GRADATIONS FROM CONTINENTAL TO MARINE CONDITIONS OF DEPOSITION IN CENTRAL MONTANA DURING THE EAGLE AND JUDITH RIVER EPOCHS.

By C. F. Bowen.

INTRODUCTION.

The large amount of geologically unexplored territory in western Rosebud and Dawson counties, Mont., led to an examination by the writer of a part of this territory for the purpose of getting general information on its stratigraphy and structure. The region proved to be one of considerable geologic interest.

The work demonstrated (1) that pronounced dome structure exists in a region heretofore supposed to be underlain by nearly flat-lying beds; (2) that the Eagle sandstone, which is a thick formation farther west, thins eastward and disappears near the western border of the area herein described; (3) that the Judith River formation, previously known only as of fresh-water and brackish-water origin, grades into a marine formation in passing eastward from the shore line of the sea along which it accumulated; and (4) that east of the meridian of 107° 30′ (approximately) the deposition of marine sediments was continuous throughout the Colorado and Montana epochs of Upper Cretaceous time in this part of the Great Plains region.

The area herein considered comprises about 1,200 square miles in Rosebud and Dawson counties and extends from Forsyth northward for a distance of 40 miles, thence westward to Musselshell River. Its geographic position is shown on the key map (Pl. IV).

The area was mapped on a scale of 1 mile to the inch. Horizontal control was based on the land survey of the General Land Office and was obtained by stadia and triangulation. A stadia traverse along the Bearpaw-Lance boundary was carried throughout the field. From this traverse triangulation points were established which furnished control in other parts of the field. Elevations were obtained by means of vertical angles, the initial elevation being a point on the Chicago, Milwaukee & St. Paul Railway a few miles west of Forsyth.

The field sheets thus prepared and the land plats obtained from the General Land Office furnished the data from which the accompanying base map (Pl. IV) was prepared. This map shows the principal streams and roads of the area, as well as the geologic formations exposed. The formation boundaries are represented by solid lines where they are accurately determined and by broken lines where, because of lack of exposures or for other reasons, they could be located only approximately.

The writer was assisted in the field by C. A. Bonine, to whom much credit is due for the results obtained.

SURFACE FEATURES.

The area is a part of the Missouri Plateau of the Great Plains, and its surface features are those produced by the erosion of such a region in a semiarid climate. Erosion has changed a comparatively level surface into one dissected by streams and surmounted by numerous buttes. This sculpturing is most pronounced along Musselshell River, where in a belt 1 to 3 miles wide intricately dissected badlands have been formed. In most parts of the area the sandstones of the Judith River and Lance formations form conspicuous ridges that rise abruptly from the lower and more nearly level surfaces occupied by the shale formations. The irregularities of the surface are due chiefly to differences in erosion induced by the unequal resistance of the formations.

GEOLOGY.

STRATIGRAPHY.

GENERAL SECTION.

The formations exposed in this area range in age from Upper Cretaceous to Tertiary (?) and include the Colorado shale (upper part), Eagle sandstone, Claggett and Judith River formations, Bearpaw shale, and Lance formation. With the exception of the Eagle sand-

