

STUDY OF THE MORRISON FORMATION¹

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INTRODUCTION

PRELIMINARY REMARKS

The present paper is the result of a study of the Morrison formation undertaken by the writer in connection with the monograph on the Sauropoda now in course of preparation for the United States Geological Survey by Professor Henry Fairfield Osborn. Library and laboratory work was done during the winters of 1912-1913, 1913-1914 and 1914-1915 at the American Museum of Natural History and at Columbia University. Field work was done in the summers of 1913 and 1914. The writer desires to express his thanks to Professor Osborn for the opportunity of studying the Morrison formation in the field, and for permission to use

data gathered for use in the above-mentioned monograph. Conferences have been held with Professors A. W. Grabau, C. P. Berkey and D. W. Johnson, of Columbia University, who have made suggestions in regard to the work. Messrs. W. T. Lee, N. H. Darton, W. Cross and C. T. Lupton have added data regarding the distribution of the Morrison in the southern areas, and the director of the United States Geological Survey has given permission to use these unpublished data, and to use the map which was redrawn by Survey draughtsmen from an original by the writer. Valuable information has also been given by Mr. S. H. Knight, of Columbia University.

DEFINITION OF FORMATION

The name Morrison was first applied to the series of deposits under discussion, by Cross, in the Pike's Peak folio of the United States Geological Survey. It was proposed to include the series of clays, sandstones and shales which underlie the Lakota-Dakota series and overlie a white sandstone, which in turn rests on the Red Beds, at the village of Morrison, nearly west of Denver, Colorado. The names "Jurassic Beds," "Dakota Beds," "Variegated Beds," "Beulah Shales," "Atlantosaurus Beds," "Como Beds," "Gunnison Formation," "McElmo Formation" and "Flaming Gorge Formation" have all been applied to beds in various regions in a general way equivalent to the Morrison in eastern Colorado, though in some cases these terms have included more than the typical Morrison.

The name Morrison has been used extensively in the publications of the United States Geological Survey for this formation in other areas than the original area in eastern Colorado. As it was the first geographical name applied to the formation, it may be used as the valid formation name for the deposits concerned. In the present paper it will be used for the areas in western Colorado and Utah, where the beds have been known as Gunnison, McElmo, and in part Flaming Gorge, as well as for the more eastern representatives. The local names are often convenient, however, to designate the formation in particular localities.

The series is composed essentially of beds of variegated clays or marls, often described as "joint-clays," sandstones and shales, with minor elements of fresh-water limestones.

The formation has produced a small and not especially characteristic invertebrate fauna, a scant flora of cycads and fossil wood and a very characteristic and varied vertebrate fauna.

PHYSIOGRAPHIC OCCURRENCE AND DISTRIBUTION OF THE MORRISON FORMATION

The Morrison formation is generally exposed at the surface in two characteristic ways. The usual occurrences are in the steep faces of hog-backs and in the walls of river canyons. The hog-backs are long, even-topped ridges running practically parallel with the axes of mountain uplifts, with a comparatively steep slope on either side, but one side often

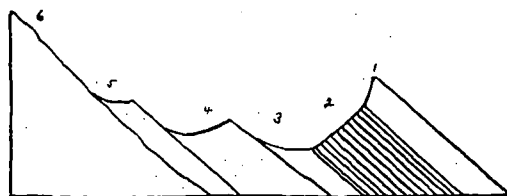


FIG. 1.—Generalized section of Rocky Mountain hog-back, showing the usual physiographic position of Morrison outcrops.

- | | |
|-------------------------------|--|
| 1.—Pre-Cambrian crystallines. | 4.—Sundance. |
| 2.—Paleozoic. | 5.—Morrison. |
| 3.—Red Beds. | 6.—Capping sandstone (usually Cloverly or Lakota). |

being steeper than the other. They are formed through uplift followed by erosion of the tilted and raised sedimentary beds which formerly covered or lapped against the mountains. The softer material is quickly eroded away, leaving ridges protected by cappings of harder strata. The Morrison formation is typically non-resistant, and so is usually found in

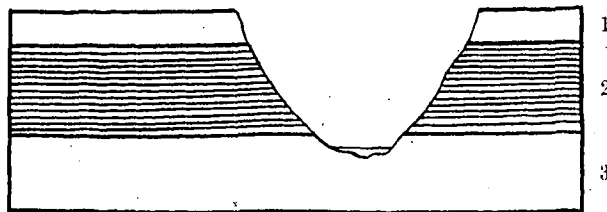


FIG. 2.—Generalized section of a Rocky Mountain or Great Plains river canyon, showing a common position of Morrison outcrops.

- | | |
|-----------------------|--------------|
| 1.—Capping sandstone. | 3.—Red Beds. |
| 2.—Morrison. | |

the erosion cliffs on the inner sides of the hog-backs. Exposures of this kind occur in eastern Colorado, extending north into Wyoming and south into New Mexico, around the Black Hills, on both sides of the Laramie Mountains; around the Bighorn and Owl Creek Mountains; around the Wind River Mountains; south of the Uinta Mountains; and in the Grand

Hogback, which extends all along the western border of the Rocky Mountains in Colorado. The river canyon exposures of the Morrison are also widespread. They occur in the canyons of streams east of the Rocky Mountains, such as the Huerfano, Purgatoire, Cimarron and Apishapa; in the canyons of the McElmo, Dolores and other rivers in western and southwestern Colorado; and in central Montana.

Other outcrops occur as combinations of hog-back and canyon exposures, such as at Cañon City, Colorado; as local surface rock, such as in southeastern Colorado (see distribution map), and near Grand Junction, Colorado; and in the erosion of local anticlines, such as Como Bluff in south-central Wyoming, and in faulted masses, such as the Sioux Fault exposure in Wyoming.

PURPOSE AND SCOPE OF THE PRESENT WORK

The purpose of the present paper is to interpret the Morrison formation, if possible, in regard to age, origin and paleogeography. It is also desired to give a summary of the present knowledge, so far as it is available in the literature, together with some new field observations.

Among the problems which have been connected with the Morrison formation is that of its age. Some writers have held that it is Jurassic, and others that it is Comanchean. Still others have held that it is both Comanchean and Jurassic. It is desired to show that the Morrison is essentially Comanchean, but that some portions of it, especially in the western areas, may possibly be Jurassic.

Various opinions have been held regarding the origin of the Morrison. It has been considered marine, lacustrine, fluvial and combinations of these. An attempt will be made in the present paper to show that the Morrison is essentially a broad alluvial plain, formed of coalescing alluvial fans, and possibly a true delta in the southeastern areas. It must have been deposited under conditions somewhat similar to those now existing in the great alluvial plains in eastern China.

The fauna and flora are listed for purposes of reference and summary.

STRATIGRAPHY

MORRISON FORMATION IN EASTERN COLORADO AND NEW MEXICO

GENERAL

The Morrison formation outcrops along the front of the Rocky Mountains in Colorado in a nearly straight line, from the Wyoming border to New Mexico, and south in New Mexico to a point a few miles south of

Las Vegas. The main line of outcrops then swings northeastward to a point 15 miles or so southwest of Clayton. The outcrops along the mountain front in Colorado and New Mexico occur in hog-backs. The northeast-southwest line of surface occurrence in New Mexico is an irregular cliff. The lines of outcrops are not completely continuous. At Golden the Morrison has been crowded out by igneous action, and at Manitou and other places it has disappeared through faulting. Outcrops also occur in the canyons of the Purgatory, Apishapa and other rivers in Colorado, and of the Cimarron in New Mexico and Oklahoma.

A. R. Marvine (1874, 3), in the seventh Annual Report of the U. S. Geological and Geographical Survey of the Territories, describes the "Jurassic" or the beds overlying the red series of supposed Triassic age as follows:

"General characters.—The series of strata lying next above the red beds form a group of rocks in which the thin-bedded and shaly element decidedly predominates. The outcropping edges of these beds have therefore generally been more eroded away than the harder beds above and below, so that they generally appear in valleys; and being soil covered, they are not usually well exposed.

"The arenaceous element still predominates, though argillaceous material is often present to a very large extent, while beds of impure limestone occur—one of which appears very persistent—and gypsum is frequent in thin layers, and sometimes occurs in workable quantities and of good quality. As before, red is the prevailing color, though a series of marked variegated shales occur, and weathering frequently produces an ashen-gray tint upon the surface. . . ."

Some of these beds are probably of lower horizon than the true Morrison.

The following description of the Morrison formation east of the Rocky Mountain front is given by Darton (1904, 8): "Its general character is nearly uniform throughout, a series of light-colored, massive clays, 'joint clays,' with thin beds of limestone and sandstone of fresh-water origin containing bones of saurians of the so-called 'Atlantosaurus' fauna. Its thickness averages less than 200 feet in most cases. It presents frequent and rapid variations in the local succession of beds, but the predominance of joint clays of chalky aspect and the occurrence of maroon and purplish layers among them are characteristic features." Lee speaks of the Morrison as "uniformly variable," a term especially applicable.

In the extreme northern part of Colorado the Morrison is said to rest upon the marine Sundance beds. Throughout most of the northern Colorado area it rests upon the red beds of the Chugwater formation. Fur-

ther south in Colorado it rests upon the Fountain or Badito formations. South of Beulah, in southern Colorado, the Morrison rests directly upon the crystallines. In the canyon of Rio Cimarron, in New Mexico, it rests on the Exeter sandstone.

"The basal unconformity is one of widespread planation, with local shallow channeling, but no perceptible discordance of dips" (Darton, 1904, 8).

The Morrison is present at intervals from the Platte River to Colorado City. North of the gateway to the Garden of the Gods it is 130 feet thick and rests upon a bed of gypsum. It is partly exposed at Colorado City, where the beds are vertical. It is exposed again, after being cut off by faulting for a few miles south of Manitou, along the mountain front to the vicinity of Cañon City. It is also well exposed in this vicinity in a structural basin north of Cañon City. South of Cañon City the formation is not present for a considerable distance. It is present near Beulah, where it rests on the gneisses. North of Beulah the "Dakota" is said to rest directly upon the Fountain formation, showing the presence of an erosion interval between the Red Beds, or possibly the Morrison, and the "Dakota." The formation is exposed in the Greenhorn Mountains, where it rests partly upon the red beds and partly upon the gneisses. The more important areas of Morrison outcrops in the eastern region have been well described in various reports, and summaries of these descriptions are given below.

The Morrison formation is overlain by the Lakota-Dakota series, the lower beds of which are known in the southern Colorado area as the Purgatoire formation. The contact is essentially conformable, but it is sometimes extremely sharp, as north of Cañon City, and it is quite probable that in many areas at least there is a stratigraphic break of slight extent between the two formations.

NORTHERN COLORADO

The following sections are given by Darton of the Morrison formation in northern Colorado (1904, 8):

Section northwest of Laporte, Colorado

	Feet
"Dakota," Coarse sandstone, with conglomerate at base.....	..
Gray massive shales, with thin limestone bed about 20 feet below top.....	80
Morrison, Limestone, gray, with algae.....	6
Sandy shale, reddish to buff, partly massive.....	20
Pinkish and buff sandstone at top of Red Beds.....	60

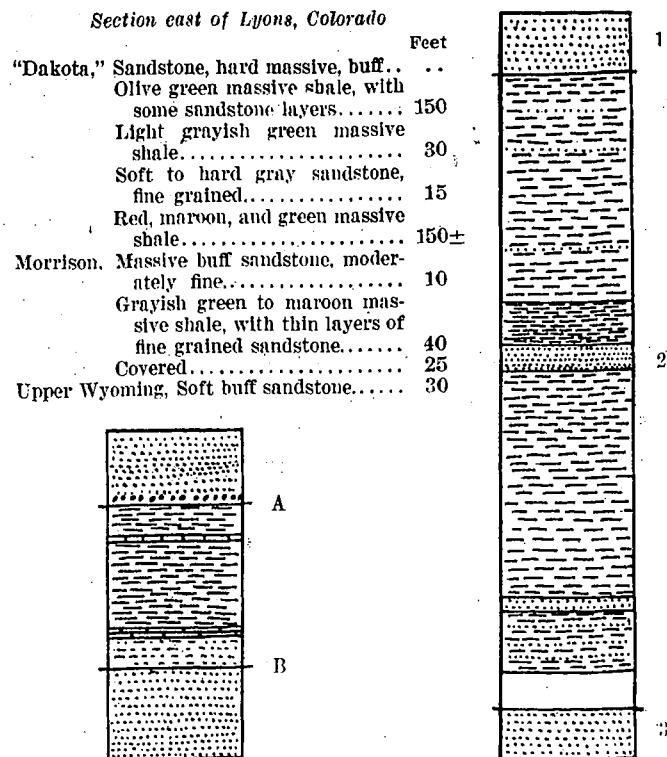


FIG. 3.—Section of the Morrison and overlying and underlying beds at Laporte, Colorado.

A-B = Morrison. Scale, 125 feet to 1 inch. (Darton.)

FIG. 4.—Section of the Morrison and adjacent formations east of Lyons, Colorado.

1.—Lakota; 2.—Morrison; 3.—Red Beds. Scale, 125 feet to 1 inch. (Darton.)

The Morrison formation in the vicinity of Boulder was described by Fenneman (1905, 9). The following remarks on the formation in this district are based on Fenneman's description. Sections of the Morrison at various places in this area differ greatly. In the main, however, the formation contains a large proportion of light-colored clays, some moderately indurated and others of flinty hardness, much gray sandstone, often calcareous, and at various horizons beds of highly compact limestone. A very much generalized section would present the beds in about the following order, beginning at the base: sandstone, clays, limestone, clays. The first and last members of the series are persistent, but the intervening clays and limestone may show two or three alternations and may inclose prominent sandstones. Fenneman estimates the maximum thickness to be a little less than 400 feet. The formation in this district

overlies the Lykins division of the Red Bed series. The basal sandstone varies from 10 to 20 feet in thickness. It is persistent and massive and is used for building stone. It is somewhat calcareous. The lowest bed of limestone varies in level, but may be within 15 feet of the basal sandstone. The intervening levels are composed of clay which is covered by waste material. One bed of limestone 40 feet thick, according to Fennemman, occurs at South Boulder Canyon. At one locality there are three distinct limestones separated by sandstones, the uppermost of the three being about 30 feet thick. Next follows 75 to 100 feet of covered beds, probably soft clays. Limestones and clays interbedded follow this covered series, in turn followed by 15 feet or less of calcareous, iron-stained sandstone. Above this sandstone the formation is composed of dense, hard clays and argillaceous sandstones.

MORRISON

The deposits of the Morrison formation are not very well exposed at the village of Morrison, six or seven miles west of Denver, from which the formation takes its name. The beds outcrop on the western slope of the hog-back at this locality and are mostly covered by talus from the



FIG. 5. The Morrison formation at Morrison, Colorado, looking south

heavy sandstones of the Lakota-Dakota series at the summit of the hog-back. The first discoveries of remains of the large dinosaurs of the so-called "Atlantosaurus fauna" were found about half way up the slope of the hog-back, on the northern side of the gap, through which Bear Creek crosses the hog-back.

The hog-back is capped by a ledge of heavy cross-bedded sandstone of the Dakota formation, underlain by white sands of the Lakota series.

Beneath these sands are the soft shales and clays of the Morrison for-



FIG. 6.—The Morrison formation at Morrison, Colorado, looking east.

mation. They are mostly pale green at this locality, with a few thin bands of sandstone and some variegated clays and red sandstones. The thickness here is evidently less than at Garden Park, near Cañon City, farther south, but more than in the exposures farther north in Wyoming. The upper and especially the lower contact could not be accurately determined. The formation appears to rest upon a coarse white sandstone, which in turn rests on deep red sandstones of the Red Bed series.

CAÑON CITY AREA

The Morrison formation is extremely well exposed in a number of localities north of Cañon City. A structural basin of A-shape, formed

by down-faulting and down-folding, has protected the Paleozoic and Mesozoic sediments of the district so that they are bounded on the east, north and west by the crystallines.

A hog-back capped by the Lakota-Dakota sandstones extends northeast from Cañon City, and a similar hog-back extends northwest from a point a few miles east of Cañon City. The dips of these two hog-backs are steep at their southern ends, but as they converge the dips become less and change in direction. Instead of being toward the southeast and

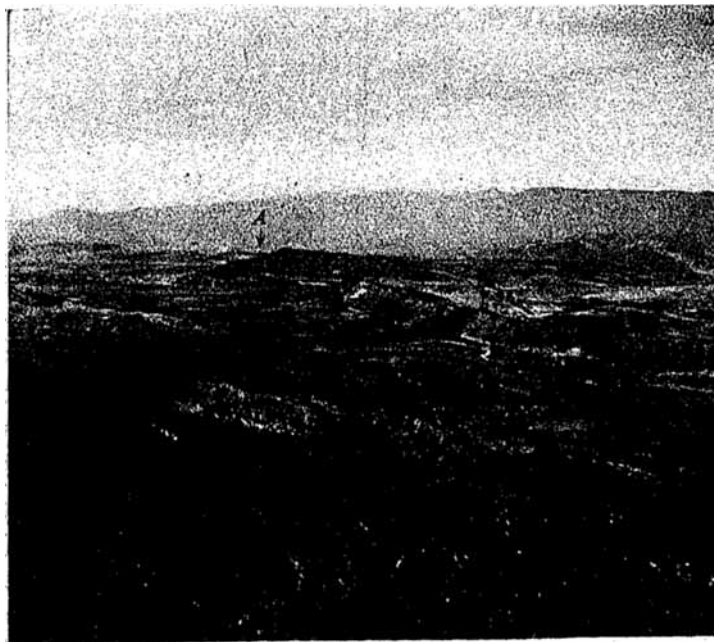


FIG. 7.—View northeast from Fremont Peak, near Cañon City, Colorado.

A indicates locality of the Marsh-Hatcher dinosaur quarry, B indicates the Morrison outcrops in the hog-back near Cañon City.

southwest respectively, the dip at the point where the Lakota-Dakota capping of the two hog-backs becomes continuous is towards the south. A short distance north of this point the dip lessens until the strata are nearly horizontal. Oil Creek, a tributary of the Arkansas River, cuts through this flat area, exposing the underlying rocks in a series of cliffs. North of this point a wider valley has been excavated, having the Triassic and lower beds as a floor. This valley is known as Garden Park.

The Morrison formation is exposed on the steeper eroded sides of the hog-backs, in the narrow gorge of Oil Creek and its tributaries, and in the



FIG. 8.—Site of the Marsh-Hatcher dinosaur quarry near Cañon City, Colorado.



FIG. 9.—Near view of the central portion of fig. 8.

An erosion channel in the lower clays, filled with a coarse sandstone, is shown.

steep cliff on the western border of Garden Park. At this latter point the beds are exposed from base to summit, affording a complete section. Several productive bone quarries have been operated at this point, and as these quarries exhibit the structure of the formation very well in some cases, they will be described in detail. The most important of these quarries is that which was operated by Professor O. C. Marsh, and later by J. B. Hatcher for the Carnegie Museum. This quarry is situated on the northeast bank of a dry brook-bed which joins Oil Creek just south



FIG. 10.—Exposure of the lower beds of the Morrison formation about 100 yards northeast of the Marsh-Hatcher dinosaur quarry, near Cañon City, Colorado.

of the entrance to Garden Park. The uppermost beds exposed at the quarry are red and brown joint-clays. Below these clays is a bed of rather coarse, heavy-bedded sandstone, about 5 feet thick. Below this is the bone-bearing sandstone, about 3 feet thick. It is a soft, coarse-grained sandstone, somewhat arkosic. In the exposures on the opposite side of the gulch the bone-bearing sandstone is distinctly cross-bedded. Below the bone-bearing sandstone is the sandstone of the quarry floor. This sandstone is heavy-bedded and is cross-bedded on a large scale. This cross-bedding makes the exact thickness difficult to determine. It is

about 5 feet on the average, and the variation in thickness is not great. Two distinct types of cross-bedding are present in this sandstone. It is underlain by a bed of clay 1 or 2 feet thick. This clay is underlain by another sandstone with a lense-shaped cross-section. It is about 15 feet thick at its thickest portion and about 2 feet thick at a point 60 or 80 feet on either side of its center.² Below this sandstone is a bed of clay, 8 feet thick, bearing small obscure shells. Below this clay is a limestone 1 foot thick, which is underlain by 9 feet of clays. These clays are under-



FIG. 11.—*The Cope dinosaur quarry northwest of the Marsh-Hatcher quarry, near Cañon City, Colorado.*

lain by a bed of lime concretions, 1 foot thick, underlain by more clays. The beds below are not exposed in the gulch, but are exposed on the west bank of Oil Creek about a hundred yards northeast of the quarry. The section at this point is as follows: clays at the top, underlain by about 3 feet of sandstone, which are in turn underlain by about 5 feet of the bone-bearing sandstone. Below this are 3 feet of the quarry-floor sandstone. There is a sharp contact between this sandstone and the underlying clays. Below the quarry-floor sandstone there is a series of beds.

² See discussion of structures, p. 117.

36 feet in total thickness, which is mostly clay, but may contain thin beds of limestone or concretions where it is covered by a thin clay talus. Below this clay series is a heavy-bedded sandstone about 8 feet thick. This sandstone is underlain by a series of clays interbedded with thin layers of limestone and nodules. This series may be taken as the base of the Morrison formation in this region. It is underlain by the reddish arkosic sandstones of the underlying formation.

Another important quarry in this region is that operated for Professor E. D. Cope in 1877. This quarry is situated about 600 yards northwest



FIG. 12.—The "Nipple," west of Garden Park, Colorado, looking east.

of the Marsh-Hatcher quarry. It is situated at the top of the hill, and the beds exposed in it are the brown and white clays of the uppermost beds of the Morrison formation in this district. They are overlain by the coarse white sandstone of the Lakota or Purgatoire formation. The contact between the two formations is very sharp.

Another quarry operated for Professor Cope is situated about 500 yards east of the above-mentioned Cope quarry. It is situated at the base of a small conical hill, locally known as the "Nipple." It is at the top of the cliff which forms the western boundary of Garden Park. The productive

bone level at this point is 20 feet or so below that of the other Cope quarry to the west. It is much higher than the bone level in the Marsh-Hatcher quarry. From the summit of the "Nipple" to the base of the cliff a complete section from the base of the Purgatoire to the upper members of the Red Bed series is exposed.

A section from the summit of the "Nipple" to the uppermost beds of the Red Bed series is as follows:

	Feet	Inches
1. At the summit of the "Nipple" and about 25 feet above the top of the cliff, white sandstone of the Purgatoire series.....	1	..
2. Brown joint-clay.....	4	..
3. Brown nodules.....	..	4
4. Brown clay.....	15	..
5. Gray clay (at the top of the cliff, contains dinosaur bones and is the productive bed of the above-mentioned Cope quarry).....	5	2
6. Sandstone.....	1	..
7. Clay.....	1	..
8. (a, b, c) Clay, nodules and clay.....	3	..
9. Variegated clay.....	9	6
10. Sandstone.....	..	4
11. Clay.....	6	..
12. Sandstone.....	..	3
13. Variegated clay, gray, purple and green ²	204	..
14. Cross-bedded sandstone.....	8	..
15. Clay.....	1	..
16. Sandstone.....	1 to 6	..
17. Clay.....	6	..
18. Sandstone.....	1	..
19. Clay.....	40	..
20. Sandstone.....	1	..
21. Clay.....	8	..
22. Sandstone.....	1	..
23. Clay.....	2	..
24. Sandstone.....	1	..
Total.....	319	1
		to
	319	7

25. Arkosic conglomerate. This conglomerate is here considered as belonging to the underlying Red Bed series, though it is possible that it may be the basal member of the Morrison formation. In the latter case the thickness of the formation would be increased by 40 or 50 feet.

The contact with the underlying beds is very indistinct, and the presence of an erosion interval between the Morrison and these underlying beds cannot be determined from the outcrops alone.

²The outcrop of this clay series is covered in many places with a thin clay *calus*, which may conceal some thin beds of limestone or nodules.

Marine fossils of Washita age have been found by Stanton (1905, 11) near Cañon City in beds immediately overlying the Morrison formation. This limits the age of the Morrison deposits near Cañon City to a certain extent. This question will be taken up again in the section on the age of the Morrison.

The general features in the Cañon City area which are especially worthy of notice are the prevalence of variegated joint-clays in the upper

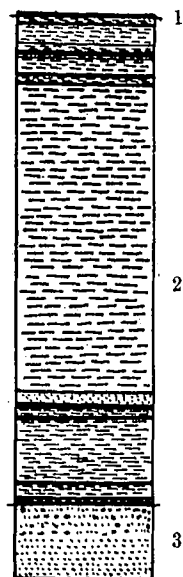


FIG. 13.—Section of the Morrison and related formations at Garden Park, near Cañon City, Colorado.

1.—Purgatoire; 2.—Morrison; 3.—Calcareous arkosic sandstone, probably the basal member of the Morrison, but may belong to the Red Bed series. Scale, 125 feet to 1 inch. (Section by the writer.)

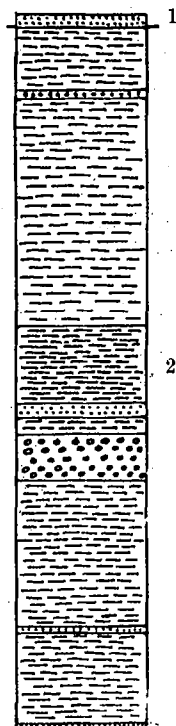


FIG. 14.—Upper part of the Garden Park section. (Fig. 11.)

1.—Purgatoire; 2.—Morrison. Scale, 12½ feet to 1 inch.

portion of the formation: the relatively larger amount of limestone, lime concretions and sandstone in the lower portion; the distribution of the dinosaur remains throughout nearly the whole thickness of the formation, though these remains appear to occur in definite levels; the sharp contacts of the sandstones and clays in the formation; the relatively small thickness of the individual sandstone members in most cases; and the lense-shaped cross-section of one of the principal sandstones.

had been eroded in the underlying clays. The frequent occurrence of cross-bedding in connection with sandstones which have sharp contacts at the top and bottom appear to indicate deposition by streams or wind; the structure of the cross-bedding sometimes being that usually assigned to stream deposition, and in other cases being of the type usually assigned to deposition by wind. The frequent sharp contacts in the formation point to the period of deposition of the formation in this region as a period of alternating deposition and erosion, deposition being the dominant process in the long run.⁴ The sharp contact at the top of the formation also indicates a period of erosion before the deposition of the basal sandstones of the overlying formation. This erosion interval may have been of long or short duration, so far as direct evidence from the contact is concerned.

CANYONS OF SOUTHEASTERN COLORADO

Across the canyon from this point, perhaps two miles away, 30 feet of limestone is found at the same horizon. Some of the sand is very pure and is used as a flux in assaying. The limestones also

Scale. 12½ feet to 1
inch.

⁴ See discussion of structures, p. 118.

vary much in their occurrence. They are usually more or less argillaceous. "The relative amount and position of sandstones, shale and limestones at any one point is no indication that a similar relation will be found at any other point. There is no abrupt lateral change, but the various beds blend into each other or pinch out laterally in a gradual though somewhat rapid manner, so that, while no sudden change is seen, a comparison of sections a few miles apart may show a total change in kind and relation of materials" (Lee, 1901, 7: 1902, 5). Dinosaur bones



FIG. 16. -The "Nipple," looking west from Garden Park, Colorado.

This view is in the opposite direction from that in fig. 12. The section shown in fig. 13 was taken in this cliff.

were found at many horizons. Some of these have been identified by Barium Brown as *Morosaurus* and *Diplodocus*.

The Red Beds, Morrison and "Dakota" all have the appearance of being conformable, though critical examination has shown that there is evidence in favor of concluding that there is a stratigraphical break both above and below the formation. There is distinct evidence of erosion at the surface of the Morrison, below the "Dakota (Purgatoire), in the presence of undulations in the line of contact with the "Dakota" (Purgatoire).

The Morrison lies on beds of gypsum in these localities. This gypsum

is not differentiated sharply from the underlying Red Beds. There is often a transition from Red Beds into gypsum. The change from the gypsum to the lower members of the Morrison is abrupt, and the gypsum often decreases in thickness where the Morrison is thick, and the reverse. "It is possible, therefore, that the gypsum beds were exposed and slightly eroded previous to the deposition of the shales" (Lee, 1901, 7).

The following sections of the Morrison in this area are given by Lee (1901, 7):

Section near Mouth of Plum Canyon

	Feet	Inches
Dakota (Purgatoire). Two massive sandstone layers separated by a soft shale of varying thickness; leaf impressions near the top of the upper division	140	...
Morrison, Greenwich clay shale, soft and fine grained.....	11	..
Dull red clay shale, soft and fine grained.....	12	..
Brown to yellow shale.....	10	..
Argillaceous limestone; numerous fine dark laminae....	..	6
Buff-colored shale.....	..	18
Argillaceous limestone; numerous fine dark laminae....	..	6
Variegated joint clay.....	18	..
Argillaceous limestone, fine grained and hard, with contorted laminae.....	2	..
Variegated shales; very soft and easily eroded.....	30	..
Red Beds, Dark shales containing irregular masses of gypsum....	15	..
Gypsum containing streaks of clay.....	..	18
Variegated shale containing nodular-like masses of gypsum which vary in size from grains to masses a foot or more in diameter. About one third of the mass is gypsum	8	..
Gypsum in well-defined layers. Often separated by layers of clay.....	25	..
Massive gypsum.....	5	..
Red gypsiferous shales, soft and regularly bedded..	30 to 40	..
Red calcareous sandstone, oolitic, cross-bedded. Individual layers variable in thickness and character. Near the top it becomes shaly and passes gradually into the gypsiferous shales above.....	60	..
Red sandstone, massive, cross-bedded.....	175 to 200	..
Red arenaceous shale.....	6	..
Red sandstone.....	1	..
Fine red shale.....	4	..
Even-bedded red sandstone.....	9	..
Red arenaceous shale.....	2	..
Red sandstone, cross-bedded; the individual layers thin out laterally.....	40	..
Poorly cemented red sandstone alternating with layers of shale.....	15	..

