of pre-Arapahoe sediments is too great a strain on the known facts, such as the occurrence of very similar if not identical ceratopsian dinosaurs in the Laramie and in the Arapahoe and Denver beds. The cited differences of the Laramie and post-Laramie in the floras are not impressive, in view of the differences in time and in physical conditions supposed to exist—in fact, they are no greater than those existing between the supposed Tertiary Arapahoe-Denver flora on the one hand and the supposed Tertiary Lance-Fort Union flora on the other, the latter said by the paleobotanists to be essentially one flora, though occurring through a great thickness of strata in which marked changes take place in the contained invertebrate and vertebrate faunas.

WESTERN AND SOUTHERN MARGINS OF THE INTERIOR REGION

In New Mexico, Arizona, Utah, and western Wyoming any beds of Fox Hills age that may be present are nonmarine and do not differ sufficiently in either lithologic constitution or faunal content from associated beds older or younger than the Fox Hills to permit any useful comparison to be made. In some regions, such as the San Juan Basin and the Raton coal field, New Mexico, unconformities are recognized within the series of nonmarine beds, but their relative importance can not now be determined. In the San Juan Basin dinosaur remains of very closely allied types occur both below and above the most conspicuous unconformity, suggesting that it is not very significant.

CONSTITUTION OF THE COLGATE SANDSTONE MEMBER OF THE FOX HILLS SANDSTONE

The record of volcanic ash in the Fox Hills sandstone east of the Missouri River near Linton, N. Dak., by Stanton⁶² led to the suspicion that the white color of the Colgate sandstone might be due to a content of volcanic ash, and to the hope that the ash might afford a basis for definite correlation.

The deposit near Linton is described as consisting of chalk-white strata some 26 feet thick and 35 feet above the base of the Fox Hills sandstone. Specimens from this deposit were examined by G. F. Loughlin, who reported them to contain 80 per cent of volcanic glass, 15 per cent of quartz and feldspar, 2 or 3 per cent of biotite, and scattered grains of other minerals. About 16 feet higher in the section is a greenalite bed that also contains volcanic glass. The nearest possible source

⁵⁹ Toepelman, W. C., Notes on the Laramie formation in central Weld County, Colo.: Jour. Geology, vol. 34, p. 834, 1926.

⁶⁰ Hay, O. P., Where do the Lance Creek ("Ceratops") beds belong, in the Cretaceous or in the Tertiary?: Indiana Acad. Sci. Proc. for 1909, p. 284, 1910.

⁶¹ Stanton, T. W., Boundary between Cretaceous and Tertiary in North America as indicated by stratigraphy and invertebrate faunas: Geol. Soc. America Bull., vol. 25, pp. 347-348, 1914.

⁶² Stanton, T. W., A Cretaceous volcanic ash bed on the Great Plains in North Dakota: Washington Acad. Sci. Jour., vol. 7, pp. 80-81, 1917.

of the glass now known is far to the west, in the Livingston region of Montana.

Clarence S. Ross examined specimens of white Colgate sandstone obtained in T. 21 N., R. 32 E., Mont., but found no evidence of volcanic material, as the following memorandum submitted by him indicates:

The specimens of Colgate sandstone examined are composed of a great variety of detrital materials. Sand grains form about one-third, and claylike material the remainder of a typical specimen. Quartz is the most abundant single mineral element in the sand grains, but minor amounts of microcline, plagioclase, muscovite, biotite, chlorite, tourmaline, garnet, zircon, and apatite are present. The materials are not well sorted and range from 0.3 to 0.01 millimeter or less in diameter. Large grains are in direct contact with small ones, and there is no evidence of concentration of large or small grains along bedding planes. The sand grains are nearly all sharply angular.

Some specimens contain several per cent of calcite, and others contain almost none. Some of this is probably of detrital origin, but euhedral rhombs of calcite and sparse grains of glauconite were probably formed during the deposition of the sediments.

The material between the quartz grains is of the most heterogeneous nature. Most of it was not deposited as fine sediment but forms individual grains that have about the same diameter as the quartz. Much of it resembles the detrital material derived from more or less metamorphosed sediments, and the ferromagnesian minerals are those characteristic of metamorphic rocks. Some of the grains appear to be fine-grained quartzite, and others are chert or jasperlike quartz. Many grains are probably highly indurated shale; others resemble a sericitized rock, and some of the larger quartz grains appear to be partly sericitized. Qualitative chemical tests of the interstitial material show the presence of essential amounts of potash, and this indicates that this material is partly mica.

Clay minerals make up a considerable part of the interstitial material, and most of these appear to have formed in place by the alteration of detrital rock grains. At least two clay minerals are recognizable. The more abundant is a mineral of the kaolin group that is probably leverrierite or anauxite,⁶³ and the other is beidellite.⁶⁴

The sandstone is nearly white, notwithstanding the fact that it contains grains of brown and other dark colors. Its light color is due to the white, chalklike appearance of the sericite and clay present as interstitial material between the grains of quartz—that is, the color of the sandstone is due to the tinting power of the large proportion of white interstitial material and not to freedom from impurities.

⁶³ Dittler, E., and Hilsch, J. E., *Min. pet. Mitt.*, vol. 36, p. 85, 1923.

⁶⁴ Ross, C. S., and Shannon, E. V., *Washington Acad. Sci. Jour.*, vol. 15, p. 467, 1925.

SUMMARY OF CONCLUSIONS

The writers believe that the foregoing description of the contact of the Fox Hills and Lance formations and of units equivalent to these formations in areas where other names are used, together covering a large part of the Western Interior of the United States, supports the following statements:

The contact of the Lance and Fox Hills is everywhere essentially transitional.

All angular unconformities reported to exist between these formations are misinterpretations of faulting, cross-bedding, or slumping.

Erosion planes in the Fox Hills and Lance formations are unimportant chronologically, being merely evidence of local channeling of near-shore deposits by tidal currents and wave scour in the Fox Hills or of flood-plain deposits by streams in the Lance—that is the result of contemporaneous erosion and redeposition.

The localities of certain collections of plants identified as belonging to the Fort Union flora and hitherto considered to occur higher than the "unconformity" above the Fox Hills are really in the upper part of the Fox Hills sandstone.

The Fox Hills sandstone, from its type region at Fox Ridge, between the Cheyenne and Moreau Rivers, S. Dak., westward at least as far as the Musselshell River, Mont., and southward as far as Glenrock, Wyo., consists usually of a variable lower member of yellowish-brown marine sandstone and sandy shale and a variable upper member of white sandstone, which is locally of marine origin, though at some places it contains coal and plant remains; above the upper member at most localities occur beds of coal of variable purity, which belong to the Lance formation.

The Laramie and Arapahoe formations and at least part of the Denver formation of the Denver Basin, most of the Medicine Bow formation of southern Wyoming, and the "Laramie" formation of northwestern Colorado, conformable on beds of Fox Hills age, are equivalent to the Lance formation.

The white color of the Colgate member of the Fox Hills sandstone does not appear to be due to a content of volcanic ash, and the formations therefore can not be correlated on this basis.