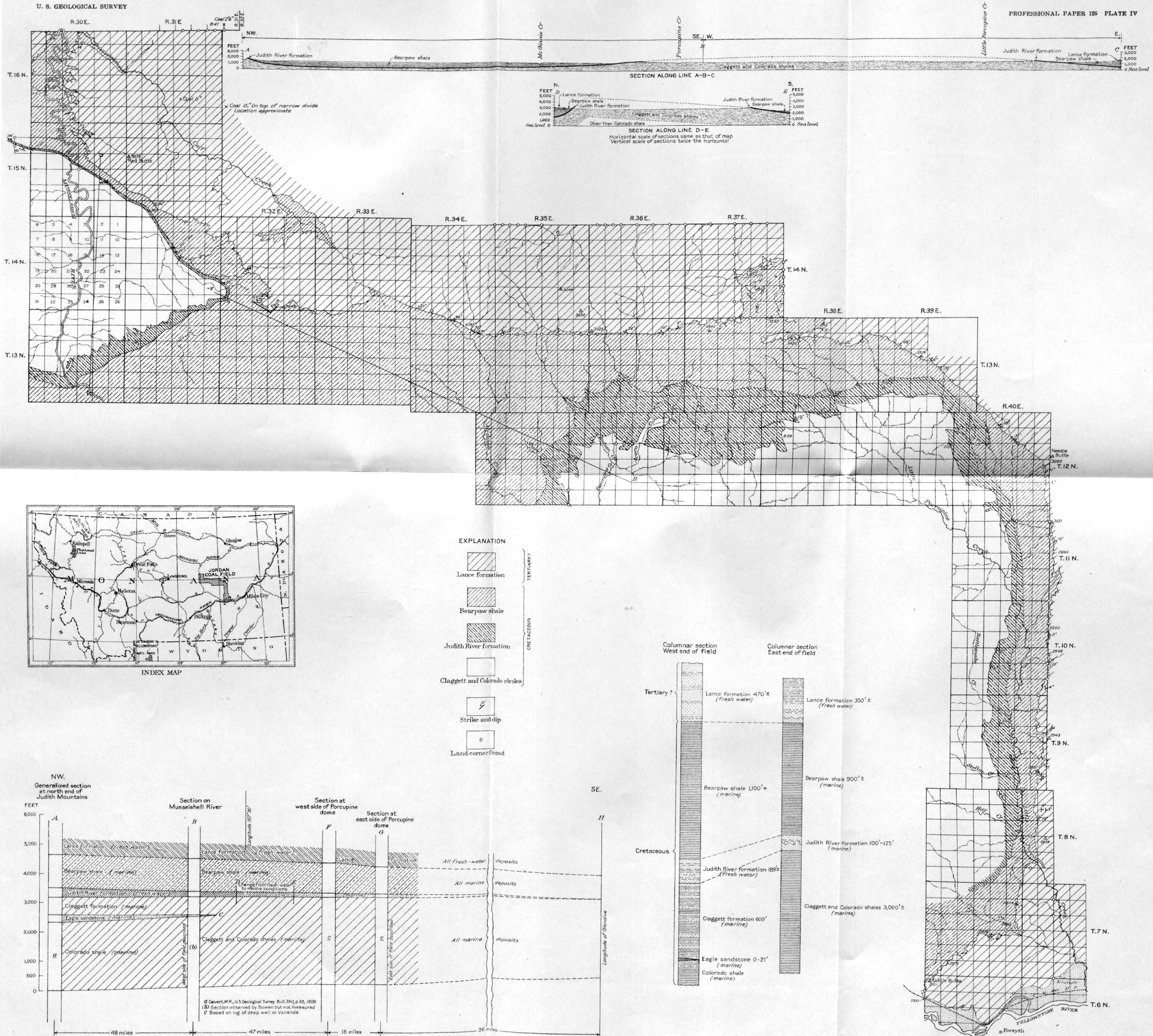
stone, which does not extend east of Musselshell River, these formations are believed to be continuous throughout the area, but the Judith River changes from a fresh-water formation in the western part of the area to a marine formation in the eastern part. In other words, marine conditions prevailed over the eastern part throughout the Montana epoch, whereas in the western part a temporary recession of the sea allowed the accumulation of fresh-water deposits. These conditions are illustrated in the diagrammatic and generalized sections shown on Plate IV.

Rocks below the upper part of the Colorado shale are not exposed in this field or anywhere in the immediate vicinity, but have been penetrated by the drill to a depth of about 2,500 feet below the top of the Colorado shale in a deep well put down at Vananda, in T. 7 N., R. 38 E., by the Chicago, Milwaukee & St. Paul Railway Co. The greater part of this thickness consists of the dark-gray to black shale of the Colorado, but the lower 157 feet seems to represent some underlying formation, probably the Kootenai.

The accompanying table presents in condensed form the sequence, character, and thickness of the exposed formations and of those penetrated by the drill in the well at Vananda, a detailed log of which is given on page 13.

Geologic formations in the area herein discussed.

System and series.	Group.	Formation.	Thickness (feet).	Character.
Quaternary.				Alluvial gravel, sand, and silt along Yellowstone and Musselshell rivers and some of the smaller streams.
Tertiary (?) (Eocene?).		Lance formation.		Brown, irregularly bedded sandstone, alternating with "somber" gray shale. Upper part (25 feet or more) is somewhat sandy, forming a transition to the Lance. This transition phase is probably what has been recognized as Fox Hills on Hell Creek about 35 or 40 miles farther north.
Cretaceous. Upper Cretaceous.	Montana.	Bearpaw shale.	900–1,100±	Dark-gray shale in which occur calcareous concretions containing marine invertebrate fossils.
		Judith River formation.	100–200±	Upper member, light-brown to light-gray massive sandstone. Middle member, light-gray to dark-gray shale. Lower member, sandstone, weathering brown and giving rise to large boulder-like masses. The formation is of fresh-water origin in the western part of the field and of marine origin in the eastern part.
		Claggett formation.	600–700±	Dark-gray shale; contains numerous large calcareous concretions in upper part, some of which show well-developed cone-in-cone structure; marine fossils similar to those in the Bearpaw.
		Eagle sandstone.	0–21	Buff massive sandstone; does not occur east of Musselshell River.
		Colorado shale.	2,300±	Dark-gray to black fissile shale, with thin beds of sandstone and sandy shale in upper part and thin beds of limestone and sandstone near the base; shale is only slightly plastic when wet. Contains marine fossils.
	Lower Cretaceous (?).	Kootenai formation (?).	157+	Consists predominantly of red and white shale, overlain by a thin bed of limestone and sandstone.