	Feet	Inches
Massive red sandstone.....	5	..
Soft red sandstone containing hard layers which are ripple-marked	30	..
Hard, white, argillaceous limestone composed of numerous thin layers; greatly contorted.....	4	..
Red sandstone in thin flaky layers.....	15	..
(River bottom.)		

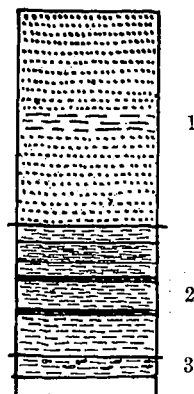


FIG. 17.—Section of the Morrison and related formations in Plum Canyon, Colorado.

1. — Purgatoire-Dakota; 2. — Morrison; 3.—Gypsum at the top of the Red Beds. Scale, 125 feet to 1 inch. (Lee.)

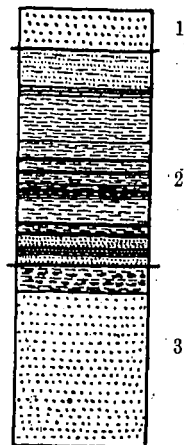


FIG. 18.—Section of the Morrison and related formations in Red Rocks Canyon, Colorado.

1.—Purgatoire; 2.—Morrison; 3.—Gypsum and Red Beds. Scale, 125 feet to 1 inch. (Lee.)

Section in Red Rocks Canyon

	Feet	Inches
Dakota (Purgatoire) sandstone.		
Brick red arenaceous shale, containing bands of hard, fine-grained sandstone.....	25	..
Reddish limestone having a conchoidal fracture and very brittle.....	3 to 5	..
Soft dark clay shale.....	30	..
Light brown clay shale.....	11	..
Argillaceous limestone.....	6	..
Brown shale.....	7	..
Concretionary limestone.....	1	..
Variegated clay shale; joint structure....	7	..
Fine yellow paper shale.....	3	..
Argillaceous limestone, finely laminated.....	6	..
Fine shale.....	18	..
White limestone.....	1	..
Variegated clay shale.....	15	..

	Feet	Inches
Argillaceous limestone, finely laminated.....	..	8
Yellow shale.....	4	..
Sandstone containing agate either in concretionary masses half an inch or more in diameter or disseminated generally throughout the mass.....	1	..
Sandstone, easily crumbling; made up of thin layers...	8	..
Massive sandstone, poorly indurated.....	2	..
Fine paper-shale.....	2	..
Massive sandstone, poorly indurated.....	7	..
Gypsum interstratified with layers of clay.....	12 to 20	..
Red sandstone (Red Beds).....

R. C. Hills (1900, 7) describes the Morrison of the Walsenberg quadrangle as follows:

"Morrison formation.—This formation aggregates about 270 feet in thickness at the southern extremity of the Greenhorn Mountains, where there is a narrow outcrop extending along the foothills a distance of about 5 miles and passing on beyond the west boundary of the quadrangle. It is also exposed along the canyons of the Cúchara and Huerfano for a distance of over 20 miles. About midway between the extremities of the Greenhorn Mountains outcrop the inclination varies from 45° to nearly vertical. The lower portion consists of about 60 feet of soft, white sandstone having a conglomerate layer at the base. This is followed by hard, shaly beds of pinkish and greenish tints, breaking into fragments with conchoidal fracture. The upper portion consists of variegated shales and clays alternating with bands of hard, fine-grained limestone, often containing vermilion-colored cherts. One band of conglomerates a few feet thick contains green pebbles. At one point the basal sandstone overlaps the Badito formation, and rests on the Archean at an angle of 15°. In the canyons of the Huerfano and Cúchara the strata have but slight inclination except where an upward bulge brings an area of the Fountain to the surface. Here the thickness of the Morrison is less than 100 feet, and corresponds to the upper, variegated part of the Greenhorn outcrop, the lower part being entirely wanting. There is still considerable doubt as to the true position of this formation in the time scale, and the assignment to the Jura-triás is therefore provisional."

In the Apishapa quadrangle the Morrison consists of blocky clay or argillite, according to Stose (1912, 7), with thin beds of limestone and some soft sandstone. The argillites are of brilliant colors, ranging from white to dark brown or red, and to green and drab. Only 120 feet of the formation is exposed in the quadrangle. Stose gives the following composite section of the upper part of the Morrison in Huerfano Canyon:

Sandstones of the Purgatoire formation.

	Feet
Variegated shale and compact argillite, green drab, and dull maroon in color, largely covered.....	37
Massive gray sandstone having ocher colored spots, with soft fine-grained chocolate colored sandstone above and red layers toward the top. Largely covered. Exact relation not known.....	58±
Greenish-gray shale and compact argillite with 6-inch beds of impure limestone and short lenses of sandstone. The limestones contain small fresh-water gastropods and lamellibranchs.....	25±
	120±

Two miles above the mouth of Jones Lake Fork there is an exposure of 100 feet of the formation. The uppermost beds at this point are covered, but there is about 30 feet of reddish shale with calcareous concretions, underlain by 8-10 feet of limestone. At the base is green argillite.

Gilbert gives the following partial section at the mouth of Jones Lake Fork (Stose, 1912, 7):

	Feet
Thin sandstone and gray shale (Purgatoire formation).	
Chocolate colored shale.....	16
Soft pale gray sandstone freckled with brown, weathering pale brown.....	10
Variegated compact blocky shale, red, chocolate, green and white, with bands of fine sandstone, some tough and brown. The lowest sandstone is a fine-grained rock freckled with pale yellow.	51

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EASTERN NEW MEXICO AND OKLAHOMA

The Morrison occurs a few miles east of Folsom, New Mexico, in the canyon of the Rio Cimarron (Lee, 1902, 5). It consists, at this point, of 25 to 50 feet of variegated clay-shales overlying the upper gypsum member of the Red Bed series. These clays thicken farther east, and 14 miles east of Folsom they are about 200 feet thick. The following section by Lee was measured at this point:

- Dakota (Purgatoire). Sandstone, massive and quartzitic, somewhat conglomeratic in places.
- Shales (Morrison). 200 feet of varicolored shales with local beds of brittle limestone and lime concretions. A coarse, loose-textured, cross-bedded sandstone occurs near the top.
- Red Beds. Deep red sandstone.

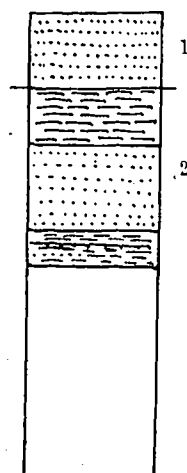


FIG. 19.—Composite section of the upper part of the Morrison formation in the Huerfano quadrangle, Colorado.

1. — Purgatoire; 2. — Morrison. Scale, 125 feet to 1 inch. (Stose.)

Still farther east, below the junction of Long Canyon and Rio Cimarron, the Morrison formation is exposed in an isolated mesa which stands in the midst of the canyon. A section at this point, measured by Lee, is as follows:

Section in Canyon of Rio Cimarron east of Long Canyon

	Feet
Dakota (Purgatoire). Sandstone, massive, quartzitic, cross-bedded, slightly conglomeratic in places. A thin seam of blue clay 100 feet from the base.....	250
Shales (Morrison). Colored shale containing layers of argillaceous sandstone and limestone.....	40
Coarse grained loose textured sandstone.....	50
Conchoidal limestone with clay and coarse sand at the base.....	10
Arenaceous shale.....	10
Conchoidal limestone....	1 to 3
Variegated shale.....	40
Argillaceous limestone....	3
Shale containing irregular seams and masses of agate-like concretions, colored in varying shades of blue and pink.....	40
Sandstone	5
Red Beds. Gypsum interbedded with clay	20
Red to purple sandstones and shales.....	..

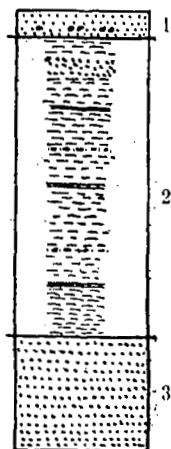


FIG. 20.—Section of the Morrison and related formations in Rio Cimarron Canyon, 14 miles east of Folsom, New Mexico.

1.—Purgatoire; 2.—Morrison; 3.—Exeter. Scale, 125 feet to 1 inch. (Lee.)

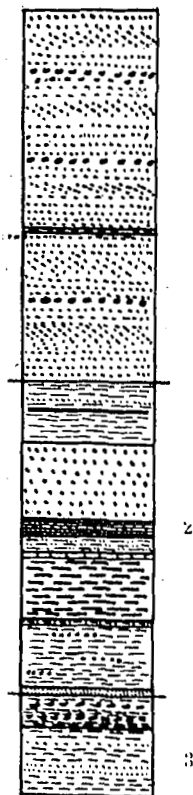


FIG. 21.—Section of the Morrison and related formations in the canyon of Rio Cimarron east of Long Canyon, New Mexico.

1.—Purgatoire-Dakota; 2.—Morrison; 3.—Red Reds and gypsum. Scale, 125 feet to 1 inch. (Lee.)

The formation was traced by Lee eastward from Folsom to a point seven miles east of the boundary between New Mexico and Oklahoma. The formation is made up, as usual, of variegated clays with minor amounts of sandstone and limestone. "All the members of this formation vary laterally in character and thickness. No two sections exhibit the same order of succession nor the same relative proportion of materials" (Lee, 1902, 5). One member which is persistent in this area is a thin bed of agate-like concretions near the base of the formation.

"In the vicinity of Exeter post-office the shales are separated from the underlying Red Beds by a well-marked unconformity. The Red Beds were thrown into gentle undulations and these undulations eroded previous to the deposition of the younger sediments upon them. Several miles west of Exeter post-office the shales rest upon the eroded edges of a local arch, from the top of which about sixty feet of the Red Beds had been removed previous to the deposition of the shales. The gypsum, which is here considered as the top of the Red Beds, appears in the flanks of the truncated arch. From this point eastward for several miles angular unconformities were noted at the top of the Red Beds" (Lee, 1902, 5).

Another section was measured by Lee a few miles east of Exeter post office. The formation is exposed on buttes and mesas in the midst of the canyon. Limestone is an important constituent of the formation at this point. The section is as follows:

Section near Exeter Post Office, in the Canyon of the Rio Cimarron

	Feet	Inches
Dakota (Purgatoire). Hard quartzitic sandstone.....	78	..
Shales (Morrison). Shale, arenaceous in places.....	10 to 15	..
Lime concretions.....	..	6
Red shale.....	8	..
Sandstone	4	..
Sandstone and shale (debris covered in places).....	50	..
Dark red shale.....	30	..
Coarse sandstone.....	4	..
Blue clay.....	2	..
Calcareous clay.....	2	..
Blue clay shale with seams of limestone.....	30	..
Hard brittle limestone.....	1	..
Shale with thin seams of limestone.....	20	..
Shale with impure limestone and sandstone bands and irregular masses of agate.....	10 to 15	..
Hard brown, nearly pure limestone.....	5	..
Unexposed	20	..
Exeter. White sandstone, massive below but passing to well de- fine layers above.....	35	..
Loose textured and readily weathering sandstone.....	8	..

	Feet	Inches
Massive chalky white sandstone, cross-bedded and cavernous weathering.....	15	..
Soft shaly sandstone.....	2	..
Massive evenly laminated sandstone, ranging in color from red at the base to white at the top.....	15	..
Red Beds. Red sandstone layers interstratified with red and purple shales

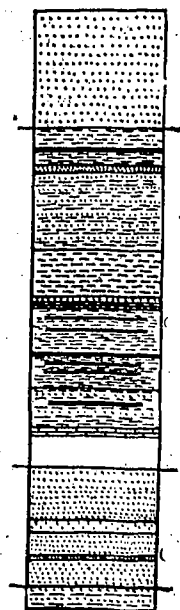


FIG. 22.—Section of the Morrison and adjacent formations in the Canyon of Rio Cimarron, near Exeter post-office, New Mexico.

1.—Purgatoire; 2.—Morrison; 3.—Exeter; 4.—Red Beds. Scale, 125 feet to 1 inch. (Lee.)

Near Exeter post office a sandstone formation appears between the Morrison and the Red Beds. It lies unconformably upon the Red Beds. It apparently underlies the Morrison conformably. It is a firm, hard and rather coarse but evenly laminated sandstone, pink to white in color. The lower members are pink, while those above are lighter colored. It has the appearance of being composed of the coarse material eroded from the Red Beds. The sandstone has a maximum thickness of 75 feet, and extends from a point several miles west of Exeter, where it thins out, eastward to the Oklahoma-New Mexico line, where it drops beneath the canyon bottom. No fossils of any kind have been found in this sandstone. It occurs in a series of nearly perpendicular cliffs, making a broad continuous band along the canyon sides (Lee, 1902, 5).

The Morrison in this locality, according to Lee (1902, 5), "rests in turn (1) upon the gypsum conformably; (2) upon the gypsum and underlying Red Beds unconformably; (3) upon the Exeter sandstone conformably." Lee also notes that the Morrison shales, as a formation, do not vary to any considerable extent in character or thickness at this locality. "Whatever may have been the physical conditions prior to the deposition of the shales [Morrison], it is evident that the shales were deposited over a well-graded surface. It follows also that there was a somewhat notable time-interval between the Red Beds and the shales. A part at least of this time-interval is represented by the unconformity between the Red Beds and the Exeter sandstone. It is uncertain whether there is a time break between the Exeter sandstone and the overlying shales. However this may be, the seeming conformity which exists in many places between the Red Beds and the shales is deceptive. The con-

tact really represents the whole time indicated by the unconformity between the Red Beds and the Exeter sandstone and the time required to form the Exeter sandstone, besides the possible period between the deposition of the Exeter and that of the shales" (1902, 5).

The Morrison formation is exposed in the canyon of the Canadian River. This river flows in a narrow gorge for fifty miles or so, then in a broad valley bordered by high escarpments. The thickness of the formation is approximately 300 feet. The beds are composed mainly of variegated clay-shales and friable sandstones. Limestones also occur in limited extent. In some localities the limestone layers are all near the top, and at others they are differently distributed. In no two sections do the limestones occur at the same horizon. The sandstones comprise a considerable part of the formation, perhaps one-third. The separate beds are in some cases firm and in others very friable. They grade from sands of pure silica to nearly pure clay. A slightly cross-bedded sandstone of considerable persistence may be seen in places near the middle of the formation. The shales contain red, brown and green members.

The contact with the overlying Purgatoire is abrupt, but without definite evidence of disconformity. A coarse, massive, pink sandstone occurs at the base. The contact with the underlying beds is sharp, but without distinct disconformity (Lee, 1902, 5).

The following section was measured by Lee, north of Bell Ranch:

<i>Section at the Escarpment north of Bell Ranch</i>		Feet
Dakota (Purgatoire). Sandstone, coarse, massive and quartzitic.....		250
Shales (Morrison). Variegated shale containing numerous thin bands of limestone and sandstone.....		50
Argillaceous fissile sandstone.....		10
Coarse sandstone.....		13
Bluish-green shale with a few bands of sandstone and impure limestone.....		45
Coarse massive sandstone.....		15
Variegated clay shale.....		12
White sandy shale.....		5
Coarse white sandstone, cross-bedded in places.....		13
Colored sandy shale.....		15
Argillaceous sandstone.....		6
Coarse sandstone containing lime concretions in places.....		15
Variegated shale containing thin layers of sandstone.....		36
Red and green shales.....		12
Poorly exposed. Shale seen at intervals.....		65
Rusty brown to red sandstone with bands of red clay..	10 to	50
?Sandstone. Massive pink to white sandstone. Forms a persistent cliff.	50 to	100
Red Beds. Friable sandstones and shales in thin layers, red to deep purple in color.....		..

MORRISON FORMATION IN WESTERN COLORADO AND EASTERN UTAH

A series of variegated clays and shales occur in many localities in western Colorado and eastern Utah, which correspond lithologically and stratigraphically with the Morrison formations east of the Rocky Mountains. The meager invertebrate fauna of these clays and sands agrees with that of the eastern Morrison, and the discovery by Riggs in 1900 of a vertebrate fauna in these beds, consisting of practically the same forms as the fauna of the eastern Morrison, proves that some part, at least, of these western clays corresponds to all or certain parts of the Morrison formation east of the Rocky Mountains.

The clays under discussion have been referred to in different localities as the Gunnison formation, McElmo formation, Flaming Gorge formation, "Lower Dakota" and "Jurassic beds." The strata included under some of these terms undoubtedly contain beds that do not correspond with any part of the eastern Morrison formation. This fact does not preclude the probability that in general these beds correspond with the eastern Morrison.

The western representatives of the Morrison formation occur in isolated areas preserved by faulting, as at Crested Butte; in hog-backs, as in the exposures east of Vernal; and in the walls of river canyons as at Grand Junction. Detailed descriptions of the formation at some of the better known localities are given below.

The following description of the Gunnison formation in the Crested Butte quadrangle is given by Eldridge (1894, 3):

In the Anthracite-Crested Butte quadrangles the Gunnison formation rests unconformably on the maroon and older formations. It consists of quartzites and shales, with a minor amount of limestone. Its thickness is from 300 to 450 feet. At the base of the formation is a heavy white

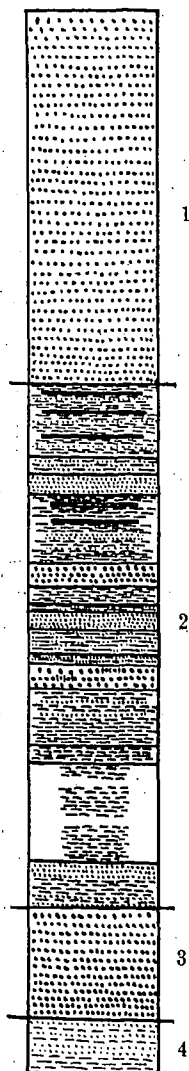


FIG. 23.—Section of the Morrison and adjacent formations in the escarpment north of Bell Ranch, New Mexico.

1.—Purgatoire - Dakota; 2.—Morrison; 3.—Exeter; 4.—Red Beds. Scale, 125 feet to 1 inch. (Lee.)

quartzite, 50 to 100 feet thick, usually in a single bed. Above this is a blue limestone, which contains shells of *Limnea*, *Valvata* and *Cypris*. In some cases this limestone is succeeded by more sandstones, and in other cases these sandstones are absent. The upper part of the formation consists of gray, drab, pink and purple clays and marls, through which run thin intermittent beds of drab limestone.

The lower part of this formation may correspond to the La Plata sandstone rather than to the McElmo or Morrison. It is quite probable, however, that most of the formation is equivalent to the latter.

This locality is about midway between the eastern front of the Rocky Mountains and the areas west of the mountains, where the Morrison has a great thickness. The presence at this point of Morrison beds of medium thickness indicates the probable former extension of the deposits across the country now occupied principally by the crystallines of the Rocky Mountains.

Peale (1877, 2) describes "Jurassic shales" in San Miguel and Dolores canyons and in the Uncompahgre Valley. The creeks tributary to the Gunnison cut through Dakota and soft "Jurassic" shales into the underlying red sandstones. The San Miguel cuts through "Jurassic shales." The following section on a creek tributary to it is given by Peale:

- 1). Upper Dakota sandstone.
- 2). Lower Jurassic shales.
- 3). Jurassic variegated beds.
- 4). Massive red sandstone, light colored.

At one point the "Jurassic shales" rest on the gneiss, according to Peale. He discusses the "Jurassic shales" as follows: "Immediately above the red beds is a group of shales and marls, with thin bands of limestone near the base. These beds are variegated in color, and correspond, lithologically and stratigraphically with the beds that, in eastern and central Colorado, I referred to the Jura. . . . They appear to correspond closely with the beds measured in the section on the Gunnison in 1874."

The Gunnison formation of Eldridge was divided by Cross in the Telluride folio into two formations, the La Plata formation corresponding to the lower part of the Gunnison formation of the Crested Butte section, and the McElmo formation corresponding to the upper part of the original Gunnison. The McElmo corresponds much more closely with the eastern Morrison than the La Plata, but in some localities it is difficult to separate the La Plata from the McElmo, and it is possible that some portions of the La Plata are represented in the eastern Morrison.

In the present discussion the McElmo will be considered as related to the eastern Morrison formation. The following descriptions are from Cross (1899, 3) in the Telluride folio of the United States Geological Survey:

The McElmo or Morrison formation in the Telluride quadrangle is a variable series of shales and sandstones, with the latter more prominent than is usual in this formation. The thickness varies from 650 to 900 feet. The sandstones are generally fine-grained, quartzose, yellow or gray, and usually friable. Some of the sandstone beds are massive and reach a thickness of 50 feet. More often they are separated by shale layers. Cross-bedding occurs in some of the sandstones. Many of the sandstones contain small flat flakes of green shale.

The shales or clays are reddish or greenish, or a mixture of both colors. They are generally calcareous and sandy. Sandstone layers occur in the shale. In following the formation along the walls of the San Miguel Canyon a shale stratum may be found to change, within a short distance, to an alternation of sandstone and shale. The reverse change often occurs in the case of sandstone beds.

At the base of the McElmo in this area is a highly colored shale resting on the La Plata sandstone.

The following is a typical section of the McElmo formation in the Telluride area:

	Feet
Shale	11
Sandstone, rather fine grained.....	22
Shale, sandy, with many thin layers of fine-grained sandstone.....	53
Sandstone, coarse, grading into conglomerate of quartz and chert pebbles at base.....	24
Shale, dull red or green, with subordinate thin bands of very fine-grained calcareous sandstone.....	155
Sandstone, coarse grained, cross-bedded.....	48
Shale	11
Sandstone, massive.....	16
Shale, red, with thin sandstone layers.....	53
Sandstone, white.....	11
Shale, red, with thin sandstone layers.....	20
Sandstone, white, cross-bedded.....	22
Alternating red shale and gray sandstone.....	85
Sandstone, massive in lower part, but with thin red shale partings above.	80
Shale, sandy.....	32
Sandstone	8
Shale, sandy, chocolate colored in upper part, thin layers of sandstone in upper part.....	64
Total.....	724

"Other sections show many changes in the relative development of sandstone and shale at any given horizon. The conglomerate, number 14 of section, is similar to the Dakota in character, but is very variable in development. Holmes noted the presence of a conglomerate near the top of his 'Lower' Dakota in the plateau country westward, and sporadic developments of the same in the Morrison beds may be seen in various places at the base of the Front Range." Owing to the similarity of the McElmo beds with the Dakota on the one hand and the La Plata on the other, it is difficult to determine the exact upper and lower boundaries of the formation.

The Morrison (McElmo) in the Rico quadrangle, according to Cross (1905, 10), is 500 feet or less in thickness. It is composed largely of shales at this point, usually of apple green or dark red color, occasionally variegated red or green. The shales alternate with sandstones in varying proportions. The sandstones are white, even grained, and friable; they often grade laterally into sandy shale and finally into clay shale.

In the Ouray quadrangle, the Morrison (McElmo) beds are described by Cross and Howe (1907, 6) as a series of alternating shales and sandstones, which vary in thickness and character. The average thickness in this district is from 500 to 700 feet, the maximum being about 800 feet. The shales are varied in color. Green predominates, but in the lower beds reds and browns are conspicuous. Many of the shale beds are fine-grained and porcelain-like, but usually they contain sand. Sandstones are numerous, and are usually quartzose, fine-grained, gray and friable. They vary considerably in thickness in short distances, and often show transition to shale or clay beds. The separate sandstone layers seldom exceed 20 feet in thickness.

The following section of the Morrison (McElmo) formation is given by Cross and Howe for a locality south of Dexter Creek in the Ouray quadrangle:

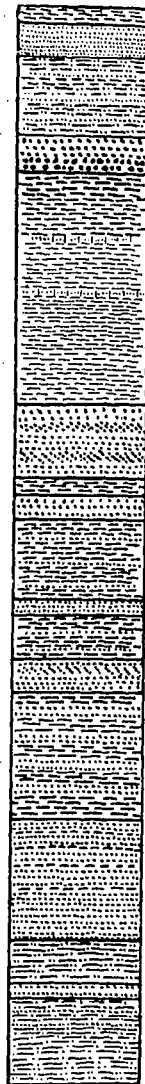


FIG. 24.—Section of the Morrison formation in the Telluride quadrangle, Colorado.

Scale, 125 feet to 1 inch.
(Cross.)

	Feet
Shales, slaty, black, alternating with shaly bituminous sandstone; individual layers less than 2 feet thick.....	16
Sandstones, yellowish or greenish, with shaly layers.....	14
Quartzite, dense, gray.....	6
Shales, sandy, black; and fine-grained sandstones, largely quartzitic, thin bedded	23
Quartzite, hard, white.....	20
Sandstone, friable, white, containing clay.....	10
Porcelain shales and thin argillaceous sandstones.....	21
Shales, fine-grained near top, dense, porcelain-like below, with sandy layers	42
Quartzite, massive, white, more friable below, with thin clay layers near base	5
Sandstone, coarse, white, lower portion indurated and containing a 2-foot shale layer.....	13
Shale, green, with some purple and gray layers, very fine grained, much of it hard like porcelain; some sandy layers, more numerous near base; dark red; rests upon 5 feet of very white and massive porcelain shales.	50
Shale, red, sandy and containing shaly sandstone.....	16
Green and red porcelain shales and sandstones with a 2-foot pink, fine-grained limestone at the top.....	78
Sandstone, massive, green above, white below.....	9
Sandy shales and shaly sandstones, green, white and red.....	69
Sandstone, white, saccharoidal.....	20
Sandstones and sandy shales, with some porcelain layers, red and green..	26
Sandstone, massive, fine-grained, gray, white.....	16
Sandy shale and sandstone, alternating green and red.....	20
Sandstone, fine, greenish white, becoming red and shaly below.....	17
Sandstone, extremely massive, white; red stains from shales above; quartzite in lower part and a thin green shaly layer near base.....	70
Sandstones, with thin limestones and calcareous shaly layers; some reds and pinks, prevailing colors buffs and yellows.....	120
Sandstones, heavy bedded, saccharoidal.....	11
Shale and thinly bedded buff sandstone.....	10
Quartzite, light colored, with bluish stains.....	18
Sandstones and shales, red.....	65

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La Plata sandstone.

In the La Plata quadrangle the Morrison (McElmo) is described by Cross, Spencer and Purington (1899, 4) as a series of alternating shales and sandstones, from 400 to 500 feet thick. The sandstones are usually characterized by the presence of green shale flakes; 50 or 60 feet below the top of the formation, there is a bed of coarse white conglomerate separated from the "Dakota" by a series of red and green shaly beds. The conglomerate contains white and dark quartz pebbles, and is 10 to 15 feet thick.

The Morrison (McElmo) formation is described by Cross (1910, 4) in the Engineer Mountain quadrangle, as follows:

"In the Engineer Mountain quadrangle the McElmo has a thickness of 400 to 500 feet. It is here composed more largely of shale than in the Telluride quadrangle, where its thickness on the San Miguel River is nearly 1000 feet and where sandstone forms its most important element. Shale and sandstone alternate in the formation in variable proportions. The beds of shale as a rule are colored some shade of green, but are locally pink or deep Indian red, and they include some variegated red and green bands. The shales are fine grained and sandy and occur in homogeneous bands, in places several feet thick, with little or no distinct lamination. The sandstones are fine and even grained and friable in texture; those of the lower portion resemble the La Plata sandstone, and at least one of the upper beds is very similar to the Dakota sandstone. The arenaceous layers are white or yellowish and locally grade horizontally and vertically into sandy shale and thence into clay shale. In the upper part of section there is a fine-grained conglomerate which is practically identical with the lowest conglomerate of the Dakota. The large number of crumbling beds in the formation cause numerous gaps in all discovered exposures, and no detailed section can be given."

GRAND RIVER AREA

The Morrison (McElmo) formation is well exposed along the Grand River, from its junction with the Gunnison River westward into eastern Utah. For some distance east of the junction with the Gunnison River it is also exposed in the walls of the canyon of the Grand River. West of Grand Junction, the beds are exposed on the south side of the river only. The exposures are usually several miles south of the river, and occur partly in the high cliff which forms the northern boundary



FIG. 25. -Section of the Morrison formation on Dexter Creek, Rico quadrangle, Colorado.
Scale, 125 feet to 1 inch.
(Cross.)

of the Uncompahgre Plateau, and partly in a lower southward facing cliff a short distance farther north.