INDEX MAP

EXPLANATION

- Lance formation — TERTIARY?
- Bearpaw shale — CRETACEOUS
- Judith River formation — CRETACEOUS
- Claggett and Colorado shales — CRETACEOUS
- Strike and dip
- Land corner found

DIAGRAMMATIC SECTION FROM NORTHWEST TO SOUTHEAST TO ILLUSTRATE CHANGES OF SEDIMENTS DUE TO OSCILLATIONS OF UPPER CRETACEOUS SEA

Thicknesses based on data obtained by C. F. Bowen except as otherwise stated in text. (Adapted from Eugene Stebinger, U. S. Geol. Survey Prof. Paper 90, figure 9, p. 67, 1915)

GEOLOGIC MAP OF THE JORDAN COAL FIELD, MONTANA, WITH COLUMNAR SECTIONS, STRUCTURE SECTIONS, AND DIAGRAMMATIC SECTION

5 0 5 10 Miles

Log of well drilled by the Chicago, Milwaukee & St. Paul Railway Co. at Vananda, in sec. 5, T. 7 N., R. 38 E., Mont., between October 23, 1913, and October 17, 1914.

[Elevation of mouth of well, 2,704 feet above sea level.]

Formation.[a]	Driller's description.	Thickness.	Depth.
		Feet.	*Feet.*
Judith River formation.[b]	Shale, sandy	23	23
	Sand; 30 gallons of water an hour	7	30
	Shale, yellow	16	46
	Sand	11	57
	Shale and sand	24	81
	Sand	8	89
	Shale, yellow	16	105
	Sand	14	119
	Sand and shale	24	143
	Shale, blue	46	189
	Sand; flow of alkaline water, 2,400 gallons an hour	26	215
Claggett shale.[c]	Shale; disintegrates when exposed to air	685	900
([d])			
Colorado shale.	Shale,[e] black surface; whitens on exposure to air	140	1,040
	Shale	907	1,947
	Oyster-shell rim, fossil determined by former State geologist of South Dakota as *Inoceramus labiatus*.	5	1,952
	Shale, dark brown	107	2,059
	Hard rock	29	2,088
	Shale, soft; color changes on exposure from dark to light brown	32	2,120
	Shale, light brown	40	2,160
	Slate	40	2,200
	Soapstone	13	2,213
	Shale, white	23	2,236
	Shale, dark	45	2,281
	Shale, black	19	2,300
	Shale, brown	100	2,400
	Shale, dark, caving	31	2,431
	Slate, caving	19	2,450
	Limestone	41	2,491
	Shale	239	2,730
	Shale and lime shells	15	2,745
	Shale, soft, caving	35	2,780
	Shale and lime shells	20	2,800
	Shale, soft, caving	105	2,905
	Shale, dark	35	2,940
	Shale and lime shells	103	3,043
	Sandstone, hard	32	3,075
	Limestone, black, sandy (May represent the Mowry shale member.)	18	3,093
	Limestone	42	3,135
	Slate	55	3,190
Kootenai (?).	Sand, water bearing; water rose within 50 feet of surface	10	3,200
	Sandstone, compact	30	3,230
	Limestone	19	3,249
	Shale, white	23	3,272
	Shale, red	7	3,279
	Shale, white	8	3,287
	Shale, red	27	3,314
	Shale, white	8	3,322
	Shale, red	35	3,357

[a] Correlation revised by author.
[b] Called Lance in log furnished by railway company.
[c] Called Pierre in log furnished by railway company.
[d] In view of the lithologic similarity between the Claggett and Colorado the position of this boundary must be regarded as uncertain.
[e] Called Niobrara in log furnished by railway company.

CRETACEOUS SYSTEM.

KOOTENAI (?) FORMATION.

That part of the Kootenai (?) penetrated by the drill in the Vananda well consists in descending order of 40 feet of sandstone, 19 feet of limestone, and 98 feet of red and white shale in alternate layers. There is no information available as to whether these beds are of fresh water or marine origin; in lithologic aspect, however, the beds, especially the red and white shales, are similar to the fresh-water Kootenai (Lower Cretaceous) of the Great Falls field. In that field the Kootenai as described by Fisher [1] is 400 to 500 feet thick and consists predominantly of clay, with thin intercalated beds of sandstone and limestone, but contains valuable beds of coal in the lower part and a basal sandstone from which building stone is obtained.

COLORADO SHALE.

The Colorado shale is the oldest formation exposed in this area. It consists of dark-gray to black fissile shale, with some thin bands of sandstone and sandy shale in its upper part, and according to the record of the Vananda well has more or less sandstone and a thin bed of limestone at the base. The shale contains large calcareous concretions in which fossils occur; some of the sandstone bands are also distinctly fossiliferous. The formation has a total thickness, as interpreted from the log of the Vananda well, of about 2,300 feet. It probably includes the time equivalents of both the Benton and Niobrara formations. In this part of Montana there appears to be no recognizable lithologic distinction between these two formations, and they are therefore grouped together under the name Colorado shale. It may be, however, that detailed paleontologic work would show the existence of a Niobrara fauna in the upper part of the Colorado shale, even though no lithologic distinction exists. Weed [2] and Stanton and Hatcher [3] have already pointed out a general resemblance between the fauna of the upper part of the Colorado in the vicinity of Fort Benton and the fauna of the Niobrara. It might be possible, therefore, on purely paleontologic grounds to separate the Colorado of this area into the Benton and Niobrara, as in Nebraska, Colorado, South Dakota, and Wyoming.