A short distance west of Mack the river turns sharply to the south, and cuts across the formations, giving complete sections of several of the formations.

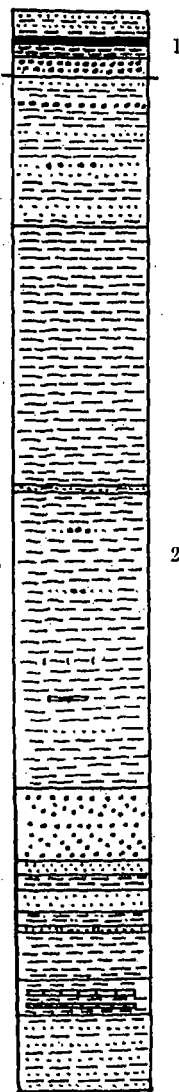
Riggs (1901, 4) describes the Morrison (McElmo) beds near Fruita as a series of four principal members, aggregating 600 to 700 feet in thickness. The lowest of the four he assigns to a marine origin. It is 100 to 120 feet in thickness, consisting of bluish-gray, gypsum-bearing clays, with thin layers of fine-grained sandstone, and very thin layers of nodular limestone. This division grades into the second, which he assigns to a fresh-water origin. The second division contains no limestone, and consists largely of homogeneous and massive clays. A ledge of fine-grained sandstone occurs near the base. The second division is about 100 feet thick, and consists of greenish clay shale, containing occasional ledges of green sandstone and a few layers of clay nodules. Conspicuous banding is not present. The third division consists of a darker zone containing frequent ledges of cross-bedded sandstone. This series is 40 to 50 feet thick. The sandstones vary from fine-grained to coarse-grained, and from thin layers to massive layers. They are often rich in iron and brown in color. In places this division is entirely absent. The fourth division consists of variegated clays 300 feet or more in thickness, characterized by brilliant coloring and conspicuous banding. "The alternation between green and purplish bands does not mark any variation in the nature of hardness of these massive joint clays." Thin layers of calcareous nodules and sandstones occur. Nodular gray sandstone and thick ledges of cross-bedded sandstone, and lenticular masses of sandstone occur locally.

Lee (1912, 6) has described the Morrison (McElmo) beds in the Grand River region as a variegated sandstone and shale formation lying between the red beds and the Cretaceous beds. The formation here has a thickness of 682 feet. The upper limit is marked by an erosional unconformity. The formation is divisible into two general divisions which are distinct lithologically, but still represent continuous deposition. The lower member [Nos. 9-17 in section] consists principally of even-bedded flaggy sandstone. This is the series Riggs referred to as the marine Jurassic. It contains some limestone. The upper member [Nos. 5-8 in section] consists principally of variegated shale with a coarse conglomerate near the top.

The following section of the Morrison (McElmo or Gunnison) formation is given by Lee:

Section of Rocks exposed in Gunnison Canyon at the Mouth of Wells Gulch

	Feet
1. Sandstone in thin flinty layers separated by dark colored shale.....	20
2. Coal	3
3. Shale, carbonaceous.....	8
4. Conglomerate, quartzitic, gray to buff (Dakota)	15
[Base of Dakota and top of Morrison.]	
5. Sandstone, conglomeratic, with beds of variegated shale. The conglomerate contains many pebbles of quartz and jasper.....	100
6. Shale, variegated.....	175
7. Sandstone, white, argillaceous.....	25
8. Shale, soft, variegated; contains pockets filled with pebbles of jasper, chert, argillite, etc.; also globular lenticular bodies of pink to red calcite, having a maximum diameter of 5 feet.....	200
9. Sandstone, gray, coarse-grained, cross-bedded.	50
10. Sandstone, brown, massive.....	8
11. Shale, pink.....	10
12. Sandstone, brown, massive.....	15
13. Shale, sandy.....	10
14. Sandstone, flinty.....	4
15. Shale, variegated.....	30
16. Shale and limestone, evenly bedded.....	25
17. Shale and sandstone in thin regularly bedded layers	50
Unconformity by erosion.	
18. Sandstone (red beds).....	(?)
	728



The Morrison (McElmo) formation is very well exposed a few miles southwest of Mack, where the Grand River makes a sharp turn and where a tributary cuts directly across the strata. The bend in the river cuts directly across a large monoclinical fold, exposing the underlying beds. Good exposures occur for considerable distances, and it is possible to make a complete section of the formation at a number of points. The chief characteristic of the formation in this district is the presence of a number of heavy, white, cross-bedded sandstones, which stand out as prominent ledges. Sandstones

FIG. 26.—Section of the Morrison formation in Gunnison Canyon at the mouth of Wells Gulch, Colorado.

1.—Dakota; 2.—Morrison. Scale, 125 feet to 1 inch. (Lee.)



FIG. 27.—Morrison formation south of Grand Junction, Colorado, looking west.



FIG. 28.—Grand Mesa, south of Grand Junction, Colorado, looking south. Morrison outcrops in the foreground.



FIG. 29.—Morrison formation south of Grand Junction, Colorado, looking north.

are especially characteristic of the lower portion of the formation, but heavy beds occur at intervals up to the top. A bed of limestone 2 feet thick is also present in the lower portion. The following section was measured by the writer in 1914:

Section of McElmo Formation near Mack, Colorado

	Feet
33. Dark, arkosic sandstone, taken as base of the "Dakota".....	2
32. Clay	34 e.
31. Sandstone	3
30. Covered	5
29. Cross-bedded white sandstone.....	11
28. Clay	40
27. Cross-bedded white sandstone.....	11
26. Clay	9
25. Lumpy clay.....	1
24. Variegated clays.....	52
23. White sandstone of varying size of grain.....	3
22. Green sandstone, in places conglomeratic.....	2
21. Clay, greenish at top.....	16
20. b. Sandstone	3
a. White clay.....	9

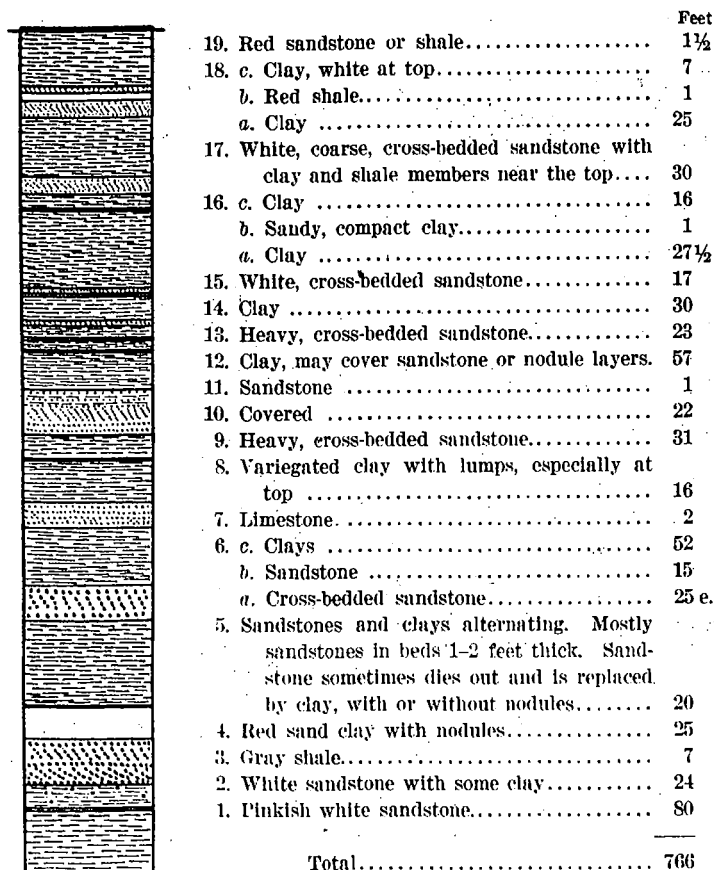


FIG. 30.—Section of the Morrison formation near Muck, Colorado.

The overlying formation is the "Dakota," and the underlying is the La Plata sandstone. Scale, 125 feet to 1 inch. (Section by the writer.)

The Morrison is underlain by the La Plata sandstone in most of the southwestern Colorado areas, with apparent conformity. Beneath the La Plata, which is Jurassic in age, there is a well marked stratigraphic break. At different localities the La Plata lies upon the Dolores beds, of Triassic age, upon the Cutler and Hermosa formations, of late Paleozoic age, and upon pre-Cambrian crystallines (Cross and Larsen, 1914, 1).

The McElmo formation near Green River, Utah, has been recently described by Lupton (1914, 3). It is from 1000 to 1200 feet thick at this place. Marine fossils in the lower part indicate, however, that part of the beds included in Lupton's section may belong to the underlying Jurassic beds.

The section is as follows:

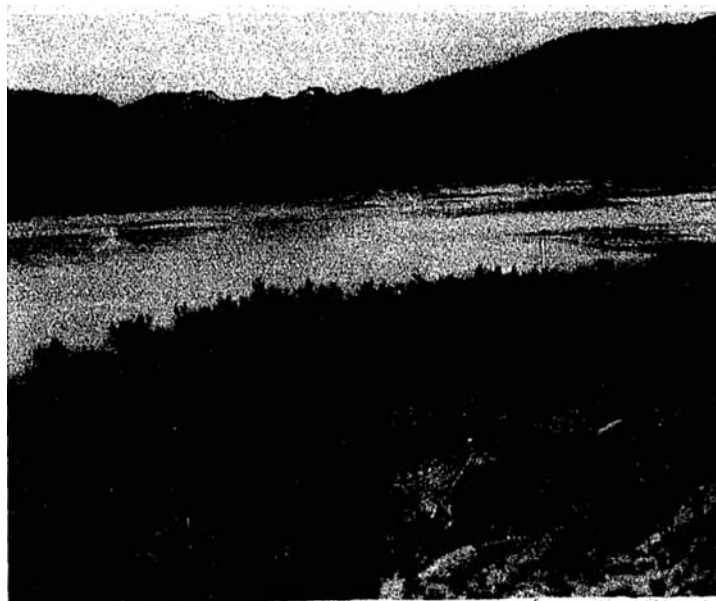


FIG. 31.—Monoclinial fold near Mack, Colorado.

The Morrison beds are seen to the left, resting on the La Plata sandstone in the center.

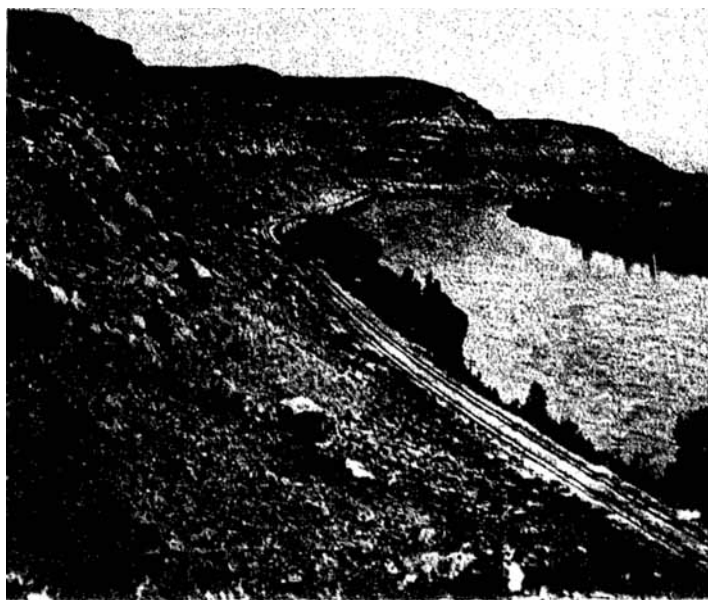


FIG. 32.—Outcrop of the Morrison formation near Mack, Colorado.

The section shown in fig. 30 was taken at this point.

	Feet	Inches
Sandstone, gray, weathers brown; contains clay-ball concretions in places.....	8	..
Clay, bluish gray; contains a little limestone about 5 feet below top	28	6
Clay, brick red, gray and purplish, sandy; contains several thin beds of gray to white sandstone.....	116	..
Sandstone, gray; weathers brown; indurated at base, conglomeratic and quartzitic in places, lenticular.....	5	..
Clay, brick red, sandy.....	52	..
Sandstone, brick red, massive.....	14	..
Clay, brick red, sandy.....	12	..
Sandstone, gray, conglomeratic; contains some interbedded gray sandy shale.....	58	..
Sandstone, reddish, calcareous.....	17	..
Sandstone, gray to white, soft, cross-bedded in places.....	10	..
Sandstone, red and gray, soft, calcareous.....	42	..
Sandstone, gray to white, soft, massive; contains a little argillaceous material.....	37	..
Sandstone, grayish brown, interbedded with gray and reddish calcareous and argillaceous sandstone.....	27	..
Sandstone, white, weathers reddish brown.....	12	..
Sandstone, red with streaks of green, calcareous.....	20	..
Sandstone, grayish brown, with calcareous layers.....	50	..
Sandstone, brown.....	2	..
Sandstone, calcareous.....	5	..
Sandstone, grayish brown, medium bedded.....	4	..
Sandstone, red below and gray above, very calcareous; contains many small nodules.....	40	..
Sandstone, brick red, thin and medium bedded. This sandstone is believed to be calcareous. It bears manganese ore in the upper part.....	128	..
Sandstone, red, massive.....	400±	..
	1,087½	

NORTHEASTERN UTAH AND NORTHWESTERN COLORADO

The Flaming Gorge formations in northwestern Colorado and northeastern Utah have been described by H. S. Gale (1910, 6) as dark-greenish shales and sandstones, with fossils. Above the fossiliferous beds are 75 feet of dark thin-bedded, ripple-marked sandstone. This part of the Flaming Gorge represents the marine Jurassic which is characteristically represented in Wyoming by the Sundance formation. Above the marine beds are 650 feet of varicolored beds, usually of light pink and green. The Carnegie Museum of Pittsburgh has been operating a dinosaur quarry in these beds near Jensen, Utah. The beds in this vicinity are largely dark colored variegated clays, with interspersed layers of

coarse sandstone of moderate thickness. The sandstones are resistant to erosion, and the beds dip steeply toward the west. The sandstones cap ridges underlain by the softer clays, making a series of parallel or con-

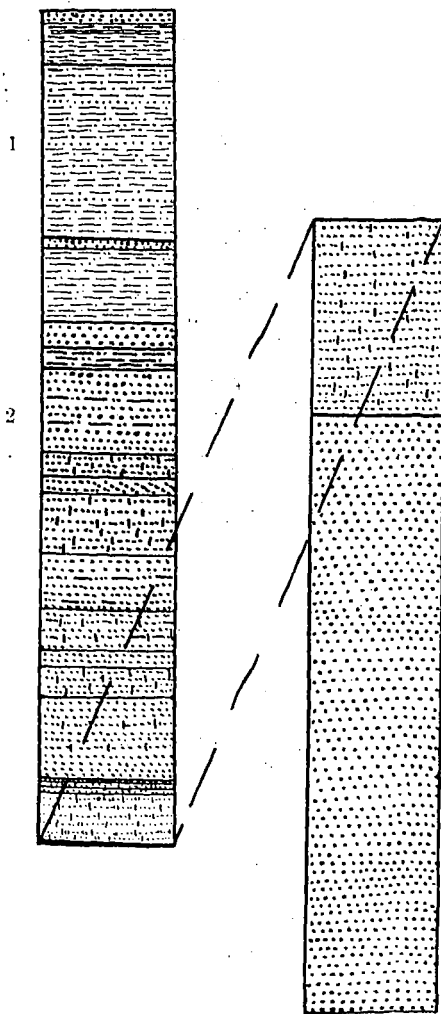


FIG. 33.—Section of the McElmo formation near Green River, Utah.

This section probably includes more than Morrison, as marine Jurassic fossils have been found in the base. Scale, 125 feet to 1 inch. (Lupton.)

centric hog-backs, the outer one of which is capped by the "Dakota" sandstone. The contact of the marine and non-marine beds is obscure and difficult to determine at the site of the Carnegie Museum's quarry.



FIG. 34.—Outcrop of the Morrison formation near Jensen, Utah.

MORRISON FORMATION IN MONTANA AND WYOMING (EXCEPT THE BLACK HILLS AREA)

CENTRAL AND SOUTHERN MONTANA

The Morrison formation has not been mapped or described from many localities in Montana. It occurs in the Great Falls coal field and neighboring localities and around the northern end of the Bighorn Mountains. It probably occurs elsewhere, but either has not been mapped, has not been separated from the Kootenie, or is buried beneath younger formations. The relation of the Kootenie to the Morrison, and its lithological similarity, may possibly indicate that the Kootenie may be in part equivalent to some parts of the Morrison.

The Morrison occurs in the Electric coal field, and has been described by Calvert (1912, 2). Calvert gives the following section:

	Feet	Inches
Sandstone, brownish, soft, capped by 1 foot of intrusive.....	23	
Shale, variegated, and sandstone, alternating, the latter reddish brown	65	
Intrusive		
Shale, purplish and maroon, alternating with thin reddish-brown sandstone	79	

	Feet	Inches
Sandstones, thin, and sandy shale, with 2 feet of brown sandstone at top.....	18	..
	185+	8

The Morrison in this locality lies over the Ellis limestone, corresponding to the Sundance beds of Wyoming. There is a break below the Ellis, indicating an erosion period of considerable length.

In the Great Falls region the Morrison has been described by Fisher (1907, 3; 1909, 11; 1909, 13). He gives the following brief description of the outcrops of the Morrison: "The formation is generally exposed in a narrow band on the inner rim of a low ridge formed by the harder overlying rocks of the Kootenie formation. It outcrops all along the base of the Little Belt Mountains from the east end of the district to Smith River. Good exposures occur along the upper courses of Sage, Skull, Running Wolf, Hazlett, Surprise, Geyser, and Otter creeks, and in the bluffs for some distance back from the mountains along Belt Creek, Sand Coulee, Smith River and its tributary, Ming Coulee." The Morrison rests with apparent conformity on the Ellis formation, which in turn rests unconformably on Carboniferous beds. The Kootenie overlies the Morrison conformably.

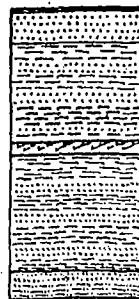


FIG. 35.—Section of the Morrison formation in the Electric Coal Field, Montana.

Scale, 125 feet to 1 inch. (Calvert.)

Fisher gives the following sections:

Section of the Morrison Formation on the east side of Belt Creek, Montana, in N. E. ¼ Sec. 30, T. 18 N., R. 7 E.

	Feet
Gray, thin-bedded sandstone.....	17
Pebbly conglomerate occurring in lenses.....	5
Maroon and green shale.....	52
Green shale capped by 1½ feet of gray sandstone.....	5
Calcareous sandstone, weathering light brown.....	5
Green shale.....	20
Massive sandstone, weathering light brown.....	7
Dark-green shale containing thin limestone layers.....	9

120

Ellis formation.

*Section of the Morrison Formation in the N. E. $\frac{1}{4}$ Sec. 3, T. 16 N., R. 10 E.,
near Shannon Creek, Montana*

	Feet	Inches
Kootenie formation.		
Beds concealed.....	20 ⁺	..
Shales, red and green, containing ironstone layers at base.....	46	..
Limestone, light colored, fossiliferous.....	5	..
Shale, green, sandy, fossiliferous.....	25	..
Limestone, white, fine-grained, thin-bedded.....	..	6
Shale, green, sandy.....	13	..
	109	6



FIG. 36.—Section of the Morrison formation on Belt Creek, Montana.

Scale, 125 feet to 1 inch. (Fisher.)

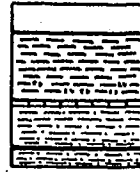


FIG. 37.—Section of the Morrison formation near Shannon Creek, Montana.

Scale, 125 feet to 1 inch. (Fisher.)

BIGHORN MOUNTAINS

The Morrison formation is exposed along the eastern, northern and western sides of the Bighorn Mountains. The following description is taken largely from Darton (1906, 2).

The band of outcrops is almost a continuous one, except in a few localities where it is overlain by Tertiary deposits. Owing to the softness of the material of the formation, most of the outcrops are poor and are often covered with talus.

The thickness of the formation varies from 100 to 250 feet. West of Greub it is 160 feet, southwest of Buffalo 250 feet, northwest of Buffalo 150 feet, on Little Rapid Creek it is 200 feet, on Wolf Creek less than 100 feet, on Little Tongue River 120 feet, on Amsden Creek 150 feet, and about 150 feet or a little less on the northeastern side of the mountains in Montana. There is a considerable variation on the southeast side of the mountains. East of Barnum it is about 150 feet, east of Houck's 100 feet, near Griggs 200 feet, on the uplift south of Tisdell's ranch it is 250 feet. In the vicinity of Tensleep it is about 250 feet. On Alkali Creek, north of Cloverly, it is 282 feet, and in the region of Thermopolis, 120 to 130 feet.

Near Cloverly, where the dip is low, the outcrops cover large areas. In most localities the Morrison occupies a low saddle between the slopes

of the Chugwater-Sundance ridge on the one hand and the hog-back of the Cloverly on the other.

The formation is mostly made up of hard clay or massive shale, varying in color from pale greenish to maroon, with darker clay at its summit. Several beds of light gray sandstone 2 to 20 feet thick are usually included. "These sandstones are usually soft, and on weathering exhibit thin, irregular bedding planes which generally have a peculiar wavy surface suggestive of incipient cross-bedding." There is apparently a conformable contact between the Morrison and Sundance beds. *In the East*

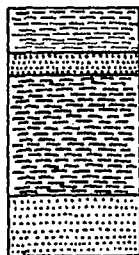


FIG. 38.—Section of the Morrison formation on South Fork of Rock Creek, northwest of Buffalo, Wyoming.

Scale, 125 feet to 1 inch. (Darton.)

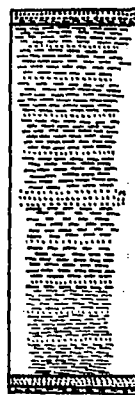


FIG. 39.—Section of the Morrison formation on the south side of Muddy Creek, southwest of Buffalo, Wyoming.

Scale, 125 feet to 1 inch. (Darton.)

hollow south of South Fork of Rock Creek, northwest of Buffalo, the base of the Morrison consists of 40 feet of soft greenish-gray and pale-buff sandstones; then 80 feet of clays, 15 feet of the typical sandstone above described, and at the top 30 feet of clays, maroon, buff and greenish below and dark above. A mile south of Muddy Creek, southwest of Buffalo, there is an exceptionally good outcrop of the Morrison formation. It exhibits at the top 10 feet of reddish shale which grades down into dark shale, followed by 240 feet of hard, chalky clays of maroon and green color. This series of clays contains occasional thin sandstone partings, and one bed 6 feet thick near the middle. This bed is hard, light-colored, and weathers in thin beds with irregular wavy surface. Near the base of the series the clay is red. Next below is an 8-foot bed of white sandstone. Below this sandstone and resting on the Sundance beds are a few feet of soft gray and buff sandstones. On Little Poison Creek

the characters are very similar to those on Muddy Creek. A mile north of Middle Fork of Crazy Woman Creek the section is as follows:

	Feet
Chalky clays, light green above, maroon below.....	80
Grayish-buff sandstone containing plants and saurian bones.....	6 to 12
Maroon and light green chalky clays with thin sandstone layers.....	70
White soft massive sandstone resembling the Unkpapa of the Black Hills region	12 to 15
Greenish sandy clays (may belong to the Sundance formation).....	20

188 to 197

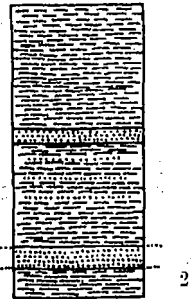


FIG. 40.—Section of the Morrison formation north of Middle Fork of Crazy Woman Creek, Wyoming.

1.—Morrison formation; 2.—Sundance formation. Scale, 125 feet to 1 inch. (Darton.)

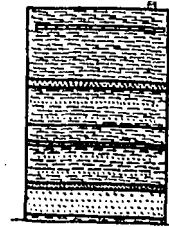


FIG. 41.—Section of the Morrison formation near Beaver Creek, Wyoming.

Scale, 125 feet to 1 inch. (Darton.)

Near Beaver Creek the section is as follows:

	Feet
Light green to maroon chalky clays containing a 2-foot bed of limestone 10 feet below the top.....	50
Sandstone	4
Clays, in part maroon.....	25
Sandstone [thickness not given, probably very thin].	
Shale	10
Limestone with no fossils.....	1½
Red to maroon clays with thin sandstone layers.....	25
Thin-bedded sandstone.....	2
Soft, massive, white sandstone.....	20
Clays (a few feet).	

137½ ft

South of Fort C. F. Smith, Montana, the following section occurs:

	Feet
Greenish-gray sandy shale, upper part soft (unconformably overlain by Cloverly sandstone).....	18
Buff sandstone.....	3

	Feet
Massive gray sandstone.....	20
Variegated shale; pale red and green tints.....	75
Light colored, fine-grained, soft sandstone lying on brown sandstone of the Sundance formation.....	25
	<hr/> 143

The section near Tensleep is as follows:

	Feet
Gray shale capped by Cloverly sandstone....	40
Greenish-gray clays.....	100
Maroon to red clays.....	50
Sandstone	58
Greenish-gray to reddish sandy shale.....	50
	<hr/> 298

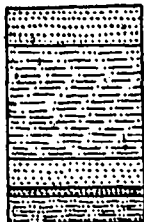
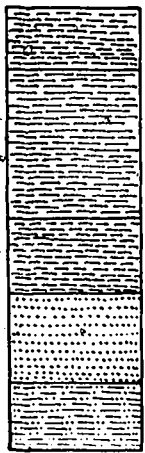



FIG. 42.—Section of the Morrison formation south of Fort C. F. Smith, Montana.

Scale, 125 feet to 1 inch. (Darton.)

FIG. 43.—Section of the Morrison formation near Tensleep, Wyoming.

Scale, 125 feet to 1 inch. (Darton.)

The following is a typical section of the Morrison on Alkali Creek:

	Feet
Pale green massive shale (overlain by Cloverly sandstone).....	50
Thin-bedded gray sandstone, brown on surface.....	15
Pale green massive shale.....	5
Blue-black shale.....	10
Maroon massive shale.....	10
Variegated massive shale.....	45
Thin-bedded gray sandstone.....	6
Variegated massive shale, drab, purple and maroon.....	65
Pale green to white sandstone.....	6
Pale green and maroon massive shale.....	85
Pale green massive sandstone.....	45
Red sandy shale (lying on the Sundance formation).....	40
	<hr/> 382

North of Thermopolis the formation contains, near its middle, a massive fine-grained, soft, greenish-gray sandstone 50 feet or more in

thickness. Above this are 400 feet of sandy shales, some dark maroon in color, then 10 feet of very dark conglomerate loosely cemented, and at the top about 10 feet of highly carbonaceous shale merging into dirty-buff clay.

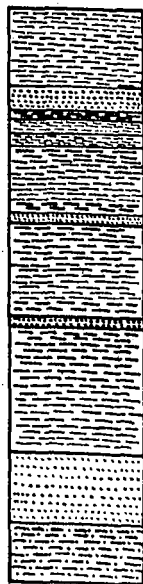


FIG. 44.—Section of the Morrison formation on Alkali Creek, Wyoming.

Scale, 125 feet to 1 inch. (Darton.)

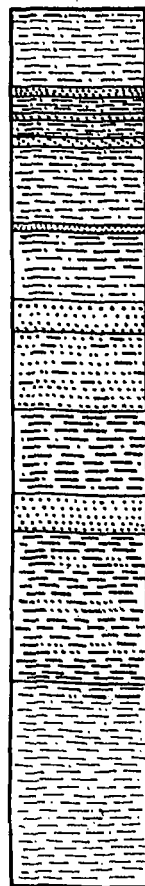


FIG. 45.—Section of the Morrison formation on the Shoshone River, Wyoming.

Scale, 125 feet to 1 inch. (Hewett.)

SHOSHONE RIVER REGION

The following section of the Morrison formation was made by Hewett, on the Shoshone River, Wyoming (1914, 2):

	Feet
Shale, maroon and gray, sandy.....	50
Sandstone, buff.....	6
Shale, gray, sandy.....	12
Sandstone, buff.....	4
Shale, gray, sandy.....	10
Sandstone, buff, cross-bedded.....	8
Clay, gray, sandy.....	50

	Feet
Sandstone, buff, fine-grained, evenly bedded and ripple-marked.....	6
Clay, maroon and yellow, sandy.....	44
Clay, dark brown to black, containing saurian vertebrae, limb bones, and gastroliths	20
Sand, gray, argillaceous, only locally indurated, containing wood silicified in places, as well as rounded pebbles of similar material; carbonized plant remains and small calcareous concretions.....	50
Clay, maroon, sandy.....	55
Sandstone, white, homogeneous, only locally indurated.....	25
Clay, prevailing gray and olive colored, but with three broad maroon bands, sandy.....	100
Shale, green sandy, transitional to upper sandstone of the Sundance formation	140
	<hr/> 580

CENTRAL AND SOUTHERN WYOMING

C. A. Fisher (1906, 4) describes the Morrison formation in the Absaroka and Owl Creek Mountain regions as follows:

"Along the western side of the basin [Bighorn] the Morrison formation is about 150 feet thick. It consists of alternating layers of gray fine-grained sandstone and dark-gray sandy shale. Near the base there is often a thin bed of gray limestone. In one locality near the southern end of the Cedar Mountain anticline a deposit of gypsum 8 feet thick was observed near the top of the formation." Fisher gives the following sections:

Section of Morrison Formation on Trail Creek, northwest of Cody, Wyoming

	Feet
Cloverly formation.	
Green, sandy shales alternating with green clay containing thin layers of gray limestone throughout.....	100
Massive, fine-grained gray sandstone lying on Sundance formation.....	30
	<hr/> 130

Generalized Section of Morrison Formation south of Clark Fork Canyon, Wyoming

	Feet
Cloverly formation.	
Massive greenish-gray sandstone.....	80
Greenish clay.....	60
Dark gray limestone.....	1
Dark gray sandy shale lying on Sundance formation.....	20
	<hr/> 161

Section of Morrison Formation near Watson's Ranch, on Embar Road, just north of Owl Creek, Wyoming

	Feet
Massive gray sandstone.....	10
Concealed material, evidently soft and sandy.....	125

135

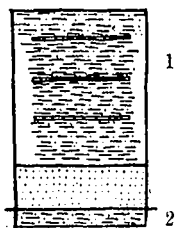


FIG. 46.—Section of the Morrison formation on Trull Creek, northwest of Cody, Wyoming.

1.—Morrison formation; 2.—Sundance formation. Scale, 125 feet to 1 inch. (Fisher.)

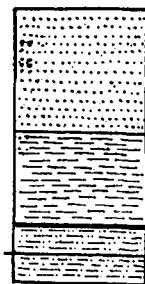


FIG. 47.—Section of the Morrison formation south of Clark Fork Canyon, Wyoming.

Scale, 125 feet to 1 inch. (Fisher.)

The following section of the Morrison formation in the Douglas oil and gas field, Wyoming, is given by Barnett (1914, 1):

Section of the Morrison and Sundance Formations in east bluff of North Platte River, in Sec. 9, T. 31 N., R. 71 W.

	Feet
Morrison formation:	
Shale, blue and red, with a 6-foot carbonaceous shale near top.....	180
Limestone, compact, fossiliferous.....	3
Sundance formation:	
Shale, blue and pink, calcareous and sandy, fossiliferous in lower part	60
Sandstone	10
Shale, bluish gray, with few bands of sandstone.....	60
Sandstone	12
Shale, bluish gray, sandy.....	30
Sandstone, gray, heavy bedded.....	75
	430

In central and southern Wyoming the Morrison formation has been well described by Darton (1908, 1). The formation outcrops along the eastern border of the Wind River Mountains, along both sides of the Owl Creek Mountains, on the north side of the Rattlesnake Mountains, in the Shirley and Freezeout Hills, south of Casper and Douglas and east of Medicine Bow and Rock Creek. It also occurs near Sheep Mountain,

east of Jelm, and in the Centennial Valley. Outcrops occur on both the east and west sides of the Laramie Mountains. In the vicinity of Lander, the thickness of the formation is 225 feet, consisting mainly of pale green to maroon massive shales, with thin beds of sandstone. Near Fort Washakie it is 200 feet thick, and has a 4-foot sandstone bed near the middle. The thickness in the Owl Creek region varies from 100 to 250 feet, in general diminishing from east to west. In this region the formation consists principally of pale green sandy shale, with some darker tints. A thick bed of soft sandstone usually occupies the central portion. "In extensive exposures on the east side of

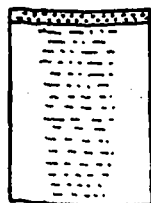


FIG. 48.—Section of the Morrison formation near Watson's ranch on Embar road just north of Owl Creek, Wyoming.

Scale, 125 feet to 1 inch. (Fisher.)

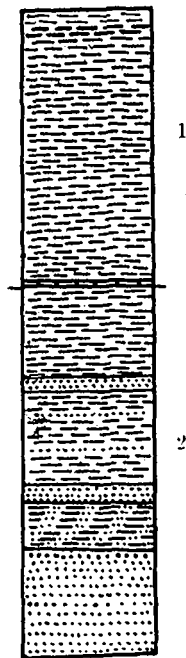


FIG. 49.—Section of the Morrison and Sundance formations in east bluff of North Platte River, in sec. 9, T. 31 N., R. 71 W., Wyoming.

Scale, 125 feet to 1 inch. (Barnett.)

Red Creek, 3 miles east of the summit of Black Mountain, the formation is about 150 feet thick." Darton gives the following section at this point:

	Feet
At the top, soft massive sandstones, mainly of buff color, also pink, lying on red and maroon clays.....	50
Red sandy clays, with a few sandstone layers from 6 inches to a foot thick	50
Massive sandy clays of alternating bands of gray and maroon.....	50
	150

The Morrison formation is well exposed in the vicinity of Medicine Bow. In Como Bluff, a few miles east of this place, a good series of outcrops occur, while on the opposite side of the anticline of which it forms the southern limb, another series of outcrops are less well exposed.

Dinosaur remains have been found in great abundance in this region, and a number of very productive bone quarries have been opened. The following section of Como Bluff is given by Darton:

	Feet
White, massive sandstone, conglomeratic (Cloverly).....	
Bluish to greenish shales.....	50
Limestone, lumpy.....	1
Bluish to olive green shales.....	30
Limestone, lumpy.....	1
Blue and red shale.....	120
	<hr/> 202



FIG. 50.—Section of the Morrison formation on Red Creek, 3 miles east of Black Mountain summit, Owl Creek Mountains, Wyoming.

Scale, 125 feet to 1 inch. (Darton.)

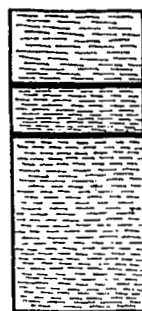


FIG. 51.—Section of the Morrison formation in Como Bluff, Wyoming.

Scale, 125 feet to 1 inch. (Darton.)

Three sections in the north and south sides of the Como anticline and in the Medicine anticline or "Bone Cabin Draw" are given by Loomis (1901, 6) as follows:

Section on north side of the Como Anticline

Dakota [Cloverly]	Feet
Straw yellow sandstone.....	120+
Black sandstone.....	3
Yellow sandstone.....	12
Jurassic [Morrison and Sundance]	
Bluish-green clay.....	20
Green clay.....	40
Flint	1/3
Green clay.....	15
Concretions	2
Green clay.....	9
Green clay with small concretions.....	9
Maroon clay with small concretions.....	28
Green clay.....	20
Sandstone	2

	Feet
Green clay.....	9
Sandstone	2
Green, maroon, red clay.....	26
Sandstone	1½
Green clay.....	20
Sandstone	2
Green clay.....	60
Sandstone	1½
Maroon clay.....	20
Sandstone	1½
Purple clay with limestones.....	20
Brown clay with limestone beds.....	70

Total of Jurassic [Morrison and Sundance]..... 378 5/6

Section on south side of the Como Anticline, or Como Bluff

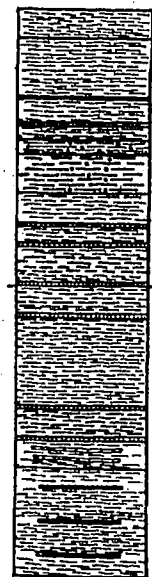


FIG. 52.—Section of the Morrison and Sundance formations on the north side of Como Anticline, Wyoming.

1.—Morrison formation; 2.—Sundance formation. Scale, 125 feet to 1 inch. (Loomis.)

Dakota [Cloverly]	Feet
Sandstone	200+
Black and red sandstone.....	4
Straw yellow sandstone.....	20
2 Jurassic [Morrison and Sundance]	
Maroon clay.....	10
Bluish green clay.....	15
Yellow green clay.....	13
Bluish green clay.....	15
Sandy clay.....	5
Green clay.....	2
Concretions	1
Green clay.....	15
Sandstone	4
Green clay.....	10
Green clay with small concretions.....	25
Maroon clay with small concretions.....	20
Green clay.....	9
Red clay.....	5
Maroon clay.....	7
Red clay.....	8
Gray sandstone.....	28
Dark green clay.....	10
Sandstone	1½
Red and green clay.....	10
Sandstone	2
Green clay.....	25
Sandstone	12
Purple clay with limestones.....	15
Gray brown clay.....	55

Total of Jurassic [Morrison and Sundance]..... 332½



FIG. 53.—Exposures of the Morrison formation in Como Bluff, Wyoming.
After Osborn.

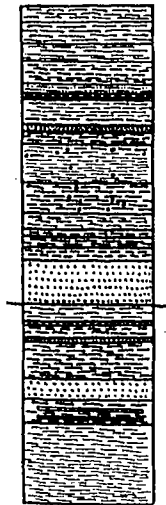


FIG. 54.—Section of the Morrison and Sandance formations at Como Bluff, Wyoming.

1.—Morrison formation; 2.—Sandance formation. Scale, 125 feet to 1 inch. (Loomis.)

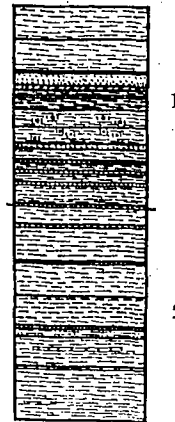


FIG. 55.—Section of the Morrison and Sandance formations on the south side of Medicine Anticline, or "Bone Cabin Draw," Wyoming.

1.—Morrison formation; 2.—Sandance formation. Scale, 125 feet to 1 inch. (Loomis.)

Section on south side of Medicine Anticline, or "Bone Cabin Draw"

Dakota [Cloverly]	Feet
Yellow sandstone.....	243
Black sandstone.....	2
Gray sandstone.....	30

Jurassic [Morrison and Sundance]	Feet
Bluish green clay.....	21
Green clay.....	20
Flint	1/3
Gray sandstone.....	10
Concretions	2
Green clay.....	3
Concretions	1½
Green clay.....	8
Green clay with concretions.....	10
Maroon clay with small concretions.....	10
Sandstone	3
Green clay.....	8
Sandstone	1
Red clay.....	5
Sandstone	2
Green clay.....	6
Sandstone	1½
Red, green, maroon clay.....	12
Sandstone	2
Maroon, green, red clay.....	10
Sandstone	2
Green clay.....	22
Sandstone	1
Green clay.....	20
Reddish clay.....	20
Sandstone	1½
Green sandy shale.....	6
Purple clay with limestones.....	22
Nucula limestone.....	1
Brown clay.....	43
Total of Jurassic [Morrison and Sundance].....	274 5/6

In these sections the Morrison is interpreted as beginning with No. 13. The contact is not very distinct.

Logan gives the following section for the Freezeout Hills (1900, 5):

"Purplish clay containing considerable arenaceous inclusions..... 40 ft.

"The clay contains, in the lower part, a thin stratum of sandy limestone in which the following fossils were found: *Pentacrinus asteriscus*, *Asterias dubium*, *Pseudomonotis curta*, *Avicula macronatus*, and *Ostrea strigilecula*.

"*The Atlantosaurus Beds*.—The last stratum is the last one containing marine fossils, and probably closes the Jura, but some of the non-fossiliferous beds lying above may belong to that formation. The succeeding stratum varies so much in thickness that it may represent the eroded surface of the Jura upon which the *Atlantosaurus* Beds were deposited.

"16. Fine-grained, grayish-white sandstone..... 10 ft. to 125 ft.

"The above stratum varies much in thickness within short distances. At

one point on the Dyer ranch it has a thickness of only 10 ft., while a few miles southeast it reaches a thickness of 125 ft. The sandstone composing the layer is of nearly uniform color and texture. Its induration is only moderate, and it weathers into many grotesque forms. Cross-bedding is well exhibited by it in many localities.

"17. Purple to greenish-colored clay..... 60 ft.

"This is apparently an unfossiliferous layer, except in the uppermost horizon, where species of dinosaurs belonging to the genera *Brontosaurus* and *Morosaurus* occur.

"18. Sandstone, grayish to light brown..... 10 ft. to 20 ft.

"The above sandstone presents some very interesting stratigraphic phenomena. It has, at the base, a layer of conglomerate about $2\frac{1}{2}$ ft. thick. The conglomerate is composed of small silicious and argillaceous pebbles, and is not very coherent. Something like two feet of sandstone rests upon the conglomerate; the bedding planes of the sandstone are oblique to the bedding planes of the beds above and below. Succeeding the sandstone above is 6 in. of sandstones in very thin layers, with lignitic seams along its horizontal but wavy bedding planes. The above is overlain by 4 in. of conglomerate, followed by 1 in. of sandstone with oblique bedding planes. Overlying this layer is a thin layer of sandstone in which the bedding planes are horizontal. The remainder of the stratum is made up of sandstone with the bedding planes as follows: One ft. oblique; then 3 in. horizontal; then 2 ft. oblique; and finally 3 in. horizontal. The stratum furnished in one place the trunk of a large fossil tree and a large number of fossil cycads. Fragments of fossil wood were found in a number of places, but cycads in only the one. Fragments of a hollow-boned dinosaur were found in one place in the horizon.

"19. Drab-colored clay..... 30 ft. to 40 ft.

"This stratum contains the bones of the large dinosaur, *Brontosaurus*. Otherwise it appears to be quite unfossiliferous.

"20. Fissile, brownish sandstone..... 4 ft. to 5 ft.

"No fossils were found in this sandstone, and the most characteristic feature about it is its uniformly brown color. It seems to be moderately persistent, as its occurrence in many places in the hills was noticed.

"21. Bluish-green clay containing very small concretions..... 30 ft.

"In the bone quarries of this horizon, which furnished species of *Brontosaurus*, *Morosaurus*, and *Diplodocus*, were found specimens of (*Planorbis*) *eternus* and *Valvata leei*. This is the lowest horizon at which any of these non-marine invertebrates were noticed. It is probable that they will be found lower down, as the dinosaurs occur much lower.

"22. Brown to bluish-gray arenaceous limestone..... 8 in. to 1 ft.

"This stratum contains the following non-marine invertebrate forms: *Unio knighti*, *U. baileyi*, *Valvata leei*, and (*Planorbis*) *eternus*. Species from the same genera have been described by Meek from a similar stratum of limestone in the Black Hills. As these occupy much the same stratigraphical position they are probably the same age. The *Lioplacodes* seem to be identical with that described by Meek in the Geology of the Upper Missouri.

"23. Drab-colored clay..... 70 ft.

"Species of the genera *Brontosaurus*, *Diplodocus*, *Morosaurus*, *Stegosaurus* and *Allosaurus* occur in this horizon. Portions of species of all these genera were found in one quarry by the Kansas University collecting party. The clay is of that quality usually designated as 'joint' clay. It contains in places iron and argillaceous concretions of small size. The iron, and sometimes the bones, are covered with selenite crystals.

"24. Grayish-white sandstone..... 50 ft.

"This layer forms a conspicuous capping for the hills, and is the highest remnant of the anticline. It breaks up into large blocks, which lie scattered along the slopes of the underlying softer beds. Its erosion and disintegration is accomplished chiefly by sapping. No fossils were found in this stratum, and its true position is in doubt."

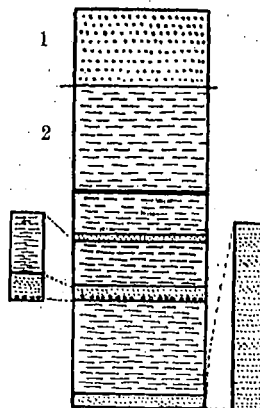


FIG. 56.—Section of the Morrison formation in the Freezeout Hills, Wyoming.

1. — Cloverly formation; 2. — Morrison formation. Scale, 125 feet to 1 inch. (Logan.)

The following sections are given by W. C. Knight (1900, 2):

Sioux Fault Section

Cretaceous:

Dakota conglomerate and sandstone.

Jurassic:

	Feet
1. Variegated marls and clays shading from dark yellow to dark maroon, with dinosaurian remains.....	38½
2. Calcareous sandstone.....	2
3. Bluish and yellowish marls, containing <i>Brontosaurus</i> at top and <i>Morosaurus</i> at base.....	22½
4. Drab calcareous sandstone.....	1½
5. Light colored clays and marls, with thin bands of sandstone...	24
6. Clays and marls varying from light gray to brown.....	23½
7. Hard band of light gray clay.....	4½
8. Drab and greenish clays.....	22½
9. Drab sandstone.....	2
10. Yellow, greenish and light brown marls shading into maroon in the upper portion.....	38½
11. Gray sandstones.....	3
12. Bluish gray clay.....	4
13. Bluish and drab clays interstratified with yellowish bands....	38½

Total thickness of fresh-water beds [Morrison]..... 226

14. Variegated clays and marls with bands of sandstone.....	43½
15. Yellowish sandstone.....	8½

	Feet
16. Dark shale beds with remains of <i>Baptanodon</i> , <i>Belemnites</i> , <i>Ostrea</i> , <i>Tancredia</i> , <i>Camptonectes</i> and a few <i>Septaria</i>	38½
17. Yellowish sandstone.....	2½
18. Gray sandstone.....	5½
19. Yellowish sandstone alternating with thin clay bands.....	6½
20. Thin bedded gray sandstones with a few bands of clay.....	5½
Total [Shirley or Sundance]	118

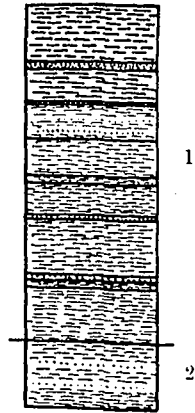


FIG. 57.—Section of the Morrison formation at Sioux Falls, Wyoming.

1.—Morrison formation; 2.—Sundance formation. Scale, 125 feet to 1 inch. (Knight.)

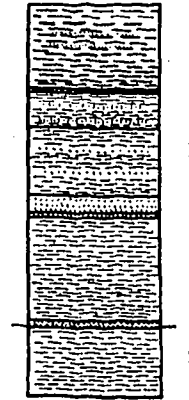


FIG. 58.—Section of the Morrison formation in the Freezeout Hills, Wyoming.

1.—Morrison formation; 2.—Sundance formation. Scale, 125 feet to 1 inch. (Knight.)

Freezeout Hills Section

Cretaceous:

1. Dakota conglomerate.

Jurassic:

	Feet
2. Drab marls and clays with a few thin bands of light colored sandstone containing remains of Dinosaurs.....	55
3. Hard clay and sand containing fresh-water molluscs and crocodiles	1½
4. Drab marls and clays with a few bands of calcareous sandstones with remains of <i>Allosaurus</i> , <i>Diplodocus</i> , <i>Brontosaurus</i> , <i>Morosauros</i> , <i>Stegosaurus</i> , <i>Ceratodus</i> and Turtles.....	24½
5. Drab marls and clays with thin beds of soft sandstone.....	46
6. Yellowish soft sandstone with cycads and petrified wood.....	10
7. Brown sandstone, cross-bedded.....	2
8. Drab shales, clays and marls.....	70
9. Greenish sandstone.....	4

Total fresh-water beds [Morrison]..... 211

	Feet
10. Reddish and brown shales and clays.....	49
11. Dark fossiliferous limestone with <i>Camptonectes</i> and <i>Ostrea</i>	2
12. Greenish shales with dark bands of clay and sandstone, with clay containing concretions of limestone rich in fossils. Fossils present: <i>Belemnites</i> , <i>Pentacrinus</i> , <i>Astarta</i> , <i>Grammatodon</i> , <i>Ostrea</i> , <i>Pseudomonotis</i> , <i>Pleuromia</i> , <i>Pinna</i> , <i>Lima</i> , <i>Megal-neusaurus</i> , <i>Baptanodon</i> and <i>Plesiosaurus</i>	50
13. Gray sandstone.....	4
14. Red and brown shales with concretions and a few fossils.....	44
15. White sandstone with upper band containing fossils.....	30
Total marine beds [Shirley or Sundance].....	179

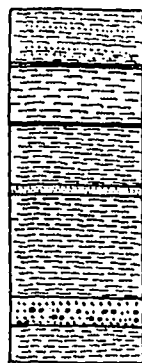


FIG. 59.—Section of the Morrison formation at Red Mountain, Wyoming. Scale, 125 feet to 1 inch. (Knight.)

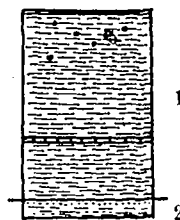


FIG. 60.—Section of the Morrison formation at Red Mountain, Wyoming.

1.—Morrison formation; 2.—Sundance formation. Scale, 125 feet to 1 inch. (Darton.)

Red Mountain Section

Cretaceous: Dakota removed but present in most instances.

Jurassic:

1. Drab marls and clay with two thin bands of limestone and one of chert and chalcedony with Dinosaur remains.....	35
2. Drab limestone.....	2
3. Variegated marls with Dinosaur remains.....	38
4. Gray limestone.....	1
5. Drab marls and clays.....	39
6. Gray sandstone.....	6
7. Drab marls and clays.....	69
8. Gray sandstone and some conglomerate.....	20
9. Drab and red marls and clays.....	25

Total, all fresh-water beds..... 235

Darton (1908, 1) gives the following section at Red Mountain:

	Feet
Bluish shales.....	40
Limestone	1
Bluish shales.....	50
Limestone	2
Bluish shales.....	36
	<hr/> 128

"The Morrison formation outcrops on the west bank of Laramie River just below the ridge a mile northwest of Laramie. There are 3 feet of dark shale at base, then 20 feet of soft, massive light colored sandstone, and at top 10 feet of gray shale with several thin, slabby limestone layers, one of which is pebbly, and a thin layer of gray sandstone. In slopes $1\frac{1}{2}$ to 2 miles south-southwest of Howell station are soft, massive buff

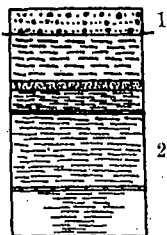


FIG. 61.—Section of the Morrison formation on the east slope of the ridge west of Downey Soda Lakes, Wyoming.

1.—Cloverly; 2.—Morrison. Scale, 125 feet to 1 inch. (Darton.)

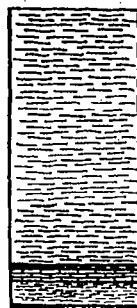


FIG. 62.—Section of the Morrison formation on the South Fork of Horse Creek (east of the Laramie Mountains), Wyoming.

Scale, 125 feet to 1 inch. (Darton.)

sandstones overlain by typical gray and greenish gray massive shale or clay with thin limestone, cherty, and sandstone layers. One of the latter is 2 to 3 feet thick. At the top are very dark shales, which have been prospected for coal; these are overlain by coarse Cloverly sandstone" (Darton, 1908, 1).

Darton also gives the following section of the Morrison formation on the east slope of the ridge west of Downey Soda Lakes:

	Feet
Cloverly sandstones and shales.....	
Drab to olive green shale.....	30
Soft, coarse-grained, disintegrated sandstone, with calcareous matrix, containing teeth and bones.....	6
Drab to blue shale.....	15

	Feet
Nodular limestone.....	1-2
Blue shale.....	50
Limestone	2
Concealed, probably blue shale.....	30+
	<hr/> 135+

On the east side of the Laramie Mountains Darton (1908, 1) describes the Morrison in the first canyon south of South Fork of Horse Creek as consisting of the following: pale green and maroon massive shale on 30 feet of light colored massive shale which contains several limestone layers, one being 6 feet thick. "On South fork of Horse creek, the 6-foot limestone member is conspicuous, underlain by 20 feet of gray shale lying on a 1-foot limestone bed at supposed base of formation. The total thickness here is about 200 feet, which appears to be the average amount, except on the southernmost prong of Horse creek, where it is less than 150 feet."

MORRISON FORMATION IN THE BLACK HILLS AREA

The Morrison formation occurs in the Black Hills area in eastern Wyoming and western South Dakota. It is present in the hog-backs surrounding the central area of the Black Hills. Outcrops are present around almost the entire circumference. For a short space on the southeastern side it is absent, however, the Lakota sandstone lying directly upon the Unkpapa sandstone. The significance of the absence of the formation at this point will be discussed later. The Black Hills Morrison is usually underlain by a reddish, banded, porous sandstone, known as the Unkpapa; in some areas, however, it rests directly upon the Sundance beds. The thickness of the formation in the various sections that have been measured are as a rule less than the thickness in the various central Wyoming areas and much less than the areas in western Colorado.

The following general description of the Morrison and Unkpapa formations in the Black Hills area is from Darton (1909, 5). Detailed descriptions of the formation in various quadrangles will be given later.

The Unkpapa sandstone has been fully described by Darton. This formation is a characteristic one in the Black Hills region. It is more extensively developed in the southern than in the northern part of the area. In the northwestern and western part of the region it consists of a thin yellowish sandstone. In the southern and southeastern part of the area it is represented by uniform-textured, fine-grained sandstone of varying colors. The following thicknesses are given by Darton: near Sturgis,

60 to 70 feet; near Tilford and Piedmont, 40 feet; south of Rapid, 30 to 50 feet; a mile north of Rapid, 150 feet; in the Bellefourche region, 10 to 30 feet (not clearly separated from the Sundance); very thin in the Aladdin and Sundance regions. It is usually clearly separable from the Sundance below and the Morrison above.

The Unkpapa is usually soft, white, buff, red or purple in color; it contains considerable material, and is often strongly banded. This banding is usually parallel with the bedding, but occasionally makes a marked angle with it. The rock is extremely porous and often exhibits interesting examples of microfaulting in hand specimens.

The name "Beulah shales" has been applied to the Morrison of the Black Hills region. The formation consists of the usual series of clays and shales, with thinner layers of sandstone and calcareous nodules. The prevailing color is gray, but other colors, such as red, maroon, pink and purple sometimes occur. Carbonaceous matter is sometimes present in the upper members. The following thicknesses of the Black Hills Morrison are given by Darton: near Rapid, 165 feet; east of Piedmont, 220 feet; rapidly decreasing to 70 feet in nearby locality; 4 miles north of Tilford, 110 feet; 1 mile south of Rapid, 90 feet; 3 miles south of Rapid, 165 feet; in the region about Sundance, 150 feet; at Aladdin, 60 feet; east of Aladdin, 80 feet or more; in Redwater Valley southwest of Bellefourche, 50 feet; near Lookout Peak, 100 feet; about Table Mountain and north of Eothen, 150 feet; near Alva, about 100 feet; in Barlow Canyon, 85 feet; 3 miles north of Hulett, 150 feet; on Miller Creek, 7 miles southeast of Devils Tower, 160 feet. The thinnest section recorded is in Barlow Canyon north of Devils Tower, the thickness there being 40 feet. Dinosaur bones of great size have been found in the Morrison near Piedmont, apparently belonging to a sauropod of great specialization, resembling *Diplodocus*.

In the Newcastle quadrangle the Morrison deposits are mostly of light gray color, but some portions are buff, pale green and maroon. The thickness averages a little more than 150 feet and is greatest in the northern part of the quadrangle. The beds outcrop along the inner side of the hog-back below the Lakota conglomerate and sandstone. In the region east of Salt Creek they occur in extensive outliers overlain by protecting caps of Lakota, and in the sloping plateau north of Newcastle they are revealed in the deep canyons. The outcrops are often obscured by talus derived from the sandstone cliffs above and by wash along the slopes. The contact with the Sundance shows an abrupt change in the character of the material. At Cambria a drill hole in the floor of the coal mine penetrated 12 feet of sandstone with coaly layers at the base

of the Lakota and passed through the following beds, probably all of which belong to the Morrison (Darton, 1904, 4):

	Feet
Fire clay, gray.....	3
Sandstone, light gray, moderately hard.....	1½
Fire clay.....	7½
Sandstone, gray, upper half very hard.....	4
Shales, lead colored, soft at base.....	11
Shale and fine sand.....	3
Shale, bluish gray.....	18
Sandstone, moderately hard.....	1
Clay, bluish and purplish, hard below.....	20

The Morrison formation in the Aladdin quadrangle has been described by Darton and O'Harra (1905, 6). It is a thin but persistent deposit of massive shale between the Sundance and Lakota formations. Its color is generally a characteristic pale olive green, with local bands of gray and maroon. In fresh exposures some of the beds are darker and in some localities portions of the deposit are black. "The thickness is variable, owing to local unconformity on its surface, and its measure is difficult to determine at most localities owing to talus and landslides along the base of cliffs of Lakota sandstone." The shale includes thin beds of sandstone, most of which is fine-grained and light in color. Nodules of hard clay occur in some of the beds. The formation outcrops extensively along both slopes of the northern extension of the Bear Lodge Mountains and outlying ridges; in the ridge between Deer and Medicine creeks; in the basins at the heads of Pine, Alum and Hay creeks; in ridges north and south of Aladdin; and in the anticline east of The Forks.

Darton and Smith (1904, 5) have described the Morrison formation in the Edgemont quadrangle. In this quadrangle the Morrison consists of massive shales and clays, partly light gray and partly red or maroon, with occasional layers of fine-grained white sandstone. West of Minnekahta the thickness is about 100 feet, but eastward, northwest of Cascade Springs, the formation thins and dies out completely. Just west of Cascade Springs the Lakota lies directly upon the Unkpapa sandstone. The Morrison is exposed in the upper part of the slope at the base of Lakota cliffs in the northern face of the hog-back westward. As the dip is low and the formation is relatively thin, the outcrop is somewhat irregular. The formation is exposed in Hell and Falls canyons and in the



FIG. 63.—Section of the Morrison formation in drill hole in floor of coal mine at Cambria, Wyoming.