In the easternmost areas just mentioned the Niobrara formation consists chiefly of limestone; farther west it is a calcareous buff shale; and apparently still farther west it loses its calcareous aspect, becoming a typical clay shale that is somewhat arenaceous. This is the sort of change to be expected in a formation of this kind when traced toward the source of its constituent materials.

The Colorado differs from the overlying Claggett in being darker and more fissile and in becoming only slightly plastic when wet; because of this last characteristic the local term "gumbo" is not generally applied to it.

The Colorado occupies an area of about 350 square miles in the central part of the Porcupine dome, which lies principally west and south of the eastern part of this area. It also occupies another small dome extending westward from a point a few miles east of Musselshell River. Except in the small area west of the Musselshell, where the Eagle can be recognized, the Colorado and Claggett have not been differentiated on the accompanying map.

EAGLE SANDSTONE.

The Eagle, which forms a prominent and persistent lithologic unit farther west, is represented in this area by a buff medium-grained sandstone consisting of quartz, feldspar, and black chert with a small amount of mica inclosed in a calcareous matrix. It ranges from a knife-edge to about 20 feet in thickness. The sandstone is recognizable as a distinct unit at the western margin of the area, from which its outcrop has been traced northwestward and southwestward for many miles. In these more western areas the formation ranges from 200 to 300 feet in thickness, but it thins eastward, so that near the east side of T. 15 N., R. 29 E., where the sandstone is exposed in a clean-cut face, it is only 21 feet thick, with marine shale both above and below. From this place the formation can be traced eastward for about 2 miles, and in that distance the sandstone is seen to become more and more interlaminated with thin bands of shale in its lower part. The sandstone passes under an old river terrace

[1] Fisher, C. A., Geology of the Great Falls coal field, Mont.: U. S. Geol. Survey Bull. 356, pp. 22, 30–35, 1909.

[2] Weed, W. H., U. S. Geol. Survey Geol. Atlas, Fort Benton folio (No. 55), p. 2, 1899.

[3] Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds: U. S. Geol. Survey Bull. 257, pp. 63, 64, 1905.

about halfway between the western margin of the area and Musselshell River and is not exposed farther east, but at the Musselshell, where there is a clean-cut exposure from the Lance down into the Colorado, the Eagle is either lacking or is represented by a sandstone 3 feet thick.

The pinching out of the Eagle is not due to an unconformity but to the seaward thinning of a shoal deposit laid down during a recessional stage of the Cretaceous sea and later covered by an off-shore deposit as the sea deepened and the shore line was shifted farther west.

CLAGGETT FORMATION.

The Claggett consists of 600 to 700 feet of dark-gray shale containing numerous calcareous concretions in which invertebrate fossils occur. The shale is but slightly consolidated and becomes very plastic when wet, so that it is commonly referred to as "gumbo." Crystals of selenite are more or less abundant in the shale and in places accumulate in considerable quantities on weathered slopes. At the top of the formation there is a zone that is especially prolific in large calcareous concretions, many of which show a well-developed cone-in-cone structure. This feature, so far as the writer is aware, is peculiar to the Claggett throughout a large part of Montana and does not occur in either the Colorado or the Bearpaw. It therefore constitutes one criterion for the recognition of the Claggett in central Montana.

JUDITH RIVER FORMATION.

Character and thickness.—The Judith River formation, as originally defined,[1] includes fresh and brackish water beds lying above the marine Claggett and below the Bearpaw. This definition was given before the full extent of the formation was known. The work of the season of 1918 has shown that in the area described the fresh-water deposits when traced eastward grade into marine deposits of the same lithologic character. In this paper the term Judith River is used to include both the fresh-water deposits exposed in the western part of the area and their equivalent marine deposits in the eastern part.

The fresh-water facies may be considered as made up of three parts—a lower division of massive brownish, poorly cemented sandstone, a middle division of ash-gray shale, and an upper division of grayish-white to brown massive to heavy-bedded sandstone. The total thickness of this facies of the formation is about 185 feet.

The marine facies likewise has a threefold character which corresponds in every way to the fresh-water divisions except that the middle shale member is darker. The upper sandstone is of a light-brown color in the eastern part of the field but farther west changes to light gray or dirty white; the lower sandstone is prevailingly brown on weathered surfaces. The marine facies has a thickness of about 125 feet near the head of Big Porcupine Creek; it is reported as 200 feet thick in the Vananda well and may be thicker than that, as it is believed that the mouth of the well is below the top of the formation; but on the east side of the field the thickness probably does not exceed 100 feet.

Detailed sections of these two facies are given below.

Section of Judith River formation (marine) in sec. 8, T. 12 N., R. 38 E.

	Feet.
Sandstone, massive, yellow to brown (marine shells and *Halymenites*)	20
Talus, sandy, probably sandstone	30
Shale, gray to yellow	20
Sandstone, massive, gray at top and full of *Halymenites*, lower part not well exposed	45
	115

Section of Judith River formation (fresh-water) on west bank of Musselshell River, in sec. 16, T. 15 N., R. 30 E.

Shale, Bearpaw.	Feet.
Sandstone	29
Shale, light gray	15
Shale, carbonaceous	8½
Sandstone	8
Shale, gray; carbonaceous in upper part	13
Sandstone	9
Shale	35
Sandstone	13
Shale, light gray	15
Sandstone	2
Shale	3
Shale, carbonaceous	8
Sandstone	31
Shale, Claggett, dark gray, sandy at top, transition.	
	189½

Composition.—As revealed by a study of thin sections the sandstones of both the fresh-water and marine facies of the formation are as similar in microscopic appearance as they

[1] Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds: U. S. Geol. Survey Bull. 257, pp. 33–34, 1905.

are in outward physical appearance. They are arkosic and consist of angular, subangular, and rounded grains of orthoclase, plagioclase, quartz, and black chert, with small amounts of muscovite and biotite, inclosed in a matrix or cement of calcite, which is more or less stained with iron oxide. Grains of limestone are numerous in one specimen of fresh-water origin and are rather well rounded; but they are not observed however in any of the other specimens examined. A rather surprising feature is the slight alteration of a considerable proportion of the feldspar. Many of the grains, especially of the plagioclase variety, are perfectly fresh and clear and show no sign of kaolinization. In the sections examined the calcite constitutes 50 per cent or more of the bulk of the rock; of the granular material feldspar is in general the most abundant, followed by black chert and quartz, which vary in amount, in some specimens the one and in some the other predominating. Another interesting feature is the small proportion of well-rounded grains. The grains of chert and quartz are subangular to rounded, whereas those of feldspar are predominantly angular and give to the thin sections the appearance of being made up largely of angular to subangular fragments. This marked angularity does not accord well with the highly assorted condition of the material, which is remarkably uniform in size and free from silt or fine particles. This highly assorted condition suggests considerable agitation, either by waves or by currents, whereas the angularity of the grains suggests but a moderate amount of abrasion. It is probably to be attributed to the cleavage of the feldspar and the smallness of the grains rather than to the amount of abrasion of the particles. The texture is fine and varies somewhat in the different specimens, the grains ranging from about 0.075 to 0.2 millimeter in average diameter.

Relations.—The Judith River is conformable with both the underlying and overlying formations. In the western part of the area the fresh-water facies overlies about 600 feet of the Claggett, including a sandy transition zone about 35 feet thick, and is in turn overlain by 1,000 to 1,100 feet of Bearpaw shale. The marine facies overlies 700 feet (Vananda well record) of the Claggett and is overlain by about 900 feet of the Bearpaw. In other words, the marine and fresh-water facies are at the same stratigraphic horizon, and the overlying shale is a unit from the locality of the one to that of the other. The marine phase represents the seaward extension of the continental deposits and marks the maximum retreat of the sea during this stage of minor oscillation.

BEARPAW SHALE.

The Bearpaw shale includes the marine shale lying between the Judith River and Lance formations. It consists chiefly of dark-gray shale that is similar in lithologic character to the shale of the Claggett except that so far as observed it contains no concretions showing cone-in-cone structure. In the upper part of the formation there is a sandy zone 25 feet or more thick which consists of sandy shale and some thin sandstones forming a transition to the Lance. This is probably the representative of the sandy shale from which, on Hell Creek, 35 or 40 miles farther north, Barnum Brown obtained a Fox Hills fauna and which he therefore designated the Fox Hills formation.[1] A small collection of marine fossils, all representing a single species of *Lingula*, was obtained by the writer in a sandstone that caps a small outlier in the SW. $\frac{1}{4}$ sec. 1, T. 14 N., R. 32 E. This sandstone is probably near the top of the transition zone just described. The species of *Lingula* obtained is not sufficiently diagnostic for purposes of close time correlation. It therefore does not establish the existence of the Fox Hills at this place, but it indicates that the sandy transition zone at the top of the Bearpaw is marine.

The thickness of the Bearpaw ranges from 1,000 or 1,100 feet in the western part of the area to about 900 feet in the eastern part. As determined by the fossils which occur in it, the formation is of Montana age and is equivalent to a part of the Pierre and possibly includes also the representative of the Fox Hills. Its correlation in this area is rendered certain not only by its included fossils but by its continuity with the undoubted Bearpaw of other regions.

[1] Brown, Barnum, The Hell Creek beds of the Upper Cretaceous of Montana: Am. Mus. Nat. Hist. Bull., vol. 23, p. 829, 1907.

TERTIARY (?) SYSTEM.

LANCE FORMATION.

Character and thickness.—The section given below is fairly representative of the lower part of the Lance formation, the only part extensively represented in this area. This part consists mainly of brownish massive to heavy-bedded sandstone and interbedded light-gray to dark-gray shale. Some of the sandstone layers are well consolidated and form protecting caps to the softer underlying beds. Large rusty-brown loglike concretions are common. Though brown is the prevailing color, some of these sandstones are dirty white to gray. Ripple marks and cross-bedding are common structural features.