Scale, 125 feet to 1 inch. (Darton.)

canyon south of Parker Peak, lying on the Unkpapa sandstone. In Hell Canyon the formation extends to within about a mile of the Cheyenne River. It is variable in thickness at this point and consists mainly of gray and red sandy clay. On the west side of Falls Canyon the formation is about 60 feet thick, greenish at the base, darker above, and light green and maroon in its upper portion; on the east side it thins to about 20 feet.

There are exposures of the Morrison in Chilson Canyon a mile southwest of Chilson, and in the heads of branches of Bennett Canyon, where it is pale greenish, massive clay, with thin, white, fine sandstone members 3 to 10 inches thick. It is also cut through by Cheyenne River east of Edgemont. In an exposure in Red Canyon, where the formation is 80 feet thick, there is a thin limestone layer containing remains of algæ at the base. In a well at Edgemont the formation appears to be about 150 feet thick. "In the western part of the quadrangle the Morrison shale is distinctly separated from the Sundance formation, and in the eastern part from the Unkpapa sandstone, by an abrupt change in character and material, but there is no evidence of erosional unconformity."

The Morrison in the Sundance quadrangle has been described by Darton (1905, 5). The formation here shows the usual light gray and maroon colors, with buff and purple. It contains thin beds of sandstone and occasional layers of limestone. The average thickness is about 150 feet. The outcrops form a zone extending across the western and southwestern parts of the quadrangle. The deposits are distinguished from those of the Sundance by the color and massive texture of the shale. The most outcrops are in the ridges adjoining Beaver Creek, along Mason Creek, in Skull Creek Valley north and west of the Holwell ranch, in Black Canyon, along Oil Creek and in Oil Creek Valley.

The following sections of the Morrison formation in the Black Hills region are given by Darton, from O'Harra (1909, 5):

*Section of Morrison Formation on north side of Sourdough Creek, 6 Miles
north of Hulett, Wyoming*

	Feet
Shale, yellow at top, red at bottom.....	18
Black shale.....	14
Black shale with 4-inch sandstone near top, slight purple or pink tinge throughout and rather conspicuous near the middle.....	17
Black shale.....	26
Slightly sandy green soft shale; some blue nodules near base.....	10
White sandstone.....	2
Green shale.....	5
White sandstone, carbonaceous streaks.....	2
Gray and reddish shales.....	40

Section of Morrison Formation on Ridge south of Lytle Creek, 8 Miles southeast of Devils Tower, Wyoming

	Feet
Argillaceous limestone.....	2
Concealed	3
Argillaceous limestone.....	1
Grayish soft shale.....	12
Argillaceous limestone.....	1
Yellowish-gray shale.....	6
Argillaceous limestone.....	1
Greenish shale.....	40
Argillaceous limestone.....	½
Greenish shale.....	30

96½

The upper and lower contacts are not clearly shown at this place.

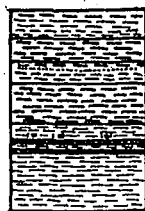


FIG. 64.—Section of the Morrison formation on north side of Sourdough Creek, 6 miles north of Hulett, Wyoming.

Scale, 125 feet to 1 inch. (Darton after O'Harra.)



FIG. 65.—Section of the Morrison formation on ridge south of Lytle Creek, 8 miles southeast of Devil's Tower, Wyoming.

Scale, 125 feet to 1 inch. (Darton after O'Harra.)

Section of Morrison Formation on prominent Lakota-capped Hill, 4 Miles east-southeast of Devils Tower, north of Lytle Creek, Wyoming

	Feet
Impure fire clay, containing rough nodular layer.....	2
Fine green shale.....	12
Sandy fire clay.....	1
Fine green shale, locally with purple tinge.....	70
Lime-clay shale.....	6
Fine green and drab shale.....	12
Green shale with some lime-clay nodules.....	16
Limestone, slightly argillaceous.....	6

125

Section of Morrison Formation on north side of Deer Creek, 10 Miles northeast of Hulett, Wyoming

	Feet
Dark purple shale, weathers to light purple.....	9
Massive sandstone.....	1

	Feet
Purple shale.....	10
Concealed	8
Purplish-gray shale.....	12
Dark purplish shale.....	20
Very dark shale.....	14
Gray shale.....	17
Concealed; contains some sand.....	24
Green and purple shale.....	6
Sandy shale.....	4
White sandstone, weathering to a dirty velvety brown.....	1
Grayish-white shale.....	5
Green shale.....	2
Fissile purple shale.....	6
Grayish-green shale with some lime nodules.....	16

155

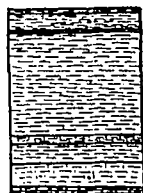


FIG. 66.—Section of the Morrison formation 4 miles east-southeast of Devil's Tower, Wyoming.

Scale, 125 feet to 1 inch. (Darton after O'Harra.)

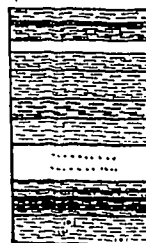


FIG. 67.—Section of the Morrison formation on north side of Deer Creek, 10 miles northeast of Hulett, Wyoming.

Scale, 125 feet to 1 inch. (Darton after O'Harra.)

Section of Morrison Formation near head of Burnt Hollow, 4 Miles northwest of Hulett, Wyoming

	Feet
Very black shale, resembling a coal outcrop on weathered surface; may possibly represent the horizon of the Aladdin coal.....	10
Gray shale.....	32
Sandstone	1
Shale with poorly preserved plant impressions.....	3
Interbedded shales and thin sandstones.....	18

64

Section of Morrison Formation a short Distance east of the foregoing Section

	Feet
Very black shale, as in above section.....	10
Brownish-gray and purple shale.....	14
Sandstone	2
Brownish-red shale.....	8

	Feet
Black shale.....	40
Light gray shale.....	36
	<hr/>
	110



FIG. 68.—Section of the Morrison formation near head of Burnt Hollow, $\frac{1}{4}$ miles northwest of Hulett, Wyoming.

Scale, 125 feet to 1 inch. (Darton after O'Harra.)



FIG. 69.—Section of the Morrison formation a short distance east of the foregoing section. (Fig. 68.)

Scale, 125 feet to 1 inch. (Darton after O'Harra.)

Section of Morrison Formation on north side of Moores Canyon, $2\frac{1}{2}$ Miles northwest of Hulett, Wyoming

	Feet
Grayish-purple shale.....	20
Dark purple shale.....	36
Yellowish, slightly sandy shale.....	4
Nodular layer.....	1
Dark greenish-gray shale.....	10
Nodular layer.....	1
Purple shale.....	6
Dark gray shale with lime-clay nodules.....	2
Drab shale.....	8
Very soft sandy shale.....	8
	<hr/>
	96

Section of Morrison Formation $2\frac{1}{2}$ Miles west of Belle Fourche River

	Feet
Purple, gray and yellowish shale with one or two thin sandstones.....	60
Flaggy to massive white sandstones.....	4
Purple and green shale with a few limestone nodules.....	60
	<hr/>
	124

Section of Morrison Formation 3 Miles south of Rapid Gap, South Dakota

	Feet
Concealed to base of Lakota sandstone.....	20
Mostly green shale, partly concealed.....	40
Dark green shale, weathering into small fragments.....	6
Massive gray sandstone.....	5

	Feet
Green and purple massive shale, with some sand; iron stains.....	12
Soft thin sandstones.....	2
Green sandy shale.....	2
Soft sandstone, green and gray.....	12
Green shale with some sand.....	12
Purple shale.....	4
Calcareous nodular layer.	
Massive shale, green and purple.....	2
Purple shale, with calcareous nodular layer.....	4
Calcareous nodular layer.....	1
Massive shale, green and purple.....	3
Massive but soft sandstone; light red and brown at bottom, but mostly white; slightly brecciated near the top and containing some calcite....	20
Massive red shale with some sand.....	12
Massive shale with calcareous nodules, purple and yellowish.....	5
Soft bright red argillaceous shale.....	3

165

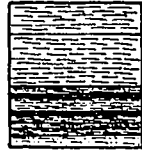


FIG. 70.—Section of the Morrison formation on north side of Moores Canyon, $2\frac{1}{2}$ miles northwest of Hulett, Wyoming.

Scale, 125 feet to 1 inch. (Darton after O'Harra.)

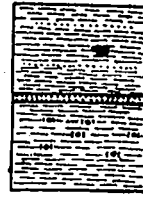


FIG. 71.—Section of the Morrison formation $2\frac{1}{2}$ miles west of Bellefourche River, Wyoming.

Scale, 125 feet to 1 inch. (Darton after O'Harra.)

The following sections of the Morrison formation in the Black Hills region are given by Loomis (1902, 7):

Section on Bellefourche River, Wyoming

	Feet
Olive green clay.....	70
Yellow-green clay with small concretions.....	12
Maroon clay.....	10
Green clay.....	6
Limestone concretions.....	1
Green clay.....	6
Maroon clay with small concretions.....	6
Green clay with small concretions.....	16
Limestone concretions.....	1
Green clay.....	4
Limestone concretions.....	1

	Feet
Green clay.....	6
Soft yellow sandstone.....	2
Green clay.....	7
Soft yellow sandstone.....	2
	144

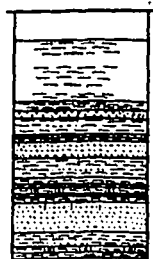


FIG. 72.—Section of the Morrison formation 3 miles south of Rapid Gap, South Dakota.

Scale, 125 feet to 1 inch. (Darton after O'Harra.)

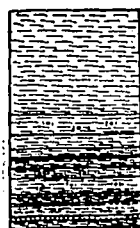


FIG. 73.—Section of the Morrison formation on the Bellefourche River, Wyoming.

Scale, 125 feet to 1 inch. (Loomis.)

Section on Inyan Kara Creek

	Feet
Olive green clay.....	40
Light green clay.....	12
Maroon clay with small concretions.....	10
Green clay with small concretions.....	5
Red clay.....	5
Green clay.....	5
Maroon clay.....	6
Green clay.....	20
Limestone concretions.....	1
Yellow sandstone.....	9
Dense gray sandstone.....	8
Yellow sandstone.....	5
Limestone concretions.....	1
Yellow sandstone.....	12
	130

Section at Sheldon Post Office

	Feet
Olive green clay.....	30
Limestone concretions.....	1
Green clay.....	10
Maroon clay.....	5
Yellow-green clay.....	9
Red clay.....	5
Limestone concretions.....	..

	Feet
Green clay.....	8
Limestone concretions.....	1
Red clay.....	3
Green clay.....	12
Limestone concretions.....	1
Green clay.....	12
Gray sandstone.....	2
	<hr/> 99



FIG. 74.—Section of the Morrison formation on Inyan Kara Creek, Wyoming.

Scale, 125 feet to 1 inch. (Loomis.)

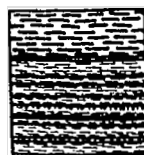


FIG. 75.—Section of the Morrison formation at Sheldon Post-office, Wyoming.

Scale, 125 feet to 1 inch. (Loomis.)

Section at Kara Peak

	Feet
Red clay.....	3
Green clay.....	3
Cream sandstone.....	8
Blue-green clay.....	6
Red clay.....	1
Limestone concretions.....	1
Purple clay.....	3
Red clay.....	2
Cream sandstone.....	2
Green clay.....	3
Cream sandstone.....	2
White sandstone.....	11
Black clay.....	2
White sandstone.....	8
Yellow sandstone.....	75
Slate green clay.....	50
Gray sandstone.....	15
	<hr/> 195

Section at Beaver Creek

	Feet
Brown-green clay.....	15
Olive green clay.....	66
Green clay with small concretions.....	15

	Feet
Maroon clay with small concretions.....	6
Green clay.....	15
Maroon clay with small concretions.....	12
Green clay.....	6
Limestone concretions.....	1
Olive green clay.....	8
Buff sandstone.....	12
	<hr/>
	111

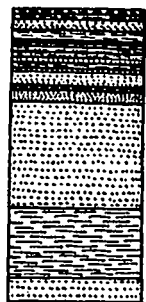


FIG. 76.—Section of the Morrison formation at Kara Peak, Wyoming.

Scale, 125 feet to 1 inch. (Loomis.)

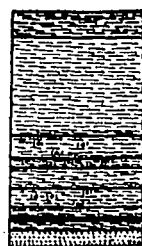


FIG. 77.—Section of the Morrison formation on Beaver Creek, Wyoming.

Scale, 125 feet to 1 inch. (Loomis.)

ATLANTIC COAST REPRESENTATIVE OF THE MORRISON FORMATION

ARUNDEL FORMATION OF MARYLAND

The Morrison formation is apparently represented in the eastern part of the United States by part of the Potomac series. It was formerly claimed that the Potomac was a unit formation. Its age has been discussed by a number of workers, some holding it to be Jurassic, others Cretaceous. More recently it has been divided into several distinct formations, separated from one another and from the underlying and overlying formations by disconformities or stratigraphic breaks. The lowest formation of the Potomac series, the Patuxent, contains none of the dinosaurian fauna characteristic of the Morrison, but the middle member, or Arundel, is characterized by many forms identical with or closely related to the forms of the Morrison fauna. The Arundel beds have been well described by Clark, Bibbins and Berry (1911, 5).

The Arundel is the lower part of the "upper oolite," or "Iron-Ore Clays" of Tyson, a part of the "Variegated Clays" of Fontaine and McGee, and of the "Baltimorean" of Uhler. It is the equivalent of the "Iron-Ore series" of Ward. It outcrops in an irregular northeast-south-

west belt, from the head of Bush River, in Hartford County, to Washington, D. C.

The Arundel consists typically of drab, more or less lignitic clays, with masses of siderite. The nodules and geodes of siderite, when exposed to the air, often change to brown hematite. The clays are usually free from grit, but are occasionally sandy, and in places carry pyrite and gypsum. Lignite beds also occur.

The thickness of the formation is not great, the maximum being about 125 feet, and usually it is much less than that. It is thickest on the western side or middle of the belt, and thins eastward as shown by borings.

The Arundel overlies the Patuxent unconformably, and appears to occupy old drainage lines in the Patuxent. Cross-bedding is occasionally found in the lower beds, but is not usually present. The formation is overlain, with unconformity, by the Patapsco formation. The fauna will be discussed in the section on the age of the Morrison formation.

SUMMARY OF STRATIGRAPHIC RELATIONS AND CHARACTERS OF THE MORRISON FORMATION

The stratigraphic relations and characters of the Morrison are summarized in the following pages.

DISTRIBUTION

The Morrison formation has a wide distribution in Utah, New Mexico, Colorado, Wyoming, Montana, South Dakota and perhaps Idaho and Arizona. The number of square miles of Morrison outcrops is not very great, but the area in which the Morrison is overlain by younger deposits probably includes several hundred thousand square miles. The areas from which the Morrison has been eroded probably includes many thousand square miles more.

The formation, after deposition and before burial or erosion, had an extremely wide distribution, which may have amounted to four or five hundred thousand square miles.

RELATION TO UNDERLYING ROCKS

In various areas the Morrison rests on formations of different ages, ranging from Archean to upper Jurassic. In the southwestern areas the Morrison or McElmo rests on the La Plata sandstone of Jurassic age. The contact with the La Plata is apparently conformable, but there is a decided break beneath the La Plata. The latter lies on the Dolores beds of Triassic age, in some localities; on the Cutler, Hermosa and Elbert

formations, of Permian, ? Pennsylvanian and Devonian ? age respectively (Cross and Larsen, 1914, 7); and in still other areas on pre-Cambrian crystallines. In northwestern Utah, near Vernal, the non-marine portion of the Flaming Gorge formation, equivalent to the Morrison, rests on marine beds of upper Jurassic age, containing *Pseudomonotis curta*, etcetera. The contact is apparently conformable, no sudden change in lithological characters being observable.

In the areas of Morrison outcrops in Montana, and in most of those in Wyoming, the formation rests on the Sundance or corresponding beds. These beds have been determined by Stanton (1909, 9) to belong to the lower part of the upper Jurassic. In certain areas in Montana there is evidence of a pre-Sundance erosion plane. The contact between the Morrison and Sundance formations is sharp in some places, while in other places it is obscure.

In general it appears that there was a slight break between the Morrison and Sundance formations, but not one of any considerable extent.

In the Black Hills area the Morrison usually lies on the Sundance beds, often with a sharp contact. In some localities, however, the Morrison is separated from the Sundance by the Unkpapa sandstone, indicating an interval between the retreat of the Sundance sea and the beginning of Morrison deposition.

In eastern Colorado the Morrison rests on Sundance beds near the Wyoming boundary. Throughout most of the area in eastern Colorado and New Mexico the Morrison rests on Red Beds of various ages. In the northern half of Colorado, except at the extreme northern end, the Morrison lies on the Chugwater Red Beds. At Morrison the formation is separated from the Red Beds by a white sandstone of unknown age. At Colorado City a bed of gypsum lies between the Morrison and the Red Beds. Farther south in Colorado the Morrison rests on the Fountain or Badito formations. South of Beulah, in southern Colorado, the Morrison rests directly on the crystallines. In northeastern New Mexico the Morrison is underlain mostly by Red Beds, which have been warped and eroded before the deposition of the Morrison. Near Exeter there is a distinct sandstone formation between the Morrison and the Red Beds. The uppermost members of the Red Bed series often consist of gypsum in this area.

It is seen from the above description that there is a widespread erosion plane beneath the Sundance formation in some areas, and there is evidence of a slight break between the Morrison and Sundance formations. Is the pre-Sundance erosion plane to be correlated with the pre-Morrison plane, which is observable where the Sundance is absent, or is the pre-

Morrison plane to be correlated with the interval between the Morrison and the Sundance? This question will be discussed in the section on the interpretation of the Morrison formation.

RELATION TO OVERLYING BEDS

In western Colorado and eastern Utah the Morrison is overlain by the Dakota sandstone. The contact is fairly sharp, but without definite

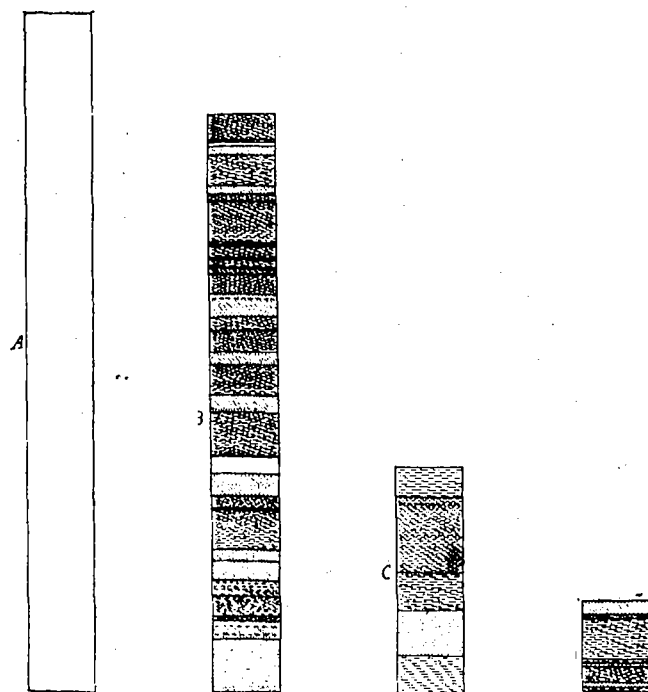


FIG. 78.—Sections of the Morrison formation showing decrease in thickness from southwestern Colorado northward.

A. Telluride quadrangle, Colorado; maximum thickness 900 feet; B. Mack, Colorado, thickness about 700 feet; C. Tensleep, Wyoming, thickness about 250 feet; D. Belt Creek, Montana, thickness about 125 feet. Scale, 250 feet to 1 inch.

evidence of erosion of the Morrison prior to the deposition of the Dakota. In Montana the Morrison is overlain by the Kootenie formation. The Kootenie is very similar to the Morrison and may belong to the same deposition cycle. In various areas in central Wyoming, from the Montana south to the Colorado line, the Morrison is overlain by the Cloverly formation, the lower part of which is probably equivalent to the Lakota. In the Black Hills area the Morrison is overlain by the Lakota sandstone.

In eastern Colorado and New Mexico the Purgatoire formation overlies the Morrison. In all three of these last-mentioned areas the contact between the Morrison and the overlying formation is sharp. Near Cañon City, Colorado, marine fossils of Washita age were found by Stanton in beds immediately overlying the Morrison.

In general, the contact between the Morrison and overlying beds is sharp, but there is no evidence of a break of any great extent between

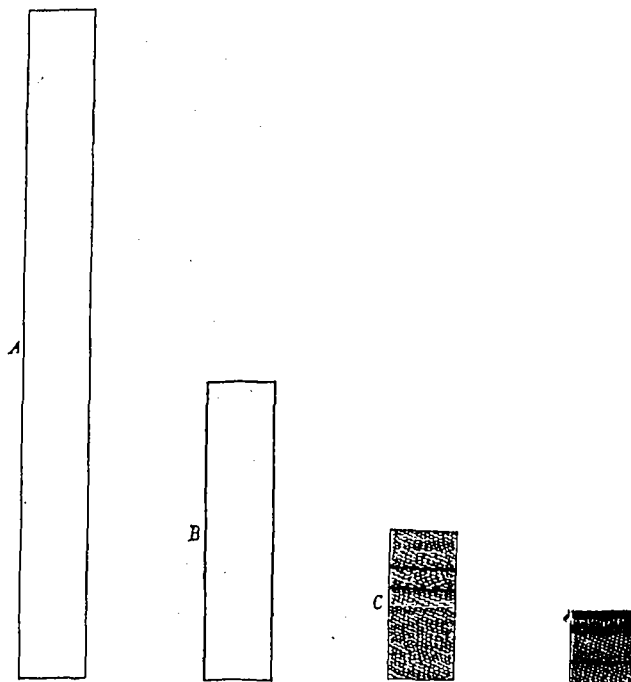


FIG. 79.—Sections of the Morrison formation showing decrease in thickness from southwestern Colorado northeastward.

A. Telluride quadrangle, Colorado, maximum thickness 900 feet; B. Encampment District, Wyoming, thickness 400 feet; C. Como Bluff, Wyoming, thickness about 200 feet; D. Devil's Tower, Wyoming, thickness about 100 feet. Scale, 250 feet to 1 inch.

the two formations. As noted by Lee (1915, 2), the Morrison is much more closely related to the overlying formations than to those underlying it.

THICKNESS

In a general way, it will be noticed, on studying the various sections of the Morrison formation, that the thickness is much greater in the

western and especially the southwestern areas than in any of the other districts in which the formation occurs. According to Lupton (1914, 3), the McElmo is over 1,000 feet thick near Green River, Utah; in the Telluride quadrangle, according to Cross (1899, 3), it varies from 400 to 900 feet; in McElmo Canyon it is between 400 and 500 feet; in the Grand River Valley, at various points between Grand Junction and the Colorado-Utah line, it is about 700 feet thick; in the region south of the Uinta Mountains the formation is about 650 feet thick; in the region of

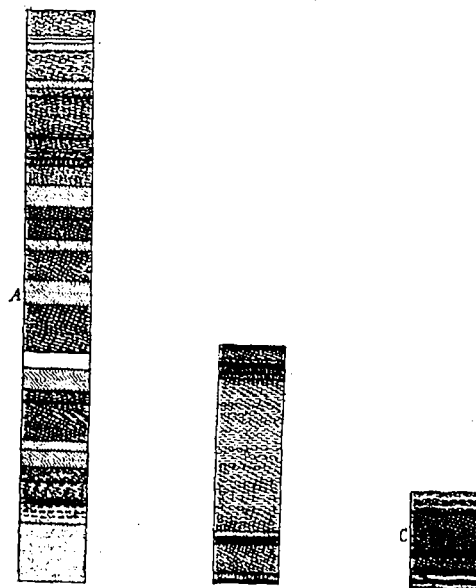


FIG. 80.—Sections of the Morrison formation showing decrease in thickness from western Colorado eastward.

A. Mack, Colorado, thickness about 700 feet; B. Cañon City, Colorado, thickness about 325 feet; C. Red Rocks Canyon, Colorado, thickness about 140 feet. Scale, 250 feet to 1 inch.

the Owl Creek and Bighorn Mountains the formation is usually between 200 and 250 feet thick; in the Great Falls region of Montana, about 100 feet thick. It must be remembered in this connection that some of the Kootenie of this area may be Morrison. In the Shoshone River region the formation is 580 feet thick; in the Encampment district, in southern Wyoming, the thickness is about 400 feet; at Como Bluff and in the Freezeout Hills about 200 feet; and in the Black Hills usually less than 100 feet, in one locality disappearing completely. In central Colorado the thickness is about 450 feet; near Cañon City, between 350 and 400

feet; in east-central New Mexico the Morrison varies from 200 to 400 feet; and in the canyons of eastern Colorado the thickness is about 200 feet.

There is thus a thinning out towards the north, northeast and especially towards the east.

LITHOLOGIC CHARACTERS

Coarse material occurs throughout the formation, but is much more abundant and in much thicker beds in the western areas than in those farther east. Fine material occurs throughout the formation and comprises the largest and most typical element in it, but is not usually abundant near the base.

VARIABLE CHARACTER OF SECTIONS

Sections of the Morrison formation, taken in different areas, present both similarities and differences. Most sections contain alternating series of banded or variegated clays or grits and heavy sandstones, with occasional thin limestone beds. No single stratum, however, continues for long distances, so far as the conditions are known. A bed of sandstone a certain number of feet from the base in one section may die out and not be represented in another section, or may disappear and another sandstone take its place. Lee has used the term "uniformly variable" for the Morrison beds, a term which fits Morrison conditions very well.

The significance of these features will be discussed in the section on the interpretation of the formation.

STRUCTURE AND PETROGRAPHY

STRUCTURAL FEATURES OF THE MORRISON FORMATION

Several structural features are often met with in the Morrison, which have considerable significance in regard to the question of the origin of the formation. Among these are cross-bedding, of both stream and wind types, lense-shaped cross-section of beds, and distinct channeling.

The stream type of cross-bedding, or cross-bedding in one direction with the inclined beds resting on flat surfaces, is seen throughout the formation in many places. It occurs on a large scale and also on a small scale. Usually the discordance of dips is not very great.

The wind type of cross-bedding, or cross-bedding at various angles and directions, with the inclined beds resting on curved surfaces, is also seen. It has been noticed near Cañon City in the vicinity of the Marsh-Hatcher

dinosaur quarry. It has been noted by Dr. H. E. Gregory⁵ in the southwestern areas in beds 200 feet or more in thickness.

Channeling is an especially characteristic feature of the Morrison formation. It is widespread and occurs on both large and small scales.

Thinning out of individual beds is common, when erosion channels may not be visible to the eye.

Several of these features are well shown at the dinosaur quarry worked by Professor O. C. Marsh's collectors, and later by Mr. J. B. Hatcher for the Carnegie Museum. The quarry is situated on the north bank of a

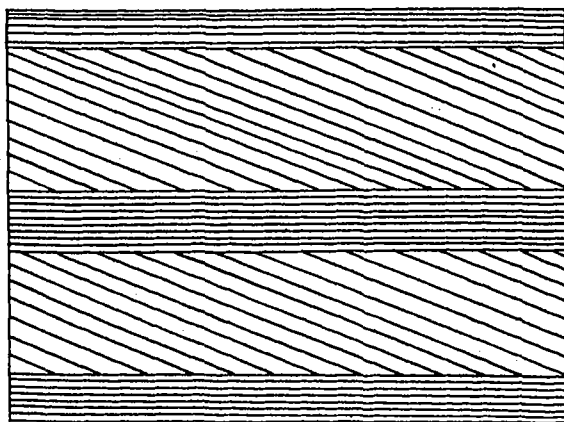


FIG. 81.—Type of cross-bedding usually known as the stream type.

small gulch which empties into Oil Creek, about eight miles north to northeast of Cañon City, Colorado. The beds for a short distance above and below the level of the quarry are well shown on both sides of the gulch.

The section of the Morrison in the vicinity of the quarry is as follows:

	Feet
Variegated clays.....	..
White sandstone.....	5 est.
Bone-bearing sandstone, coarse, calcareous, somewhat arkosic, with grains of volcanic material.....	3
Strongly cross-bedded sandstone at the floor of the quarry.....	5
Clay (absent at the quarry but present on the opposite side of the gulch)	1—
Sandstone, white, fairly coarse.....	2 to 15
Clay with nodule layers.....	..

⁵ Personal communication.

The base of the formation is not shown in this section,⁶ but judging from another outcrop in the bank of Oil Creek, a few hundred feet east of the quarry, the base of the quarry-floor sandstone is about 80 feet above the calcareous sandstone which is here considered as immediately underlying the Morrison.

The quarry-floor sandstone is cross-bedded; on the north side of the gulch the cross-bedding is of the stream type, with the beds dipping north; on the south side of the gulch the upper part of the quarry-floor sandstone shows cross-bedding of the wind type.