The interbedded shale is light-gray to lead-gray and contains some carbonaceous members, though these are rare. The shale is unconsolidated and weathers rapidly where not protected by the more resistant sandstone. Thin layers of impure fossiliferous limestone occur in a very few places.

In the northeast corner of the area the beds above described are overlain by a zone consisting chiefly of "somber" gray shale with interbedded layers of carbonaceous shale and yellow and brown sandstone. Some of the sandstone layers, which are as much as 20 feet thick, are well consolidated and resemble in every way the sandstones in the lower part of the formation.

There is no abrupt change between this member and the lower member described above. They seem to represent continuous deposition and a gradual change from the conditions favoring the accumulation of sandstone to those favoring the accumulation of shale. This shale member, although not definitely included in the Lebo shale member of the Little Sheep Mountain field, seems to be identical in character with it. So far as the writer was able to ascertain, this member pinches out or at least thins markedly farther west; however, more detailed work on the overlying beds and a careful study of the extent and character of the various phases are necessary in order to establish their continuity and determine their relations.

Section of a part of the Lance formation exposed in Table Butte, in the SE. ¼ sec. 32, T. 7 N., R. 41 E.

	Feet.
Sandstone, massive, cross-bedded, containing clay balls	25
Shale, becoming sandy toward top	80
Shale, carbonaceous	1
Shale, yellow to drab	70
Sandstone, massive, buff; contains bone fragments and small scattering pebbles	30
Shale, buff	20
Sandstone, massive, brown	10
"Somber" and yellow clay shale, alternating	60
	296

Composition.—The sandstones of the Lance, including those interstratified in the dark-shale member described above, as well as those which make up the bulk of the lower distinctly sandy portion of the formation, are arkosic and are shown on microscopic examination to consist of the same material as the sandstones of the Judith River formation, the only difference being the higher degree of oxidation of the material of the Lance. In all the thin sections examined the principal granular minerals present are feldspar, chert, quartz, muscovite, and biotite, named in the order of their abundance; these are embedded in a matrix of calcium carbonate, which constitutes 50 per cent or more of the bulk of the rock. Grains of limestone are also sparingly present in some specimens. The feldspar, including orthoclase, plagioclase, and microcline, is commonly the predominant granular mineral. Many of the grains are comparatively fresh and unaltered and show cleavage or crystal boundaries and beautifully marked striations; others are more or less cloudy and opaque from the development of kaolin. Most of them are angular or subangular, well-rounded grains being exceptional. The chert, which in the hand specimen is gray or black, is invariably present. In the thin section it is clear and transparent and exhibits a cryptocrystalline texture. It is variable in amount, being in some specimens almost as abundant as the feldspar but in others less abundant than the quartz. The grains of chert show a much more marked tendency toward rounding than those of feldspar.

The quartz occurs in subangular to rounded grains. It is variable in amount, being almost wholly absent in one specimen and in others constituting 25 per cent or more of the granular material. Muscovite is present in notable amount and is easily recognized in the hand specimens; biotite is also sparingly present. The calcite, which constitutes the matrix of the rock, shows a finely crystalline texture. It is commonly more or less stained and obscured by limonitic material, which in most of the specimens also occurs to a greater or less degree in distinct grains. Like the sandstones of the Judith River, those of the Lance are medium grained, and their grains are of fairly uniform size, showing a marked degree of assortment.

Age and correlation.—Paleontologists are not agreed as to the age of the Lance formation, the invertebrate and vertebrate fossils being regarded as related to Cretaceous types, whereas the plants are regarded as of Fort Union age. Under these circumstances the Geological Survey has only provisionally assigned the Lance to the Tertiary system.

The formation is identified in this area and its relations are established by (1) the finding of *Triceratops* remains near the base of the formation at Castle Butte, northwest of Forsyth, and the occurrence in it of many fragments of dinosaur bones in other parts of the area; (2) its stratigraphic position between the Bearpaw shale and the Fort Union formation; and (3) its continuity with beds that undoubtedly belong to the Lance in other parts of Montana.

Distribution and surface features.—The Lance formation occurs at the southern, eastern, and northern margins of this area and extends beyond the area in each of these directions. In general it occupies a zone from 1 mile to several miles broad, its width depending on the attitude of the beds and the stage of erosion.

The outcrop of the formation has a marked effect on land forms. Its lower part produces a prominent ridge which rises abruptly, in some places almost precipitously, from the lower areas occupied by the Bearpaw. From the margin it extends as a dissected upland studded with buttes, pinnacles, and other features characteristic of the weathering of moderately consolidated beds in a semiarid region.

STRUCTURE.