The heavy sandstone member below the quarry-floor sandstone is semi-lense-shaped in cross-section and occupies a trough in the clays beneath. The trough is a hundred feet or so in breadth and about 13 feet deep, the sandstone which fills and covers it varying from 2 to 5 feet in thickness. The contact between the clays and the sandstone in the trough is very sharp. The only satisfactory explanation of this trough is that the clays

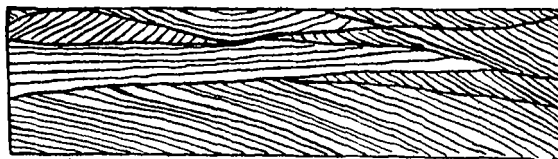


FIG. 82.—Type of cross-bedding usually known as the *æolian* type.

were eroded and the sandstone deposited over them, by a stream of considerable size. This means a stratigraphic break. While the channel in the clays was being eroded and before the deposition of the sands filling it, continuous deposition must have been going on in some other areas. This break need not have been long, in fact was probably short, as the same stream which eroded the channel probably deposited the sands on suffering an increase of load or a decrease of volume or gradient.

The gulch cuts directly across the old channel at this locality, and therefore exposes its characteristics completely. Stream banks cut parallel to old channels would not show their trough character at all, and banks exposed obliquely to old channels in position would exhibit a long gradual thinning out of the beds, without any pronounced lense-shaped cross-section. Thinning out of this character is common throughout the entire area of Morrison outcrops, and distinct lense-shaped sections, which are only exposed under very favorable circumstances, are not rare. Stream channeling and deposition are consequently especially characteristic features of the Morrison formation.

⁶ See also figs. 8 and 9, p. 50.

The presence of small stratigraphic breaks at many localities and levels in the Morrison formation emphasizes the force of the statements of Hatcher, that in the production of a continental formation of the character of the Morrison, the main process of deposition is not continuous for any given area. The process is rather one of alternating deposition and erosion, deposition being the dominant factor. The situation is analogous with the conditions at the front of a glacier, where the ice front may stand still, while the actual ice advances, through melting at the front. If melting goes on faster than ice advance, the front retreats;

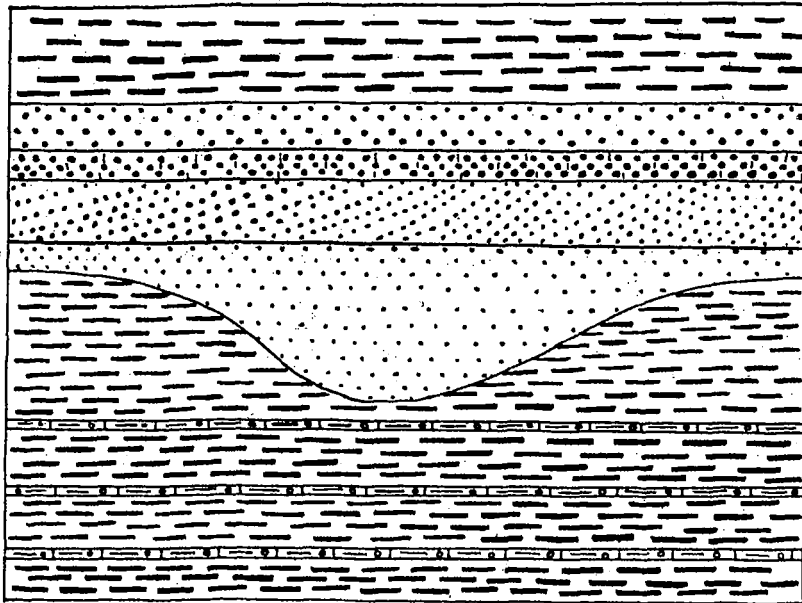


FIG. 83.—Diagrammatic section of the exposure of the Morrison formation at the Marsh-Hatcher dinosaur quarry, near Cañon City, Colorado.

if melting goes on slower than ice advance, the front advances. In the case of a continental formation ultimate deposition of a considerable thickness would be brought about by excess of deposition over erosion. If erosion predominated over deposition, there would be no formation produced, but a great stratigraphic break.

In considering the age of such a formation as the one under consideration, it must be remembered that deposition under the conditions indicated above will be much slower in producing a great thickness of beds than under conditions of continuous deposition. A total thickness of

200-400 feet produced by deposition predominating over erosion, means a much greater time interval than the same thickness deposited under conditions of continuous deposition.

Sudden lithologic changes from one bed to another are very common in the Morrison. Fine clay-shales will be overlain by coarse cross-bedded sandstones and the reverse. These abrupt successions do not necessarily mean breaks or lost time intervals, but rather sudden changes of conditions in definite areas.

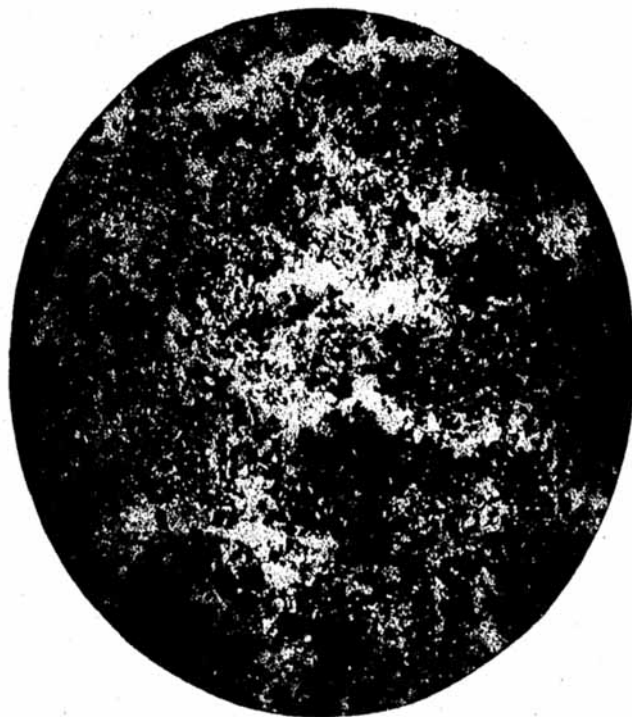


FIG. 84.—Red hematitic grit, from the top of the Morrison formation at Garden Park, near Cañon City, Colorado.

The light grains are quartz; the light patches are holes in the slide; the dark areas are clay stained with hematite. About 28 \times .

PETROGRAPHIC CHARACTERS OF THE MORRISON FORMATION

A number of distinct types of sediments occur in the Morrison formation. Broadly speaking, these are: (1) fine red or brown sandstones; (2) clays; (3) calcareous sandstones; (4) limestones; (5) coarse white sandstones. These grade into each other in a rather complex manner,

forming many intermediate varieties. Other types are also present, but in minor amounts.

The most characteristic beds in the Morrison are the so-called "joint-clays." These are fine sediments which have the appearance of clay, and which weather into clays. They are variegated in color, and have been the cause of the name "variegated beds" formerly applied to the formation. These "joint-clays" are composed of a variety of sedimentary types,

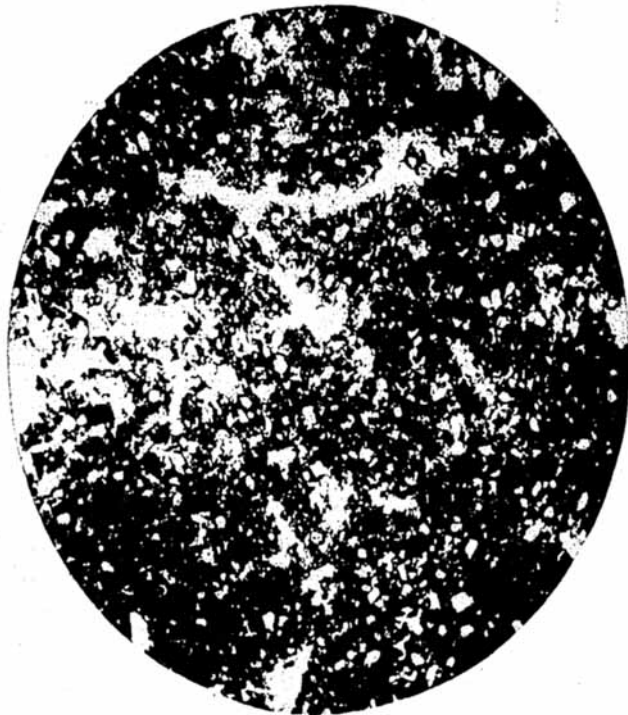


FIG. 85.—Fine grit, from near the top of the Morrison formation at Garden Park, Colorado.

The light grains are quartz; the light patches are holes in the slide; the dark patches are limonite. About 28 \times .

more or less distinct from each other in character, though there are often gradational varieties. This variety of elements is responsible for the variegated color. The sediments which make up the "joint-clays" are: fine-grained hematitic sandstones or grits; true kaolinic clays; fine calcareous sandstones; siliceous limestones; and argillaceous limestones. Intermediate or compound types are also abundant.

The first variety of sediment to be considered is the fine hematitic sandstone. As this is composed largely of fine angular quartz grains, it will be spoken of as a grit. This grit is usually more prominent in the upper members of the formation in any given locality, but also occurs in smaller amount near the base. In the field it is reddish to chocolate brown in color. In thin section, seen with reflected light, it is red. The principal mineral constituent is quartz, in small grains. The interstitial



FIG. 86.—Argillaceous limestone or calcareous clay, from the lower part of the Morrison formation near Mack, Colorado.

About 28 \times .

material is clayey matter stained to a bright red by hematite. The origin of this hematite will be discussed below. The relative proportions of quartz and hematitic matrix vary greatly.

This red quartz grit grades into fine calcareous sandstone through fine sands with the interstitial matter partly stained by hematite and partly made up of fine-grained carbonates. It also grades into the true clays through members with a similar amount of quartz and a considerable amount of kaolin. Such a type occurs near the top of the Garden Park

section (Fig. 85). The iron in this case is sometimes, at least, in the form of limonite, rather than hematite. Magnetite is present in small amounts, and dense patches of limonite represent oxidized pyrite. The kaolin is more or less abundant and is mixed with fine-grained carbonitic material. Hematite is also present in small amount.

The hematite in the red or brown grits has probably originated through oxidization of the siderite present in the light colored calcareous sand-

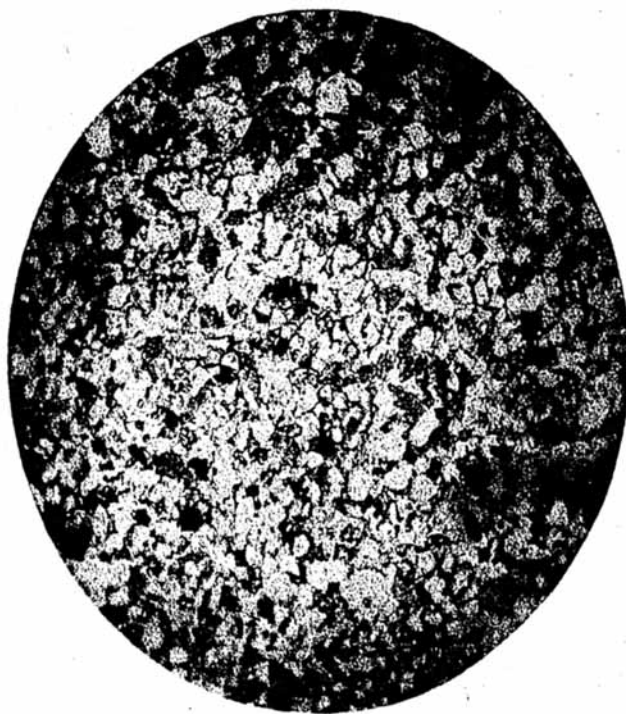


FIG. 87.—Calcareous sandstone, from the lower beds of the Morrison formation at Garden Park, Colorado.

The clear grains are quartz, and the mottled grains are calcite. About 28 X.

stones. The iron carbonate was probably present in the original deposits. The alteration may have taken place to some extent before burial, but it is more likely that it is the result of a long-continued process in the buried rock.⁷

The clays are nearly always impure. They usually contain, along with the kaolin, a considerable amount of fine angular quartz and very

⁷ See the discussion of the origin of the formation, p. 168.

fine granular calcite and other carbonates. Mixtures of this kind comprise a large proportion of the formation.

Fine calcareous sandstones are very common and occur in thick beds. They consist typically of fine angular quartz with a matrix of fine granular calcite and probably dolomite and siderite. They grade into the clays through varieties with more kaolinic matter, and into the limestones through members with less quartz. They also grade into arkoses through



FIG. 88.—*Calcareous arkosic sandstone, from the lower beds of the Morrison formation at Garden Park, Colorado.*

The clear light and dark grains are quartz; the interstitial material is calcite; and the banded grains are plagioclase feldspar. About 28 \times . (Crossed nicols.)

fine sandstones in which feldspars occur. The latter are especially abundant in the lower beds of the formation. The calcareous sandstones also grade into quartz sandstones through varieties with less calcite and more quartz.

The limestones are usually only a foot or two in thickness. They vary from practically pure carbonates to siliceous and argillaceous varieties. Small molluscan fossils are sometimes present.

Calcareous nodules and concretions often form beds amidst less calcareous sandstones or clays.

The coarser sandstones vary from nearly pure quartz sands to highly calcareous and arkosic members. One of the typical coarser sandstones is that in which the dinosaur bones occur in the Marsh-Hatcher quarry near Cañon City, Colorado. This sandstone consists largely of medium-sized to large quartz grains, often well rounded, with finer angular quartz



FIG. 89.—*Calcareous argillaceous sandstone, from the Morrison formation near Cañon City, Colorado.*

The light grains are quartz; and the dark interstitial material is mixed carbonates and clay. About 28 \times .

grains scattered among them. Feldspars are fairly abundant and often of large size. Volcanic ash grains occur, some of which are perfectly fresh, others being altered to masses of granular quartz. Calcite, and probably some dolomite, occurs in the interstitial spaces. Some of this is granular and some of it is coarsely crystalline.

Coarse, round-grained sandstones of this type often show avolian cross-bedding.

Hard, quartzitic sandstones, with clay pebbles, often occur.

Conglomerates occur occasionally, but are not especially abundant and are never very coarse.

Gypsum is fairly abundant in the formation, but not in the form of distinct beds.



FIG. 90.—*Fossiliferous limestone, from the Morrison formation near Cañon City, Colorado.*

About 28 X.

The coarse sandstones are often resistant and stand out in cliffs (Fig. 32). In some cases where they are very calcareous, the coarser beds are friable and crumble easily. The finer materials are usually easily eroded, but are sometimes resistant to the hammer.

PALEONTOLOGY

FLORA OF THE MORRISON FORMATION

The following species of cycads from the Morrison formation have been described by Ward:

<i>Cycadella reedii</i>	<i>Cycadella ferruginea</i>
<i>Cycadella beechertiana</i>	<i>Cycadella contracta</i>
<i>Cycadella wyomingensis</i>	<i>Cycadella gravis</i>
<i>Cycadella knowltoniana</i>	<i>Cycadella verrucosa</i>
<i>Cycadella compressa</i>	<i>Cycadella jejuna</i>
<i>Cycadella jurassica</i>	<i>Cycadella concinna</i>
<i>Cycadella nodosa</i>	<i>Cycadella crepidaria</i>
<i>Cycadella cirrata</i>	<i>Cycadella gelida</i>
<i>Cycadella exogena</i>	<i>Cycadella carbonensis</i>
<i>Cycadella ramentosa</i>	<i>Cycadella knightii</i>

There is also *Cycadella utopiensis* (Ward) Wieland, *Araucarioxylon* ? *obscureum* Knowlton, and possibly *Pinoxylon dacotense* Knowlton.*

This flora is of no great value in indicating the age of the formation, but it does signify that the climate in which it lived was warm and probably moist in places at least.

INVERTEBRATE FAUNA OF THE MORRISON FORMATION

The invertebrate fauna of the Morrison consists of fresh-water pelecypods and gastropods, with a few crustaceans. A number of species have been described and considerable material collected. There is nothing in the fauna of any value in determining the age of the formation. The following species have been described:

PELECYPODA

Unio felchii White, On the Fresh-Water Invertebrates of the North American Jurassic. U. S. Geol. Surv., Bull. No. 29, p. 16, pl. 1, figs. 1-5, 1886.

*The flora is described and discussed in the following works:

Ward, L. F. Description of a New Genus and Twenty New Species of Fossil Cycadean Trunks from the Jurassic of Wyoming. Wash. Acad. Sci., Proc., vol. 1, pp. 253-300, pls. xiv-xvi, 1900.

Ward, L. F. Status of the Mesozoic Floras of the United States. U. S. Geol. Surv., 20th Ann. Rep., pt. 2, pp. 211-747, pls. xxi-cxxxix, 1900.

Ward, L. F. Status of the Mesozoic Floras of the United States. U. S. Geol. Surv., Monograph No. 48, pt. 1, text, 616 pp., pt. 2, plates, 119 pls., 1905.

Wieland, G. R. American Fossil Cycads. Carnegie Inst. Wash., Pub. 34, 286 pp., 50 pls., 137 figs., 1906.

Berry, E. W. Lower Cretaceous Floras of the World. Md. Geol. Surv., vol. Low. Cret., pp. 99-151, 1 fig., 1911.

Unio toxonotus White, On the Fresh-Water Invertebrates of the North American Jurassic. U. S. Geol. Surv., Bull. No. 29, p. 17, pl. 2, figs. 1, 2, 1886.

Unio macropisthus White, On the Fresh-Water Invertebrates of the North American Jurassic. U. S. Geol. Surv., Bull. No. 29, p. 17, pl. 2, fig. 7, 1886.

Unio iridoides White, On the Fresh-Water Invertebrates of the North



FIG. 91.—Calcareous arkosic sandstone, from the Morrison formation near Cañon City.

The clear round grains are quartz and feldspar; the interstitial banded grains are calcite; and the large grain at the left, with the dark grain above it, is replaced volcanic ash. About 28 X.

American Jurassic. U. S. Geol. Surv., Bull. No. 29, p. 17, pl. 2, figs. 3, 4, 1886.

Unio lapilloides White, On the Fresh-Water Invertebrates of the North American Jurassic. U. S. Geol. Surv., Bull. No. 29, p. 18, pl. 2, figs. 5, 6, 1886.

Unio stewardi White, Report on the Geology of the Eastern Portion of the Uinta Mountains and a Region of Country Adjacent Thereto, by J. W.

Powell, p. 110. U. S. Geological and Geographical Survey of the Territories, 1876.

Unio nucalis Meek and Hayden, Phila. Acad. Nat. Sci., Proc. 1858, p. 52.

Unio willistoni Logan, The Stratigraphy and Invertebrate Faunas of the Jurassic Formation in the Freezeout Hills of Wyoming. Kans. Univ. Quart., vol. ix, p. 133, pl. 31, fig. 10, 1900.



FIG. 92.—The same slice and field as fig. 91, with crossed nicols.

This shows the banded feldspars and the granular quartz which has replaced the volcanic ash.

Unio knighti Logan, The Stratigraphy and Invertebrate Faunas of the Jurassic Formation in the Freezeout Hills of Wyoming. Kans. Univ. Quart., vol. ix, p. 134, pl. 31, figs. 7, 9, 1900.

Unio baileyi Logan, The Stratigraphy and Invertebrate Faunas of the Jurassic Formation in the Freezeout Hills of Wyoming. Kans. Univ. Quart., vol. ix, p. 134, pl. 31, figs. 4, 6, 8, 11, 1900.

GASTROPODA

Limnæa ativuncula White, On the Fresh-Water Invertebrates of the North American Jurassic. U. S. Geol. Surv., Bull. No. 29, p. 20, pl. 4, figs. 10, 11, 1886.

Limnæa consortis White, On the Fresh-Water Invertebrates of the North American Jurassic. U. S. Geol. Surv., Bull. No. 29, p. 20, pl. 4, figs. 8, 9, 1886.



FIG. 93.—*Calcareous arkosic sandstone; the same rock as figs. 91 and 92.*

The large dark grains are partly replaced volcanic ash, and the large grain with inclusions in the center of the field is unaltered volcanic ash. About 28 X.

Limnæa ? accelerata White, On the Fresh-Water Invertebrates of the North American Jurassic. U. S. Geol. Surv., Bull. No. 29, p. 20, pl. 4, figs. 12-15, 1886.

Planorbis veteris Meek and Hayden, Phila. Acad. Nat. Sci., Proc. for 1860, p. 418, 1861.

Vorticifex stearnsii White, On the Fresh-Water Invertebrates of the

North American Jurassic. U. S. Geol. Surv., Bull. No. 29, p. 21, pl. 4, figs. 4-6, 7, 1886.

Valvata scabrida Meek and Hayden, Phila. Acad. Nat. Sci., Proc. for Oct. 1860, p. 418, 1861.

Viviparus gilli Meek and Hayden, Palaeontology of the Upper Missouri. Smiths. Contr. Knowledge, vol. xiv, no. 4, p. 115, pl. 5, figs. 3a, 3b, 1865.

Lioplacodes veternus Meek and Hayden, Phila. Acad. Nat. Sci., Proc. for Dec. 1861, p. 444 [1862?].

Neritina nebrascensis Meek and Hayden, Phila. Acad. Nat. Sci., Proc. for Dec. 1861, p. 444 [1862?].

Valvata leei Logan, The Stratigraphy and Invertebrate Faunas of the Jurassic Formation in the Freezeout Hills of Wyoming. Kans. Univ. Quart., vol. ix, p. 133, pl. 31, figs. 1-3, 1900.

OSTRACODA

The following ostracods are reported by White, identified by T. Rupert Jones:

Metacypris forbesii Jones.

Metacypris ? Bears a distant resemblance to "*Cypris* ? *conculcata*" Jones.

Darwinula leguminella E. Forbes.

Cypris purbeckensis ? Forbes sp.

Two undetermined species of *Cypris*.

ARUNDEL FORMS

The following species are reported by W. B. Clark from the Arundel formation of Maryland:

Bythinia arundelensis Clark, [Systematic Paleontology], "Mollusca." Md. Geol. Surv., vol. Low. Cret., p. 211, pl. 21, fig. 6, 1911.

Viviparus marylandicus Clark, [Systematic Paleontology], "Mollusca." Md. Geol. Surv., vol. Low. Cret., p. 212, pl. 21, figs. 1-3, 1911.

Viviparus arlingtonensis Clark, [Systematic Paleontology], "Mollusca." Md. Geol. Surv., vol. Low. Cret., p. 212, pl. 21, figs. 4, 5, 1911.

Cyrena marylandica Clark, [Systematic Paleontology], "Mollusca." Md. Geol. Surv., vol. Low. Cret., p. 213, pl. 21, figs. 8, 9, 1911.

The only reference of importance in connection with the invertebrate fauna of the Morrison formation not included in the above list is: White, C. A. Review of the Non-Marine Fossil Mollusca of North America. U. S. Geol. Surv., 3rd Ann. Rep., pp. 405-550, 32 pls., 1883.

The invertebrate fauna is exclusively fresh-water in character.

VERTEBRATE FAUNA OF THE MORRISON FORMATION

The vertebrate fauna of the Morrison formation is a remarkable one. It consists of a number of primitive mammals, a variety of reptiles, and a few fish. The most conspicuous element in the fauna is the dinosaurs. Representatives of the three principal groups of dinosaurs are present, each with a number of forms. The Sauropoda are especially abundant, being represented by many genera and species. In fact, all the American Sauropoda occur in beds of Morrison age, or very close to it. It is beyond the province of the present paper to enter into an extensive discussion of the various vertebrate remains in detail. The more important forms are discussed briefly. References are given to the original literature on the various forms.

MAMMALIA

Allodon laticeps Marsh

Allodon laticeps Marsh, Notice of New Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxi, p. 511, 1881.

Allodon fortis Marsh

Allodon fortis Marsh, American Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxxiii, p. 327 (331), 1887.

Asthenodon segnis Marsh

Asthenodon segnis Marsh, American Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxxi, p. 327 (336), 1887.

Dryolestes priscus Marsh

Dryolestes priscus Marsh, Fossil Mammals from the Jurassic of the Rocky Mountains. Amer. Journ. Sci., 3rd ser., vol. xv, p. 459, 1878.

Dryolestes arcuatus

Dryolestes arcuatus Marsh, Notice of New Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 396 (397), 1879.

Dryolestes gracilis Marsh

Dryolestes gracilis Marsh, Notice of New Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxi, p. 511 (513), 1881.

Dryolestes obtusus Marsh

Dryolestes obtusus Marsh, Notice of Jurassic Mammals representing two New Orders. Amer. Journ. Sci., 3rd ser., vol. xx, p. 235 (237), 1880.

Dryolestes vorax Marsh

Dryolestes vorax Marsh, Additional Remains of Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 215, 1879.

Ctenacodon serratus Marsh

Ctenacodon serratus Marsh, Notice of New Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 396, 1879.

Ctenacodon nanus Marsh

Ctenacodon nanus Marsh, Notice of New Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xx, p. 511 (512), 1880.

Ctenacodon potens Marsh

Ctenacodon potens Marsh, American Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxxiii, p. 327 (333), 1887.

Dicrocynodon victor Marsh

Diplocynodon victor Marsh, Notice of Jurassic Mammals representing two New Orders. Amer. Journ. Sci., 3rd ser., vol. xx, p. 235, 1880.

Dicrocynodon victor Marsh. (In Osborn, H. F. On the Structure and Classification of the Mesozoic Mammalia. Phila. Acad. Nat. Sci., Journ. (2), ix, p. 186 (263), 1888.)

Docodon striatus Marsh

Docodon striatus Marsh, Notice of New Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxi, p. 511 (512), 1881.

Ennacodon crassus Marsh

Enneodon crassus Marsh, American Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxxiii, p. 327 (339), 1887.

Ennacodon crassus Marsh, Additional Genera established by Prof. O. C. Marsh, 1880-1889. Printed privately, probably in 1889.

Ennacodon affinis Marsh

Enneodon affinis Marsh, American Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxxiii, p. 327 (339), 1887.

Ennacodon affinis Marsh, Additional Genera Established by Prof. O. C. Marsh, 1880-1889. Printed privately, probably in 1889.

Paurodon valens Marsh

Paurodon valens Marsh, American Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxxiii, p. 327 (342), 1887.

Stylacodon gracilis Marsh

Stylacodon gracilis Marsh, Notice of a New Jurassic Mammal. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 60, 1879.

Stylacodon validus Marsh

Stylacodon validus Marsh, Notice of Jurassic Mammals representing two New Orders. Amer. Journ. Sci., 3rd ser., vol. xx, p. 235 (236), 1880.

Laodon venustus Marsh

Laodon venustus Marsh, American Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxxiii, p. 327 (337), 1887.

Priacodon ferox Marsh

Tinodon ferox Marsh, Notice of Jurassic Mammals representing two New Orders. Amer. Journ. Sci., 3rd ser., vol. xx, p. 235 (236), 1880.

Triconodon ferox Cope, The Mechanical Causes of the Development of the Hard Parts of the Mammalia. Journ. Morph., vol. iii, p. 137 (227), 1889.

Priacodon ferox Roger, Verzeichniss der bisher bekannten fossilen Säugethiere. Neu zusammengestellt von Dr. Otto Roger, kgl. Regierungs- und Kreis-Medizinrath in Augsburg. Bericht. naturwiss. Vereins f. Schwaben und Neuburg (a. V.), xxxii, p. 1, 1896.

Menacodon rarus Marsh

Menacodon rarus Marsh, American Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xxxiii, p. 327 (340), 1887.

Tinodon bellus Marsh

Tinodon bellus Marsh, Additional Remains of Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 215 (216), 1887.

Tinodon lepidus Marsh

Tinodon lepidus Marsh, Notice of New Jurassic Mammals. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 396 (398), 1879.

Tinodon robustus Marsh

Tinodon robustus Marsh, Notice of New Jurassic Mammals. Amer. Journ. Sci., 3rd sér., vol. xviii, p. 396 (397), 1879.

Triconodon bisulcus Marsh

Triconodon bisulcus Marsh, Notice of Jurassic Mammals representing two New Orders. Amer. Journ. Sci., 3rd sér., vol. xx, p. 235 (237), 1880.

The mammals are all archaic in character and belong to primitive forms of marsupials and monotremes. They are known only from jaws and teeth.

Valuable information concerning the Morrison mammals is contained in "American Jurassic Mammals," by O. C. Marsh; "On the Structure and Classification of the Mesozoic *Mammalia*," by H. F. Osborn; and "Evolution of the Mammalian Molar Teeth," by H. F. Osborn. For further references the reader is referred to O. P. Hay's "Bibliography and Catalogue of the Fossil Vertebrata of North America."

AVES

Laopteryx priscus Marsh

Laopteryx priscus Marsh, Discovery of a Fossil Bird in the Jurassic of Wyoming. Amer. Journ. Sci., 3rd sér., vol. xxi, p. 341, 1881.

From the Morrison formation of Wyoming, probably from Como Bluff. Known from part of a skull.

REPTILIA

DINOSAURIA

SAUROPODA^{*}**Astrodon johnstoni** Leidy

Astrodon Johnston, Amer. Journ. Dental Sci., 1859.

Astrodon johnstoni Leidy, Memoir on the Extinct Reptiles of the Cretaceous Formations of the United States. Smiths. Contr. Knowledge, xiv, pp. 102, 119, 1865.

This form is known from teeth only. It was discovered in the Arundel beds of Maryland.