In its broad general relations the structure in this part of Montana is anticlinal and represents the southeastward extension of the Big Snowy anticline. More locally the eastern part of the area occupies the eastern and northern flanks of the Porcupine dome, around which the beds have a quaquaversal dip and are therefore in this area inclined southward, eastward, and northward. As shown on the accompanying map, the dips in this part of the area range from 1° or 2° to 40°. This dome is separated by a broad, shallow transverse syncline from a pronounced anticline in the vicinity of Musselshell River. On the west side of the syncline the strata dip 15°–25° E.; on the east side the westward dip is not more than 2° or 3°. West of this cross syncline the Big Snowy anticline is the dominant structural feature. Around the point of this anticline the Judith River formation dips from 5° on the south limb to 45° on the north. These steep dips do not continue for any considerable horizontal distance in the direction of the dip, as the overlying Lance rarely shows dips of more than 10° along its border and within half a mile lies essentially flat. It is a noteworthy fact throughout the area that the steeply dipping beds become approximately horizontal within short distances. The features above described are shown graphically by the structure sections along the lines ABC and EF on Plate IV.

Besides the main structural features outlined above there are local irregularities, such as the anticlines in T. 14 N., Rs. 32 and 33, 37, and 38 E.

SOURCE OF THE SAND.

The feature that most impresses one who studies the sandstones of the Lance and Judith River, and, so far as can be judged by a microscopic examination, this applies also to the Eagle sandstone, is their identity in mineral composition and the relative abundance of the predominant minerals. The abundance of feldspar, the invariable occurrence of black chert, commonly in considerable amount, together with quartz and mica, and the almost complete absence of other granular constituents strongly suggest derivation either from a common source or at least from rock of similar composition, and the uniformity in

texture and assortment certainly points to similar physiographic conditions of accumulation. This striking resemblance is still more remarkable in view of the fact that the formations are separated from one another by several hundred feet of marine shale. The conclusion is inevitable that the oscillations which give rise to the alternate deposits of shale and sandstone during the Upper Cretaceous were of a gentle, rhythmic type.

This conclusion at once raises a question as to the age of the Rocky Mountain orogenic disturbance. The petrographic evidence may ultimately have more weight in deciding this question than has yet been assigned to it. At present this evidence seems to warrant the belief that there was no great physical break between the deposition of the formations underlying the Lance and that of the Lance and to corroborate the evidence afforded by the attitude of the Lance and Fort Union formations, namely, that the present Rocky Mountains are of post-Fort Union rather than pre-Lance age.

As to the probable source of the material, it is hardly profitable in our present state of knowledge to speculate further than to say that it was evidently derived from the land mass to the west that is supposed to have been in existence during the Cretaceous period. It would yield interesting data, however, if observations of this character were extended over the entire region involved, and it might then be possible to form more definite conceptions, not only as to the source of the material, but also as to the conditions of its accumulation.

UPPER CRETACEOUS HISTORY.

Variations in the character of sediments involving changes from sandstone to shale and from marine to fresh-water deposits imply corresponding changes in physiographic conditions during the period of their accumulation and therefore furnish a basis for the interpretation of the past history of the region in which they occur.

Such changes occurred in north-central Montana during the Upper Cretaceous epoch. The area herein described happens to be favorably situated in that it furnished more exact evidence than has heretofore been available as to the magnitude of some of these oscillations of the sea and as to the extent and character of the formations involved.

An understanding of these conditions will be facilitated by a study of the diagrammatic section on Plate IV which extends from Black Butte, at the north end of the Judith Mountains, about 48 miles west of this area, southeastward to the longitude of Glendive, a total distance of about 210 miles. Section A is compiled from measurements made by W. R. Calvert in the Lewiston field and those made by the writer in 1912; sections B, F, and G are compiled from data collected by the writer while examining the area herein described; and information regarding conditions at Glendive is based on the record of a well put down near that place by the Northern Pacific Railway Co. It is not possible to plot this record because the exact horizon of the mouth of the well is not known. The well was begun, however, somewhere near the top of the Pierre shale and continued to a depth of 2,710 feet, which would bring it near the base of the Colorado shale.

Upper Cretaceous time seems to have been ushered in by a widespread transgression of the sea extending westward beyond the eastern front of the present Rocky Mountains. During the Colorado epoch great quantities of mud and silt were spread out over the floor of this epicontinental sea, and its waters teemed with life, the remains of which were in part entombed in the accumulating muds that now constitute the Colorado shale. The fine texture and homogeneous character of this shale and its freedom from notable amounts of sandy material, except perhaps near its base, indicate that it was laid down under very uniform conditions. This implies that the relative elevations of land and sea must have remained nearly constant throughout the Colorado epoch. So the sea was filled to a depth of more than 2,300 feet by the accumulated mud and as the land surface was necessarily lowered by the removal of this material, it seems necessary to infer that the relations between land and sea level could not have remained constant unless the sea floor was being gradually depressed at about the same rate as that at which the sediments accumulated.