^{*} This group will be treated thoroughly in the forthcoming monograph by Professor H. F. Osborn.

***Dystrophæus viæmalæ* Cope**

Dystrophæus viæmalæ Cope, On a Dinosaurian from the Trias of Utah. Amer. Philos. Soc., Proc., vol. xvi, p. 579, 1877.

The type locality of this species is Painted Canyon, in southeastern Utah. The beds were considered by Cope to be Triassic, but have since been found to be the McElmo formation. Only a small part of the skeleton is known.

***Atlantosaurus montanus* Marsh**

Atlantosaurus montanus Marsh, Notice of a new and Gigantic Dinosaur. Amer. Journ. Sci., 3rd ser., vol. xiv, p. 87, 1877.

Atlantosaurus montanus Marsh, Notice of New Dinosaurian Reptiles from the Jurassic formation. Amer. Journ. Sci., 3rd ser., vol. xiv, p. 514, 1877.

This form was discovered at Morrison, Colorado. It was the first form of the Sauropoda found in the eastern Rocky Mountain area of the Morrison formation and the one which gave its name to the formation as "Atlantosaurus beds."

***Camarasaurus supremus* Cope**

Camarasaurus supremus Cope, On a Gigantic Saurian from the Dakota Epoch of Colorado. Paleontological Bulletin No. 25, 1877.

From the uppermost beds of the Morrison formation near Cañon City, Colorado. A well known and characteristic Morrison form.

***Caulodon diversidens* Cope**

Caulodon diversidens Cope, On Reptilian Remains from the Dakota Beds of Colorado. Amer. Philos. Soc., Proc., vol. xvii, p. 193, 1877.

Probably from the uppermost beds of the Morrison formation near Cañon City, Colorado. Known only from teeth.

***Apatosaurus ajax* Marsh**

Apatosaurus ajax Marsh, Notice of New Dinosaurian Reptiles from the Jurassic formation. Amer. Journ. Sci., 3rd ser., vol. xiv, p. 514, 1877.

Type locality. Morrison, Colorado. Characteristic portions of the skeleton known.

***Morosaurus grandis* Marsh**

Apatosaurus grandis Marsh, Notice of New Dinosaurian Reptiles from the Jurassic formation. Amer. Journ. Sci., 3rd ser., vol. xiv, p. 514, 1877.

Morosaurus grandis Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. I. Amer. Journ. Sci., 3rd ser., vol. xvi, p. 414, 1878.

This form is widespread in the Morrison formation. The type locality and level is the Morrison formation at Como Bluff, Wyoming. Almost the entire skeleton is known.

***Amphicœlias altus* Cope**

Amphicœlias altus Cope, On Amphicœlias, a genus of Saurians from the Dakota epoch of Colorado. Paleontological Bulletin No. 27 (Amer. Philos. Soc., Proc., vol. xvii, p. 243), 1877.

Probably from the uppermost beds of the Morrison formation near Cañon City, Colorado. Known from a small part of the skeleton.

***Amphicœlias latus* Cope**

Amphicœlias latus Cope, On Amphicœlias, a genus of Saurians from the Dakota epoch of Colorado. Paleontological Bulletin No. 27 (Amer. Philos. Soc., Proc., vol. xvii, p. 243), 1877.

Probably from the uppermost beds of the Morrison formation near Cañon City, Colorado. Only a small part of skeleton known.

***Symphrophus musculosus* Cope**

Symphrophus musculosus Cope, On the Vertebrata of the Dakota Epoch of Colorado. Paleontological Bulletin No. 28 (Amer. Philos. Soc., Proc., vol. xvii, p. 246), 1878.

From near Cañon City, Colorado, probably from the uppermost beds of the Morrison formation. Not very well known.

***Caulodon leptoganus* Cope**

Caulodon leptoganus Cope, On the Vertebrata of the Dakota Epoch of Colorado. Paleontological Bulletin No. 28 (Amer. Philos. Soc., Proc., vol. xvii, p. 247), 1878.

Same locality and horizon as above. Known only from teeth.

***Atlantosaurus immanis* Marsh**

Atlantosaurus immanis Marsh, Notice of New Dinosaurian Reptiles. Amer. Journ. Sci., 3rd ser., vol. xv, p. 241, 1878.

From the middle Morrison beds near Morrison, Colorado. Comparatively small part of skeleton known.

Morosaurus impar Marsh

Morosaurus impar Marsh, Notice of New Dinosaurian Reptiles. Amer. Journ. Sci., 3rd ser., vol. xv, p. 242, 1878.

Type locality and level, Morrison formation at Como Bluff, Wyoming. Known from very imperfect material only.

Epanterias amplexus Cope

Epanterias amplexus Cope, A New Opisthocœlous Dinosaur. Amer. Nat., vol. xii, p. 406, 1878.

Probably from the uppermost Morrison beds near Cañon City, Colorado. Known from very imperfect remains.

Amphicœlias fragillimus Cope

Amphicœlias fragillimus Cope, A New Species of Amphicœlias. Amer. Nat., vol. xii, p. 563, 1878.

From the uppermost beds of the Morrison formation near Cañon City, Colorado. Not well known.

Morosaurus robustus Marsh

Morosaurus robustus Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. I. Amer. Journ. Sci., 3rd ser., vol. xvi, p. 414, 1878.

Type locality and level probably the Morrison formation at Como Bluff, Wyoming. Parts of skull and skeleton known.

Diplodocus longus Marsh

Diplodocus longus Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. I. Amer. Journ. Sci., 3rd ser., vol. xvi, p. 414, 1878.

From the middle beds of the Morrison formation near Cañon City, Colorado. Several more or less complete skeletons of this form are known.

Apatosaurus laticollis Marsh

Apatosaurus laticollis Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. II. Amer. Journ. Sci., 3rd ser., vol. xvii, p. 88, 1879.

Only a small portion of the skeleton is preserved.

Camarasaurus leptodirus Cope

Camarasaurus leptodirus Cope, New Jurassic Dinosauria. Amer. Nat., vol. xiii, p. 402, 1879.

From the upper beds of the Morrison formation near Cañon City, Colorado. Only a few vertebrae are known.

Brontosaurus excelsus Marsh

Brontosaurus excelsus Marsh, Notice of New Jurassic Reptiles. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 503, 1879.

This form is perhaps the best known of the Sauropoda. The type specimen was found in the Morrison beds at Como Bluff, near Medicine Bow, Wyoming. Other material of the species has been found in the Morrison beds at various localities. Nearly the complete skeleton is known.

Brontosaurus amplus Marsh

Brontosaurus amplus Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. V. Amer. Journ. Sci., 3rd ser., vol. xxi, p. 421, 1881.

Morrison formation at Como Bluff. Part of skeleton known.

Diplodocus lacustris Marsh

Diplodocus lacustris Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. VII. Diplodocidae, a New Family of the Sauropoda. Amer. Journ. Sci., 3rd ser., vol. xxvii, p. 166, 1884.

Morrison formation near Morrison, Colorado. Known from fragmentary material only.

Pleurocælus nanus Marsh

Pleurocælus nanus Marsh, Notice of a New Genus of Sauropoda and other new Dinosaurs from the Potomac Formation. Amer. Journ. Sci., 3rd ser., vol. xxxv, p. 90, 1888.

From the Arundel beds in Maryland, probably near Muirkirk. Characteristic parts of the skeleton are known.

Pleurocælus altus Marsh

Pleurocælus altus Marsh, Notice of a New Genus of Sauropoda and other new Dinosaurs from the Potomac Formation. Amer. Journ. Sci., 3rd ser., vol. xxxv, p. 92, 1888.

From the Arundel formation near Muirkirk, Maryland. Part of hind limb only is known.

Morosaurus lentus Marsh

Morosaurus lentus Marsh, Notice of New American Dinosauria. Amer. Journ. Sci., 3rd ser., vol. xxxvii, p. 333, 1889.

Morrison beds of Wyoming, probably from Como Bluff. The type specimen consists of a nearly complete skeleton of an immature individual.

Morosaurus agilis Marsh

Morosaurus agilis Marsh, Notice of New American Dinosauria. Amer. Journ. Sci., 3rd ser., vol. xxxvii, p. 334, 1889.

From the middle beds of the Morrison formation near Cañon City, Colorado. The skull and a few other parts of the skeleton are known.

Barosaurus lentus Marsh

Barosaurus lentus Marsh, Description of New Dinosaurian Reptiles. Amer. Journ. Sci., 3rd ser., vol. xxxix, p. 85, 1890.

From the Morrison formation near Piedmont, South Dakota. A comparatively small part of the skeleton is known.

Pleurocœlus montanus Marsh

Pleurocœlus montanus Marsh, The Dinosaurs of North America. U. S. Geol. Surv., 16th Ann. Rep., Pt. 2, p. 184, 1896.

Type locality and horizon unknown. Very little of skeleton is known.

Barosaurus affinis Marsh

Barosaurus affinis Marsh, Footprints of Jurassic Dinosaurs. Amer. Journ. Sci., 4th ser., vol. vii, p. 228, 1899.

From the Morrison formation near Piedmont, South Dakota. Very little of the skeleton is known.

Diplodocus carnegii Hatcher

Diplodocus carnegii Hatcher, *Diplodocus* Marsh, its Osteology, Taxonomy, and Probable Habits, with a Restoration of the Skeleton. Carn. Mus. Mem., vol. i, p. 1, 1901.

From the Morrison beds near Sheep Creek, Wyoming. Most of the skeleton is well known. Restorations of this form have been installed in many of the large museums of the world; consequently this is one of the best known of the Sauropoda.

Elosaurus parvus Peterson and Gilmore

Elosaurus parvus Peterson and Gilmore, *Elosaurus parvus*; a new Genus and Species of the Sauropoda. Carn. Mus. Ann., vol. i, p. 490, 1902.

From the Morrison formation near Sheep Creek, Wyoming. Characteristic parts of the skeleton of a young individual are known.

Haplocanthosaurus priscus Hatcher

Haplocanthus priscus Hatcher, A New Sauropod Dinosaur from the Jurassic of Colorado. Biol. Soc. Wash., Proc., vol. xvi, p. 1, 1903.

Haplocanthosaurus priscus Hatcher, A New Name for the Dinosaur Haplocanthus. Biol. Soc. Wash., Proc., vol. xvi, p. 100, 1903.

From the middle beds of the Morrison formation near Cañon City, Colorado. A considerable part of the skeleton is known. The form is the most primitive of the American Sauropoda (along with *H. utterbacki*).

Brachiosaurus altithorax Riggs

Brachiosaurus altithorax Riggs, *Brachiosaurus altithorax*, the Largest Known Dinosaur. Amer. Journ. Sci., 4th ser., vol. xv, p. 299, 1903.

From the McElmo beds in the Grand River Valley, near Fruita, Colorado. This is a remarkable form in which the humerus is longer than the femur. It is represented by several species in German East Africa. The present species is known from characteristic parts of the skeleton.

Haplocanthosaurus utterbacki Hatcher

Haplocanthosaurus utterbacki Hatcher, Osteology of Haplocanthosaurus, with Description of a New Species, and Remarks on the Probable Habits of the Sauropoda and the Age and Origin of the Atlantosaurus beds. Carn. Mus. Mem., vol. ii, p. 27, 1903.

From the middle beds of the Morrison formation near Cañon City, Colorado. It is larger than *H. priscus*, and is known from characteristic parts of the skeleton.

Apatosaurus louisæ Holland

Apatosaurus louisæ Holland, A New Species of Apatosaurus. Carn. Mus. Ann., vol. x, p. 143, 1915.

A large and well characterized form from the Morrison formation near Jensen, Utah.

THEPODA

Dryptosaurus trihedrodon (Cope)

Laelaps trihedrodon Cope, U. S. Geol. and Geog. Surv. Terr., vol. iii, art. xxxiii, p. 805, 1877.

Dryptosaurus trihedrodon Marsh, Notice of a new and Gigantic Dinosaur. Amer. Journ. Sci., 3rd ser., vol. xiv, p. 87, 1877. [Footnote to p. 88 states *Laelaps* Cope to be preoccupied by *Laelaps* Koch. *Dryptosaurus* is proposed to replace it.]

Discovered near Cañon City, Colorado. Probably from the uppermost beds of the Morrison formation. Known from fragmentary remains only.

***Hypsirophus discurus* Cope**

Hypsirophus discurus Cope, A New Genus of Dinosauria from Colorado. Amer. Nat., vol. xii, p. 188, 1878.

Probably from the uppermost beds of the Morrison formation near Cañon City, Colorado. Known from part of the skeleton.

***Allosaurus fragilis* Marsh**

Allosaurus fragilis Marsh, Notice of New Dinosaurian Reptiles from the Jurassic formation. Amer. Journ. Sci., 3rd ser., vol. xiv, p. 514 (515), 1877.

"Upper Jurassic of Colorado." Probably the middle beds of the Morrison formation near Cañon City, Colorado. Known from practically complete skeletons.

***Creosaurus atrox* Marsh**

Creosaurus atrox Marsh, Notice of New Dinosaurian Reptiles. Amer. Journ. Sci., 3rd ser., vol. xv, p. 241 (243), 1878.

From the "Upper Jurassic of the Rocky Mountains," probably the middle beds of the Morrison formation near Cañon City, or near Morrison, Colorado. Known from representative portions of the skeleton.

***Antrodemus lucaris* (Marsh)**

Allosaurus lucaris Marsh, Notice of New Dinosaurian Reptiles. Amer. Journ. Sci., 3rd ser., vol. xv, p. 241 (242), 1878.

Labrosaurus lucaris Marsh, Principal Characters of American Jurassic Dinosaurs. Amer. Journ. Sci., 3rd ser., vol. xvii, p. 86 (91), 1879.

Antrodemus lucaris Hay, Bibliography and Catalogue of the Fossil Vertebrata of North America. U. S. Geol. Surv., Bull. No. 179, p. (489), 1902.

From the "Upper Jurassic of the Rocky Mountains," probably from the middle beds of the Morrison formation near Cañon City, or near Morrison, Colorado. Small part of the skeleton is known.

Antrodesmus valens Leidy

[*Poecilopleuron*] (*Antrodesmus*) Leidy, Phila. Acad. Nat. Sci., Proc., vol. for 1870, p. 3 (4), 1870.

Labrosaurus ferox Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. VIII. The Order Theropoda. Amer. Journ. Sci., 3rd ser., vol. xxvii, p. 329 (333), 1884.

Antrodesmus valens Hay, Bibliography and Catalogue of the Fossil Vertebrata of North America. U. S. Geol. Surv., Bull. No. 179, p. (490), 1902.

From Middle Park, Colorado. Small part of skeleton known.

Cœlurus agilis Marsh

Cœlurus agilis Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. VIII. The Order Theropoda. Amer. Journ. Sci., 3rd ser., vol. xxvii, p. 329 (335), 1884.

"Jurassic, Colorado." Probably the middle part of the Morrison formation, near Cañon City, or near Morrison, Colorado. Small part of skeleton known.

Cœlurus fragilis Marsh

Cœlurus fragilis Marsh, Notice of new Jurassic Reptiles. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 501 (504), 1879.

"Jurassic." Probably from the Morrison formation. Small part of skeleton known.

This species was about the size of a wolf, being unusually small for a dinosaur.

Tichosteus lucasanus Cope

Tichosteus lucasanus Cope, On Reptilian Remains from the Dakota of Colorado. Amer. Philos. Soc., Proc., vol. xvii, p. 193 (195), 1877.

From near Cañon City, Colorado. Probably from the uppermost beds of the Morrison formation. Only small part of the skeleton is known.

Tichosteus æquifacies Cope

Tichosteus æquifacies Cope, Descriptions of new Extinct Vertebrata from the Upper Tertiary and Dakota Formations. U. S. Geol. and Geog. Surv. Terr., vol. iv, p. 379 (392), 1878.

Probably from the uppermost beds of the Morrison formation near Cañon City, Colorado. Only a small part of the skeleton is known.

***Ceratosaurus nasicornis* Marsh**

Ceratosaurus nasicornis Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. VIII. The Order Theropoda. Amer. Journ. Sci., 3rd ser., vol. xxvii, p. 329 (330), 1884.

Probably from the middle beds of the Morrison formation near Cañon City, Colorado. Most of the skeleton is known.

***Ornitholestes hermanni* Osborn**

Ornitholestes hermanni Osborn, *Ornitholestes Hermanni*, a New Compsognathoid Dinosaur from the Upper Jurassic. Amer. Mus. Nat. Hist., Bull., vol. xix, art. xii, p. 459, 1903.

From "Bone Cabin Quarry" near Medicine Bow, Wyoming, in the Morrison formation. This form is especially light and small.

***Allosaurus medius* Marsh**

Allosaurus medius Marsh, Notice of a New Genus of Sauropoda and other new Dinosaurs from the Potomac Formation. Amer. Journ. Sci., 3rd ser., vol. xxxv, p. 89 (93), 1888.

From the Arundel formation, near Muirkirk, Prince Georges County, Maryland. Known from teeth only.

***Creosaurus potens* Lull**

Creosaurus potens Lull, [Systematic Paleontology], Reptilia. Md. Geol. Surv., vol. Low. Cret., p. 183, 1911.

From the Arundel formation in Washington, D. C. Known from fragmentary material only.

***Cœlurus gracilis* Marsh**

Cœlurus gracilis Marsh, Notice of a New Genus of Sauropoda and other new Dinosaurs from the Potomac Formation. Amer. Journ. Sci., 3rd ser., vol. xxxv, p. 89 (94), 1888.

From the Arundel formation, near Muirkirk, Maryland. Small part of the skeleton is known.

PREDENTATA

***Stegosaurus armatus* Marsh**

Stegosaurus armatus Marsh, A New Order of Extinct Reptilia (Stegosauria) from the Jurassic of the Rocky Mountains. Amer. Journ. Sci., 3rd ser., vol. xiv, p. 513, 1877.

According to Marsh, the type was found in the Jurassic of the Rocky Mountains in Colorado, near the locality of *Atlantosaurus montanus*. This means the Morrison formation at Morrison. Most of the skeleton is known.

***Stegosaurus discurus* (Cope)**

Hypsirophus discurus Cope, A New Genus of Dinosauria from Colorado. Amer. Nat., vol. xii, p. 188, 1878.

Stegosaurus discurus Hay, Bibliography and Catalogue of the Fossil Vertebrata of North America. U. S. Geol. Surv., Bull. No. 179, p. (496), 1902.

Probably from the uppermost beds of the Morrison formation near Cañon City, Colorado. Characteristic portions of the skeleton are known.

***Stegosaurus seeleyanus* (Cope)**

Hypsirophus seeleyanus Cope, New Jurassic Dinosauria. Amer. Nat., vol. xiii, p. 402 (404), 1879.

Stegosaurus seeleyanus Hay, Bibliography and Catalogue of the Fossil Vertebrata of North America. U. S. Geol. Surv., Bull. No. 179, p. (496), 1902.

Locality not given. Hay notes it as from the "Jurassic, Colorado." Characteristic portions of the skeleton are known.

***Stegosaurus unguatus* Marsh**

Stegosaurus unguatus Marsh, Notice of New Jurassic Reptiles. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 501 (504), 1879.

Locality not given in the original description, but the form is known to exist in the Morrison formation. The complete skeleton is known. This is one of the best known members of the Morrison fauna.

***Stegosaurus affinis* Marsh**

Stegosaurus affinis Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. IV. Spinal Cord, Pelvis, and Limbs of *Stegosaurus*. Amer. Journ. Sci., 3rd ser., vol. xxi, p. 167 (169), 1891.

Locality not given. Parts of the skeleton are known.

***Stegosaurus stenops* Marsh**

Stegosaurus stenops Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. IX. The Skull and Dermal Armor of *Stegosaurus*. Amer. Journ. Sci., 3rd ser., vol. xxxiv, p. 413 (414), 1887.

Probably from the middle beds of the Morrison formation near Cañon City, Colorado. Practically the complete skeleton is known.

***Stegosaurus sulcatus* Marsh**

Stegosaurus sulcatus Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. IX. The Skull and Dermal Armor of *Stegosaurus*. Amer. Journ. Sci., 3rd ser., vol. xxxiv, p. 413 (415), 1887.

No locality is given. Part of the skeleton is known.

***Stegosaurus duplex* Marsh**

Stegosaurus duplex Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. IX. The Skull and Dermal Armor of *Stegosaurus*. Amer. Journ. Sci., 3rd ser., vol. xxxiv, p. 413 (416), 1887.

Locality not given. Posterior portion of the skeleton known.

***Diracodon laticeps* Marsh**

Diracodon laticeps Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. V. Amer. Journ. Sci., 3rd ser., vol. xxi, p. 417 (421), 1881.

From the *Atlantosaurus* beds of Wyoming, probably from Como Bluff. Very little of the skeleton is known.

***Stegosaurus longispinus* Gilmore**

Stegosaurus longispinus Gilmore, Osteology of the Armored Dinosauria in the United States National Museum, with Special Reference to the Genus *Stegosaurus*. U. S. Nat. Mus., Bull. No. 89, 136 pp., 37 pls., 73 figs., 1914.

From the Morrison 1½ miles east of Alcova, Natrona County, Wyoming. Characteristic portions of the skeleton are known.

***Hoplitosaurus marshi* Lucas**

Hoplitosaurus marshi, from the Lakota beds of the Black Hills region, may also occur in the Morrison formation, but has not been definitely reported.

***Camptosaurus dispar* Marsh**

Camptonotus dispar Marsh, Notice of New Jurassic Reptiles. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 501, 1879.

Camptosaurus [*dispar*] Marsh, Names of Extinct Reptiles. Amer. Journ. Sci., 3rd ser., vol. xxix, p. 169, 1885.

No locality given. Characteristic portions of the skeleton are known.

Camptosaurus amplus Marsh

Camptonotus amplus Marsh, Notice of New Jurassic Reptiles. Amer. Journ. Sci., 3rd ser., vol. xviii, p. 501 (503), 1879.

Camptosaurus [amplus] Marsh, Names of Extinct Reptiles. Amer. Journ. Sci., 3rd ser., vol. xxix, p. 169, 1885.

From a lower horizon than *C. dispar*. No locality given. A small part of the skeleton is known.

Camptosaurus medius Marsh

Camptosaurus medius Marsh, The Typical Ornithopoda of the American Jurassic. Amer. Journ. Sci., 3rd ser., vol. xlviii, p. 85, 1894.

No locality given. Parts of the skeleton are known.

Camptosaurus nanus Marsh

Camptosaurus nanus Marsh, The Typical Ornithopoda of the American Jurassic. Amer. Journ. Sci., 3rd ser., vol. xlviii, p. 85, 1894.

No locality given. Small part of the skeleton is known. This form is one of the smallest of the dinosaurs, being only about six feet long, according to Marsh's estimate.

Laosaurus celer Marsh

Laosaurus celer Marsh, Notice of New Dinosaurian Reptiles. Amer. Journ. Sci., 3rd ser., vol. xv, p. 241 (244), 1878.

Probably from the middle beds of the Morrison formation near Cañon City, Colorado. Characteristic portions of the skeleton are known. This form is remarkably bird-like, and is very small, being only about the size of a fox.

Laosaurus gracilis Marsh

Laosaurus gracilis Marsh, Notice of New Dinosaurian Reptiles. Amer. Journ. Sci., 3rd ser., vol. xv, p. 241 (244), 1878.

Locality not given. It is known from Como Bluff. Exceedingly small.

Laosaurus consors Marsh

Laosaurus consors Marsh, The Typical Ornithopoda of the American Jurassic. Amer. Journ. Sci., 3rd ser., vol. xlviii, p. 85 (87), 1894.

From the Morrison of Wyoming, probably from Como Bluff. Characteristic portions of the skeleton are known.

Dryosaurus altus Marsh

Laosaurus altus Marsh, Principal Characters of American Jurassic Dinosaurs. Pt. I. Amer. Journ. Sci., 3rd ser., vol. xvi, p. 411 (415), 1878.

Dryosaurus altus Marsh, The Typical Ornithopoda of the American Jurassic. Amer. Journ. Sci., 3rd ser., vol. xlviii, p. 85 (86), 1894.

From the Morrison formation in Colorado and Wyoming. Characteristic portions of the skeleton are known.

Macelognathus vagans Marsh

Macelognathus vagans Marsh, A New Order of Extinct Jurassic Reptiles (Macelognatha). Amer. Journ. Sci., 3rd ser., vol. xxvii, p. 341, 1884.

Morrison beds of Wyoming, probably from Como Bluff. Known from fragmentary remains only. The position of this form is unknown. Marsh placed it among the turtles and Hay provisionally placed it among the dinosaurs.

Apatodon mirus Marsh

Apatodon mirus Marsh, Notice of Some New Vertebrate Fossils. Amer. Journ. Sci., 3rd ser., vol. xiv, p. 249 (255), 1877.

Lower Cretaceous or Jurassic, according to Marsh, no locality being given. Fragmentary remains only are known. The form is probably a dinosaur.

Camptosaurus depressus Gilmore

Camptosaurus depressus Gilmore, Osteology of the Jurassic Reptile *Camptosaurus*, with a Revision of the Species of the Genus, and Descriptions of Two New Species. U. S. Nat. Mus., Proc., vol. xxxvi, p. 197 (292), 1909.

The type specimen of this species was discovered in the Lakota beds near Buffalo Gap, South Dakota. A specimen has been found in the Morrison formation near Como, Wyoming, which probably belongs to this species. Known from the posterior portion of the skeleton.

Camptosaurus browni Gilmore

Camptosaurus browni Gilmore, Osteology of the Jurassic Reptile *Camptosaurus*, with a Revision of the Species of the Genus, and Descriptions of Two New Species. U. S. Nat. Mus., Proc., vol. xxxvi, p. 197 (295), 1909.

From the Morrison formation 8 miles east of Como, Wyoming. Known from a considerable portion of the skeleton.

Brachyrophus altarkansanus Cope

Brachyrophus altarkansanus Cope, Descriptions of New Reptiles from the Upper Tertiary and Dakota Formations and Geog. Surv. Terr., Bull. No. iv, p. 379 (390), 1878.

Near Cañon City, Colorado; probably from the upper Morrison formation. Known from several vertebrae.

RHYNCHOCEPHALA

Opisthias rarus Gilmore

Opisthias rarus Gilmore, A New Rhynchocephalian, Jurassic of Wyoming, with Notes on the Fauna of "Q Nat. Mus., Proc., vol. xxxvii, p. 35, 1909.

From the Morrison formation at Como Bluff, Wyoming. Secondary bones of several individuals.

CROCODYLIA

Goniopholis lucasii (Cope)

Amphicolylus lucasii Cope, Descriptions of New Reptiles from the Upper Tertiary and Dakota Formations. Geog. Surv. Terr., Bull. No. iv, p. 379 (391), 1878.

Goniopholis lucasii Zittel, Handbuch der Paläontologie, III Bd., p. 677, 1890.

From the uppermost beds of the Morrison formation, Colorado. Known from vertebrae and skull.

Goniopholis felix (Marsh)

Diplosaurus felix Marsh, Notice of Some New Vertebrates, Amer. Journ. Sci., 3d ser., vol. xiv, p. 249 (251), 1877.

Goniopholis felix Zittel, Handbuch der Paläontologie, III Bd., p. 677, 1890.

According to Marsh, from the Lower Cretaceous of Colorado. Probably from the middle beds of the Morrison Cañon City, Colorado. This form is known from the vertebrae.

Goniopholis gilmorei Holland

Goniopholis gilmorei Holland, A New Crocodile from Wyoming. Carn. Mus. Ann., vol. iii, p. 131, 1905.

From the Morrison formation in the Freeze-out Hill. The skull is known.

Brachyrophus altarkansanus Cope

Brachyrophus altarkansanus Cope, Descriptions of New Extinct Vertebrates from the Upper Tertiary and Dakota Formations. U. S. Geol. and Geog. Surv. Terr., Bull. No. iv, p. 379 (390), 1878.

Near Cañon City, Colorado, probably from the uppermost beds of the Morrison formation. Known from several vertebrae.

RHYNCHOCEPHALIA**Opisthias rarus Gilmore**

Opisthias rarus Gilmore, A New Rhynchocephalian Reptile from the Jurassic of Wyoming, with Notes on the Fauna of "Quarry 9." U. S. Nat. Mus., Proc., vol. xxxvii, p. 35, 1909.

From the Morrison formation at Como Bluff, Wyoming. Known from dentary bones of several individuals.

CROCODYLIA**Goniopholis lucasii (Cope)**

Amphicotylus lucasii Cope, Descriptions of New Extinct Vertebrata from the Upper Tertiary and Dakota Formations. U. S. Geol. and Geog. Surv. Terr., Bull. No. iv, p. 379 (391), 1878.

Goniopholis lucasii Zittel, Handbuch der Paläontologie. I. Abth. Paläozoologie. III Bd., p. 677, 1890.

From the uppermost beds of the Morrison formation near Cañon City, Colorado. Known from vertebrae and skull.

Goniopholis felix (Marsh)

Diplosaurus felix Marsh, Notice of Some New Vertebrate Reptiles. Amer. Journ. Sci., 3rd ser., vol. xiv, p. 249 (254), 1877.

Goniopholis felix Zittel, Handbuch der Paläontologie. I. Abth. Paläozoologie. III Bd., p. 677, 1890.