This gradual submergence was arrested and the Colorado epoch was brought to a close in the western part of the epicontinental sea by an uplift of the western land mass. As a result

of this uplift the sea became shallow and probably withdrew from local areas, and the accelerated streams brought down great quantities of sand, which were spread over the shallow sea floor and now constitute the Eagle sandstone. As the uplift progressed the sea withdrew from its former western shore to a point, in the latitude represented by the diagrammatic section on Plate IV, a few miles east of section A, for from that place westward the upper part of the Eagle sandstone contains thin beds of carbonaceous shale and lignite. The distance seaward to which this uplift was effective in producing a change of sedimentation is 2 or 3 miles east of section B, Plate IV, or about the present site of Musselshell River in the western part of the area here discussed. At that place the Eagle sandstone feathers out between the Colorado and Claggett formations and thence eastward the deposition of shale was continuous through the Colorado, Eagle, and Claggett epochs.

Another submergence in the Claggett epoch restored the sea over at least a part of the area from which it had been withdrawn, and the deposition of shale was extended westward, covering the Eagle sandstone in this part of Montana. This submergence did not extend as far northwest, however, as that of the Colorado epoch, because, as shown by Stebinger,[1] the entire interval between the Colorado and Bearpaw epochs in the vicinity of the front range of the Rocky Mountains was characterized by the deposition of sediments that were mainly of continental origin.

After 500 to 700 feet of marine shale had been laid down another emergence set in which marked the beginning of the Judith River epoch. This emergence was more widespread than that of the preceding Eagle epoch, and during its progress the sea was withdrawn from the area herein considered to about the longitude of 107° 30′—that is, to some position between the points indicated by D and E in the diagrammatic section on Plate IV. The clay and sand not transported by the streams from the adjacent highlands were in part spread out as continental deposits on the emerged sea floor and in part carried out to the sea and deposited beneath its surface. Westward from point B the resulting sandstones and shales of the Judith River formation contain the remains of land and fresh-water vertebrates and invertebrates, leaves, stems, trunks of trees, and beds of lignite; whereas east of point E these deposits contain the remains of marine organisms.

How far eastward this Judith River uplift was effective is not known. Sections A to G in Plate IV show that the formation gradually thins from west to east, and apparently it either disappears or is represented by not more than 15 feet of sandstone at point H, in the longitude of Glendive. The well drilled by the Northern Pacific Railway Co. in sec. 20, T. 14 N., R. 55 E., about 10 miles southwest of Glendive, was begun near the top of the Pierre shale and penetrated a bed of sandstone 15 feet thick at a depth of 745 feet and another bed 6 feet thick at a depth of 900 feet. The remainder of the well log is given as shale down to a depth of 2,710 feet, or near the base of the Colorado. It is evident, therefore, that in the longitude of Glendive conditions of sedimentation were practically uniform throughout Colorado and Montana time and that the oscillations which gave rise to the Eagle and Judith River deposits to the west did not extend that far east.

A renewed submergence brought the Judith River epoch to a close and restored the sea over the entire known area of the Judith River formation. During this, the last widespread submergence, 1,000 feet or more of marine shale was laid down, constituting the Bearpaw formation. This submergence was followed by a widespread emergence that resulted in the withdrawal of the sea from this part of the continent, which has since remained above sea level except in small areas. This uplift was probably of epeirogenic character, because the next succeeding deposits seem to have suffered the same amount of orogenic deformation as the underlying Bearpaw shale.

On the lowlands produced during this uplift the continental sediments and associated coal beds of the Lance and Fort Union were laid down apparently without interruption and under only such changes in conditions as resulted in the alternate deposition of sand and mud and the more or less extensive accumulation of vegetable growth. This period of deposition was brought to a close by a widespread orogenic disturbance, accompanied by folding

[1] Stebinger, Eugene, The Montana group of northwestern Montana: U. S. Geol. Survey Prof. Paper 90, pp. 62–63, 1914.

and thrusting, which produced the principal tectonic features of the Rocky Mountain system. Since that time erosion has reduced the land surface to its present form, though it may be that between the epochs of deformation and erosion the Oligocene and Miocene deposits now found farther east were deposited over parts of this region as well.

By way of summary it may be said that eastern Montana remained beneath the sea and was not affected by any oscillations of land and sea level throughout the Colorado and Montana epochs, whereas in the central part of the State, at least as far west as the front of the present Rocky Mountains, there were oscillations of land and sea level produced either by rhythmic gentle depressions of the sea floor or by uplifts of the land mass to the west. The first of these uplifts, which resulted in the deposition of the Eagle sandstone, was of the shortest duration and was effective in the area here described for only a few miles east of its western boundary. The uplift during the Judith River epoch was of longer duration, to judge by the thickness of material deposited, and was considerably more widespread. As a result of this uplift the sea withdrew to about the longitude of 107° 30′ and the site of sedimentation was shifted to some point east of the longitude of Forsyth, perhaps nearly as far east as Glendive. Because of this change the Montana group is in the central part of the State divisible into the Eagle, Claggett, Judith River, and Bearpaw formations but farther east consists of a single lithologic unit—the Pierre shale—to which a thin representative of the Fox Hills sandstone is added near the eastern boundary. In this eastern region also there is little if any lithologic distinction between the shales of the Colorado and Montana epochs.