According to Marsh, from the Lower Cretaceous or Wealden of Colorado. Probably from the middle beds of the Morrison formation near Cañon City, Colorado. This form is known from the skull and a few vertebrae.

Goniopholis gilmorei Holland

Goniopholis gilmorei Holland, A New Crocodile from the Jurassic of Wyoming. Carn. Mus. Ann., vol. iii, p. 431, 1905.

From the Morrison formation in the Freezeout Hills of Wyoming. The skull is known.

CHELONIA

Compsemys plicatulus Cope(Syn. *Glyptops ornatus* Marsh)

Compsemys plicatulus Cope, On Reptilian Remains from the Dakota Beds of Colorado. Amer. Philos. Soc., Proc., vol. xvii, p. 193 (196), 1877.

From the uppermost beds of the Morrison formation near Cañon City, Colorado. Known from a considerable portion of the skeleton.

PTEROSAURIA

Dermodactylus montanus Marsh

Pterodactylus montanus Marsh, New Pterodactyl from the Jurassic of the Rocky Mountains. Amer. Journ. Sci., 3rd ser., vol. xvi, p. 233, 1878.

Dermodactylus montanus Marsh, Note on American Pterodactyls. Amer. Journ. Sci., 3rd ser., vol. xxi, p. 342, 1881.

From the Morrison formation in Wyoming, probably from Como Bluff. Known from various remains of wings, teeth, and vertebrae.

PISCES

Ceratodus guntheri Marsh

Ceratodus guntheri Marsh, New Species of *Ceratodus*, from the Jurassic. Amer. Journ. Sci., 3rd ser., vol. xv, p. 76, 1878.

"Jurassic of Colorado." Probably from the middle beds of the Morrison formation near Cañon City, Colorado. Known from a left lower dental plate.

Ceratodus robustus Knight

Ceratodus robustus Knight, Some New Jurassic Vertebrates from Wyoming. Amer. Journ. Sci., 4th ser., vol. v, p. 186, 1898.

From the Morrison formation in Albany County, Wyoming, associated with crocodile and dinosaur bones. Known from part of a tooth.

Ceratodus americanus Knight

Ceratodus americanus Knight, Some New Jurassic Vertebrates from Wyoming. Amer. Journ. Sci., 4th ser., vol. v, p. 186, 1898.

From the Morrison formation in Carbon County, Wyoming, associated with bones of a carnivorous dinosaur. Known from part of a left mandibular tooth.

This fauna in its general character seems to require low, or at least level and aquatic, conditions. Woodworth (1894, 1), in discussing the relations of peneplanation to organic evolution, states that the reptiles and in particular the dinosaurs are correlated in development with the growth of the peneplain. He makes the following remarks regarding the reptilia:

"Reptilia are characteristic lowland forms. They will endure the cold of high altitudes and latitudes only by falling into a state of torpidity. In the development of the peneplain from the high relief of the Permian, and again, at the close of the Jura-Trias, the widening out of the lowland, with plains and jungles near tide-level, followed by depression of the land, must have highly favored the water-loving reptilia. It is to these geographic circumstances, I think, that we must look for an explanation of the remarkable history of this class in Mesozoic times."

Many of the forms listed above are no doubt synonyms, but their determination is beyond the scope of the present paper.

AGE OF THE MORRISON FORMATION

The age of the Morrison formation has been the subject of considerable discussion in the past. The reports of the early surveys refer to the Morrison beds as "Jurassic beds," "Lower Dakota" and other terms signifying various ages. Cope (1877, 5; 1878, 8) described typical Morrison reptiles as coming from beds of the "Dakota Epoch" in Colorado.

Cope (1884, 1) made a faunal comparison of the Morrison and Wealden formations, but made no definite statement as to their age or correlation. Osborn (1888, 2) compared the mammals of the Morrison with those of the Purbeck beds, and considered the former to be of Jurassic age. Emmons, Cross and Eldridge (1896, 1) stated that from the point of view of the stratigrapher the assignment of the Morrison beds to the Lower Cretaceous (Comanchean) was more desirable than assignment to the Upper Jurassic, "not only because it accords better with the sequence of sedimentation thus far disclosed in the adjoining regions of Kansas and Texas, but because it places the physical break whose effects are recognized over the whole continent between these two great time divisions rather than in the midst of one of them." Marsh (1896, 5; 1896, 7) vigorously maintained the Jurassic age of the *Atlantosaurus* Beds and correlated them with the Wealden of Europe. Scott (1897, 5) in his *Manual of Geology* placed the Morrison or Como in the Comanchean. Ward (1900, 6) considered the evidence from the cycads sufficient to place the formation in the Jurassic. Knight (1900, 2)

placed the formation in the upper Jurassic, being closer to the Purbeckian than to the Oxfordian in age. Logan (1900, 5) correlated the Morrison of the Freezeout Hills region with the Wealden of England. Riggs (1901, 4) described the Morrison or McElmo of the Grand River Valley as Jurassic. Loomis (1901, 6) noted the resemblance of the Morrison mammalian fauna to the fauna of the Purbeck beds of England, and on this ground assigned the formation to the Jurassic. Hatcher (1903, 4) correlated the lower beds of the Morrison at Cañon City with the Sundance beds in Wyoming. He considered the cycads as pointing to the Jurassic age of the deposits, and the dinosaurs as agreeing most closely with those of the Middle Oölite series of Europe. He concluded that there is undoubtedly Jurassic represented in the formation, but that it was quite probable that some of the formation might be of Lower Cretaceous age. Williston (1905, 4) gave strong evidence from the vertebrate fauna for Comanchean age of the Morrison. Lull (1911, 8) discussed the fauna of the Arundel formation and considered it to be Lower Cretaceous or Comanchean in age.

In view of the great differences of opinion concerning the age of the Morrison it is important to review the evidence at present available on this subject. The principal evidence from the stratigraphic relations is here summarized.

The youngest beds upon which the Morrison rests are the sandstones of the Unkpapa formation in the Black Hills area. (It is possible that the Exeter sandstone in New Mexico may be equivalent in age to the Unkpapa.) Below the Unkpapa, which is thin, lies the Sundance formation. Over wide areas the Morrison lies on the Sundance directly. The Sundance, according to Stanton (1909, 9), belongs to the lower part of the upper Jurassic. The Jurassic sea retreated, therefore, considerably before the close of the Jurassic period, although it is possible that post-Sundance beds were laid down and eroded before the deposition of the Morrison. The Morrison over wide areas cannot be older than middle or late upper Jurassic in age. It is probable that some of the lower beds in the southwestern areas where the Sundance is absent may be slightly older than the oldest Morrison beds which directly overlie the Sundance. In the Black Hills area there is a time interval between the Sundance and the base of the Morrison which is represented by the Unkpapa sandstone. There is often a sharp contact between the Morrison and Sundance formations in the Wyoming areas. This indicates that the Morrison in these areas may be considerably younger than the Sundance.

The oldest beds overlying the Morrison, the age of which is definitely

known, are the Washita beds near Cañon City, Colorado (Stanton, 1905, 11). The upper beds of the Morrison at this locality cannot be later than Fredericksburg in age, but may be much older. In Montana the Morrison is overlain by the Kootenie formation, which contains Comanchean plant remains, some of which are represented in the Patuxent formation in Maryland. The Kootenie apparently lies conformably on the Morrison, and it is quite probable that the Morrison and Kootenie are not distinct formations, but belong to the same deposition cycle. This question will be taken up again in considering the evidence from the vertebrate fossils.

In many areas the Morrison is overlain by the Cloverly, Lakota, or Purgatoire formations, which belong, in whole or in part, to the Comanchean period. In western Colorado the Morrison is overlain by the Dakota sandstone. The contact with the Cloverly and Purgatoire is often sharp, but there is no evidence of extensive erosion between the two formations. Erosion to a slight extent probably did take place, however. As noted by Lee, the relations of the Morrison to the overlying formations are much closer than to those beneath.

In Texas and adjoining regions, where the Morrison is absent, there is a great development of Comanchean marine deposits. Where the Morrison is present in considerable thickness, the marine Comanchean is absent or is very thin.

The evidence from the stratigraphic relations indicates, therefore, that for the *eastern areas at least*, the age of the Morrison is Comanchean rather than Jurassic.

The evidence from the flora as to the age of the Morrison is not conclusive, a number of species of cycads comprising the entire known flora. As noted above, Ward placed the age of these as Jurassic. The flora of the overlying formations has more significance and will be considered in connection with the discussion of the evidence from the vertebrates.

The invertebrate fauna has no value in determining the age of the formation. Most of the genera range from Morrison to recent time, a few being older. The species also have considerable range and are difficult to determine accurately, owing to poor preservation or lack of distinguishing characters.

The vertebrate fauna, which is one of the largest and most characteristic vertebrate faunas in any known geological formation, has often been appealed to in connection with the age of the Morrison. Marsh (1878, 2) referred the Morrison, or *Atlantosaurus Beds*, as he called it, to the Jurassic on the basis of evidence from the reptilian fauna. Just what this evidence consists in was never published by Marsh. He correlated

the beds with the Wealden of Europe, which he considered to be Jurassic (1895, 1). In discussing the age of the Wealden he correlated it with the Morrison on the basis of its reptilian fauna, and considered it, on this evidence, to be Jurassic. It seems to the present writer that, so far as the reptilian faunas of the Morrison and Wealden were concerned, Marsh was arguing in a circle. Marsh (1896, 7; 1896, 4) quoted Seward as favoring the Jurassic age of the Wealden on the evidence of its fossil plants, and Smith-Woodward as maintaining the Jurassic age of the Wealden on the evidence from the fossil fishes. Marsh also considered the Sauropoda of the Potomac beds to be more primitive than those of the Morrison, and from this judged the Morrison to be younger than the Potomac.

Hatcher (1903, 4) held that the reptilian fauna of the Morrison was closer to that of the middle Jurassic of Europe than to the Wealden.

Lull (1911, 8), discussing the reptilian fauna of the Arundel formation, said: "The character of these dinosaurs, and of the crocodile as well, correlates the beds wherein they are found absolutely with the Morrison (Como) of the West. An accurate comparison with European formations is more difficult, as the faunas have fewer forms in common. *Pleurocælus* is reported from the Kimmeridgian as well as from the Wealden, but that from the former horizon may readily have been ancestral to the Arundel type, although the European material is too fragmentary to admit of a just comparison. Of the other dinosaurs, the affinities seem to be entirely with Wealden forms, *Calurus* being found therein, while *Allosaurus* compares in point of size and dentition with the Wealden *Megalosaurus*. *Dryosaurus* has its nearest European ally in *Hypsilophodon*, again a Wealden type, and the crocodile, *Goniopholis*, is reported from the Wealden and its marine equivalent, the Purbeckian, not from the older Jurassic levels.

"The weight of this evidence would seem to place this fauna beyond the Jurassic into the beginning of Cretaceous times."

The most complete comparison between the Morrison and corresponding vertebrate faunas has been made by Williston (1905, 4), and the following is extracted from his paper:

"*Cetiosaurus longus* Owen is from the Great Oolite, or Middle Jura; *C. glymptonensis* Phillips, imperfectly known, is from the same horizon; while *C. brevis* Owen, also imperfectly known, is from the Wealden, but is referred by Seeley to *Ornithopsis*, by Lydekker to *Morsanius*. *Ornithopsis* Seeley is from the Wealden; *O. humerocristatus* Hulke, from the Kimmeridge. Other uncertain forms are from the Wealden of England. *Titanosaurus* is referred by Lydekker to probable Upper Greensand.

Remains of the Sauropoda are spoken of as 'frequent' in the Wealden, while from the Middle Jura only a few are known, and all these are of one, or at most two, species. I certainly cannot see what evidence these forms present that would lead one to say that the American forms are clearly Jurassic. The range of this suborder, so far as is known, is from the Middle Jurassic to the Upper Cretaceous, though there may be doubt as to the real age of the Indian form. Their known geographic distribution is Europe, India, Madagascar, Africa, South and North America—that is, over the whole world. The generalized characters presented by them are not at all sufficiently well understood to say off-hand that certain forms are older than others. . . .

"It is quite true that the Brachiosauridae of Riggs (*Brachiosaurus* Riggs and *Haplocanthosaurus* Hatcher) have a more generalized structure in this respect than has *Celiosaurus* even, but we have no reason to assume that all the generalized forms died out with the advent of specialized ones, such as are most of the American Sauropoda. Nor do I think it quite certain that the Brachiosauridae are the most generalized, certainly not if the hypothesis that the Sauropoda have been derived from primitive ornithopoda is at all probable. Furthermore, the genus *Pleurocelus*, originally described from the Potomac beds, has been recognized in the Atlantosaurus beds by Marsh, and later by Hatcher, and forms from the Wealden have been referred, provisionally at least, to the same genus.

"For the most part, the carnivorous dinosaurs have little value in the correlation of the horizons. *Megalosaurus* is reported from Europe from the Lias to the Wealden. In America we have three or four genera of the Megalosauridae in the Atlantosaurus beds, *Creosaurus*, *Allosaurus*, *Antrodemus*, and *Ceratosaurus*, and the family survived to the Laramie Cretaceous. *Caelurus* was described from the Atlantosaurus beds, but is known to occur in the Potomac beds. In the Wealden of England *Aristosuchus* is very closely allied, indeed is supposed to be identical, and all the other genera referred to the Caeluridae are from the Wealden. In the extensive hollowness of the bones of the skeleton, *Caelurus* is not only the most specialized of dinosaurs, but of all vertebrate animals. The evidence then to be derived from the Theropoda is for the contemporaneity of the Wealden with the Atlantosaurus beds.

"So far from the evidence of the Iguanodontia being against this correlation, I believe that it is decidedly for the identity of the two horizons. Iguanodonts are found in abundance in the Atlantosaurus beds, and of the largest size and high specialization. . . . And, so far from the American forms being the most generalized, Lydekker says that *Hypsilophodon* is 'the smallest and least specialized member of the

family?" Perhaps this opinion is not decisive, but *Hypsilophodon* certainly cannot be called the most specialized. Lydekker even refers certain Kimmeridge and Wealden species to the American genus *Camplosaurus*.

"Perhaps the best evidence we have for the Jurassic age of the American deposits is that of *Stegosaurus*, which is so closely allied to *Omosaurus* Owen from the Kimmeridge that Marsh believed the two genera to be identical. On the other hand, this type of the predentate dinosaurs seems to range from the Lower Liás in *Scelidosaurus* to *Paleoscincus* from the Laramie, with four or five genera referred to the group from the Wealden. Its value, then, is slight.

"Other evidence offered by the reptiles from the American beds is slight. A genus of crocodiles called by Marsh *Diplosaurus* seems to include *Hyposaurus vebbii* Cope from the Comanche Cretaceous of Kansas. Years ago Zittel referred both of these forms to the genus *Goniopholis* from evidence communicated by Professor Marsh, and *Goniopholis* is said to be 'a genus very characteristic of the Wealden' (Lydekker). The recently published figure of the type specimen of *Diplosaurus*, when compared with figures of *Goniopholis*, shows a startling resemblance. Indeed, so far as I can learn, there are no brevirostral crocodiles known from below the Purbeck or lithographic slates. The evidence, then, of the crocodiles is decidedly for the uppermost Jurassic or Wealden age of the American beds.

"Of the Chelonia the single species *Compsemys plicatulus* Cope (*Glutops ornatus* Marsh) is not at all decisive. If the species is correctly referred to *Compsemys*, all its related forms are of Cretaceous age. Nor is there any evidence to be obtained from the pterosaurs or birds. Of the mammals I will not venture to speak, save that I think that there are too few forms known from the Wealden to offer any basis of comparison. Of the fishes a few species of *Ceratodus* only are known, and inasmuch as this genus is supposed to range from the Trias to the present time, these species have no correlating value whatever.

"To sum up: there is no valid vertebrate evidence pointing to an age greater than the Purbeck for the *Atlantosaurus* beds, and but very little for a greater age than that of the Wealden.

Unfortunately, in most of the discussions hitherto the *Atlantosaurus* beds have been considered as some brief epoch. The faunas of the upper and lower parts have never been differentiated, save in some exceptional cases. Marsh, indeed, rarely ever gave any precise location for his type specimens, referring them simply to Wyoming, Colorado, etc. The term 'Upper Jurassic' has been applied indiscriminately to the whole fauna.

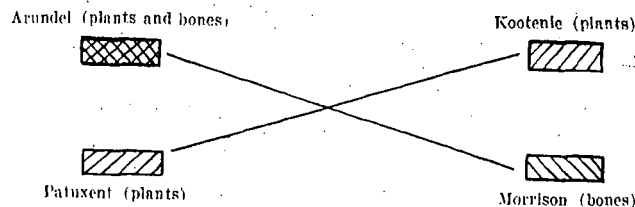
. . . Hatcher was the first to distinctly point out that the uppermost part of the beds might include a part of the Lower Cretaceous. . . .

"I am strongly of the opinion that these deposits, nowhere, so far as known, exceeding a thickness of 500 feet, really represent various epochs between the Jurassic and the Upper Cretaceous, and that sooner or later we shall have evidence to distinguish the later from the earlier faunas. . . .

"The upper part of the *Atlantosaurus* beds is, it seems to me, indisputably Cretaceous; the lowermost part is probably not older than the Wealden, though possibly of Purbeckian age. I therefore strongly protest against the common usage of referring all the fossils from these beds to the upper Jura. Until more is known of the different faunas contained in it, the only proper designation for the composite faunas included in them is Jura-Cretaceous; this assumes that the Wealden is really Jurassic."

A sauropodan coracoid was discovered by Larkin (1910, 2) in the Trinity formation in Oklahoma. There is no Morrison present at this locality, but it is possible that the bone had been transported some distance.

Berry (1911, 7) has discussed the three divisions of the Potomac formation and their floras at some length, and has shown that the floras of the Patuxent and Arundel beds, which have many forms in common, are closely allied to the flora of the Kootenic formation. "The two floras [Patuxent-Arundel and Kootenic] have a great many elements in common, and upon the basis of the floras alone the conclusion would be reached that the base of the Kootenic was approximately the same age or slightly older than the base of the Patuxent." The Patuxent formation, however, which contains a larger flora than the Arundel, lies below the Arundel, which contains the Morrison fauna. In the west this condition is reversed; the Kootenic, which contains a flora very closely allied to that of the Patuxent-Arundel series, lies above the Morrison with its fauna. This relation is shown by the following diagram:



The conclusion seems to be that the Kootenic and Morrison are practically the same thing, and that the Patuxent and Arundel are very closely

related. Berry gives the correlation of Morrison-Kootenie together approximately equalling the Patuxent-Arundel.

Lee (1915, 2) has recently given strong diastrophic evidence for the Comanchean age of the formation.

The evidence for Comanchean age of the Morrison seems much stronger than that for Jurassic age. The interval between the Sundance and the Washita is a long one, and the Morrison may not occupy the whole of it, but only the upper portion. It is probable that the Morrison is not of exactly the same age throughout the whole area of its occurrence, and it is very improbable that every particular bed in a given locality necessarily has a corresponding bed in some other locality. The Morrison is the product of a slow accumulation process, and therefore may fill a considerable part of the interval between the Sundance and Washita. The most probable condition is that the greater part of the Morrison is Comanchean in age, with Jurassic members in its lower portion in some areas. It is possible also that in the southwestern areas the base of the Morrison is much lower than in the eastern areas, and may include considerable Jurassic.

ORIGIN AND INTERPRETATION OF THE MORRISON FORMATION

SUMMARY OF CHARACTERS

In the preceding pages many facts regarding the Morrison formation have been recorded. A number of these which may have a bearing on the question of the origin and geologic significance of the Morrison are here briefly summarized:

1). The Morrison has a very wide distribution. As noted in the summary of the stratigraphic relations of the formation, the area which is now underlain by the Morrison probably covers several hundred thousand square miles, and its original area, before being exposed to the extensive erosion which occurred in the Rocky Mountain region at the end of Cretaceous time, probably amounted to four or five hundred thousand square miles and perhaps more.

2). Considering the vast area occupied by the formation, it is very thin. The greatest thickness reported is something like 900 feet, but it is usually very much less than that.

3). The thickness is variable over large areas, and to a lesser extent in small areas. In the southwestern areas the thickness varies from 400 to 900 feet; in the northwestern areas the actual thickness and variation are both somewhat less; in the eastern and central Wyoming areas the

thickness is usually about 200 feet, but in some cases it is as high as 300 or as low as 150 feet; in the Black Hills area the thickness is never more than 200 feet, and ranges from that down to zero, averaging about 100 feet; in the southeastern Colorado and New Mexico areas the thickness varies from 400 to 200 feet. It will be seen from this that while there is a considerable variation in individual areas, the *thickness is much greater in the western areas than in the eastern, and that there is a thinning out eastward, which is very gradual considering the distances involved.*

4). The size of grain of the sediments varies to a considerable extent. Fine-grained material is the most abundant; a considerable amount of medium-grained material is present, with a smaller amount of coarse-grained rock. Very coarse sediment does not appear to be present. Coarse material is more abundant in the western than in the eastern areas.

5). The succession of beds varies greatly from point to point, but the kind of succession is practically the same in every locality. Fine joint-clays or grits usually make up the greater part of the outcrops, especially toward the top. Sandstone and nodule layers are usually present at intervals in the section, and often thin limestones or occasionally conglomerate beds. These various members are found to be arranged in a certain order in one locality, and in another locality not far away the succession will be different. Sandstone beds that are thick in the first section may be thin or absent in the second. Limestone beds present in a certain position in the first section may be in another position in the second section, or absent altogether. On studying the various sections of the formation a constant thinning and thickening or replacement of individual members is to be seen. An examination of the sections in the stratigraphic division of this paper will emphasize the prevalence of the conditions above described. This type of succession in many sections has been described by Lee as "uniformly variable."

6). The contacts of the various members with each other is usually sharp, showing rather rapid changes of conditions of deposition. Beds of fine grits or clays are often followed directly by beds of medium-grained sandstone and vice versa.

7). Channeling is often present, certain layers lying in troughs eroded in the underlying beds. This has been discussed in the section on structures.

8). Cross-bedding is common in the Morrison. Both the stream and wind types have been observed.

9). The principal mineral ingredient in the Morrison sediments is quartz. Other materials usually or often present are calcite, kaolin, iron oxides, mixed carbonates, gypsum and feldspar. Mica and volcanic ash are present in very small amounts.

10). The larger quartz grains are usually well rounded: the smaller ones are often angular.

11). The iron oxides usually occur as interstitial material between fine quartz grains, and sometimes as a staining of fine-grained binding matter. In some cases it is uniformly distributed, and in other cases it is scattered in patches.

12). The limestones are thin, often very pure calcite or dolomite, and consist almost entirely of very fine-grained material. They are sometimes argillaceous and sandy.

13). The sandstones are often nearly pure quartz; when fine-grained they sometimes have interstitial materials of iron oxides, kaolin and mixed carbonates; when coarse they are often extremely calcareous, and sometimes arkosic.

14). The arkosic sandstones usually occur near the base of the formation. They are occasionally found in the middle beds, and are rare near the top.

15). The color of the rocks of the formation varies greatly, often in short distances, so that the formation was formerly called the "Variegated Beds." This variegated character is sometimes present in a hand specimen. There is often a pronounced color banding in the formation.

Gray and purplish red are the usual colors, but green, white, blue, yellow and black are also often present, and all these colors grade into each other in a complex fashion.

16). The coarse sandstones are usually gray or white. The finer clays and grits may be either green, gray, white, blue, red or dark brown. The green clays are often finer than the red or brown grits.

17). The flora of the formation is of such a nature as to indicate a warm and moist climate at the time of deposition, in some areas at least. This flora is not especially abundant, however.

18). The invertebrate fauna consists of fresh-water types. They belong to genera having a wide geologic range.

19). The vertebrate fauna is composed of aquatic, amphibious, terrestrial and aerial forms. The fish were aquatic, of course. The habitat of the sauropod dinosaurs has been the subject of controversy; some writers have held that they were exclusively terrestrial, others that they were exclusively aquatic, and still others that they were amphibious. The latter theory seems the most probable. They certainly possess aquatic

adaptations, but they also possess adaptations for walking on land, in some forms at least. The crocodiles were amphibious and probably the turtles as well. The theropod and predentate dinosaurs were terrestrial, and probably the mammals as well. No marine vertebrates have been found in beds which have been definitely identified as Morrison.

20). The skeletons of the large dinosaurs often indicate, to a certain extent, by their preservation, some of the physical processes connected with their burial. In some cases, of which the Bone Cabin Quarry near Medicine Bow, Wyoming, is an example, the bones of many individuals and species are found mixed up in an intricate manner, so that anything like a complete skeleton is rare. In other cases complete or nearly complete skeletons are found in position. In still other cases a skeleton will be found complete up to a certain point and then end suddenly, with not a bone to be found beyond in any direction.

The mixed-up bones indicate that they were gathered together from their original resting-places by current action, in a restricted area, such as one individual stream. The complete skeletons indicate swift burial in relatively quiet waters or by wind action. The partial skeletons point toward erosion of the beds they were deposited with, after their burial.

21). The Morrison is more closely related to the overlying than to the underlying formations.

22). The contact with the overlying beds is sharp in places, and indicates a change of depositional conditions. There may have been a small amount of erosion of Morrison beds prior to the deposition of the overlying beds in places, but if so it was probably slight.

23). In Texas, where the Morrison is absent, its place in the stratigraphic column is occupied by great thicknesses of marine Comanchean beds.

24). In the north the Morrison is overlain conformably by the Kootenic formation. The Kootenic is similar in character to the Morrison, and part of it, at least, may belong to the Morrison. The flora of the Kootenic and Potomac formations have a bearing on this question, which has been discussed in the section on the age of the Morrison.

25). The formation lies on beds of various ages, from Archean to upper Jurassic.

26). There is a widespread erosion plane beneath the Morrison over most of its area. The relation to the Sundance will be discussed later.

27). The formation is present in isolated areas in the Rocky Mountains in Colorado, about midway between the eastern and western Colorado areas.

HISTORY OF PREVIOUS OPINIONS AS TO THE ORIGIN OF THE FORMATION

The origin of the Morrison formation has been the subject of considerable attention in the past. Some of the more important discussions are noted at this point. Their merits will be discussed later.

C. A. White (1886, 2) in discussing the Morrison and its invertebrate fauna came to the following conclusions: "The character of the strata in which these fresh-water Jurassic fossils were found, both at the Colorado and at the Wyoming localities, in addition to the character of the fossils themselves, is such as to indicate for them a lacustrine, and not an estuary or a fluvatile, origin: that is, the rocks are regularly stratified and have such an aspect and character as to indicate that they were deposited in one or more large bodies of water. If the strata of the Colorado and of the Wyoming localities really contain an identical fauna, it may be regarded as probable that they were deposited in one and the same lake. The distance between the Colorado and the Wyoming localities indicates that the supposed lake was nearly 200 miles across; and, if the Black Hills fossils also belonged to the same contemporaneous fauna, the assumed lake was much larger."

Riggs (1901, 4) described the Morrison of the Grand River Valley, and gave an interpretation of the history of deposition as follows: "Let us attempt to trace the history of the Jurassic formation as evidenced by the nature of the rocks, the stratigraphy and the occurrence of fossils: Given an arm of the Jurassic sea, fed by rivers and open to the ebb and flow of tide waters. Under these conditions the sediments washed down by the river everywhere accumulated slowly, and alternating with them thin ledges of limestone and gypsum were laid down. Occasional strata of sand accumulated by the action of the retarded currents about the estuaries of streams. Later, by some change in levels, the ingress of seawater was cut off, but the outlet still remained and so ensued the gradual change from salt to fresh water. Then followed a period of comparatively uninterrupted deposition in which the green shale was laid down under still water. Along with it were deposited near the mouths of streams the occasional homogeneous beds of green sand. As the basin filled up and its outlet deepened, the lake became shallower until its bed was invaded by the shifting channels of broad and shallow streams. Its sand-bars have formed the cross-bedded sandstone ledges which mark the transition from the lower to the upper clays. With the shallower waters came the great land and shore reptiles and about the estuaries of streams their remains were deposited abundantly.

"Again the lake waters invaded the region and the deposition of sand

in this locality was cut off. The period following was one of greater changes and probably of slower deposition than that preceding the river period. The presence of fine reeds or sedges shows that the water was shallow, at least in places, and parts of skeletons found on irregular surfaces imbedded in these reedy clays suggest mud-bars or islands, on which they have stranded. In one instance part of a skeleton found imbedded in a stratum of blue clay which thinned out and was replaced by sandstone with pebbles at the base, indicates that the carcass was buried in a mud-bank bordering a stream or water-current. The interruption of the vertebral column and the displacement of the ribs in one direction show that the stream was sufficient to carry away the missing part of the skeleton.

"The tendency toward a more shaly nature and the presence of carbonaceous matter in the upper measures indicate the return of shallows and the greater abundance of vegetable matter. This condition evidently culminated in the great influx of sand laden with deciduous leaves which marks the period represented by the Dakota sandstone."

Loomis (1901, 6) discussed the Morrison in the Como Bluff region. He referred to the beds as "non-marine Jura," and later in the same paper stated that the shore line, which was about 30 miles south of Como Bluff during Shirley or Sundance time, moved 100 miles to the south at the beginning of Como or Morrison time, and that the deposits were then laid down in shallow water; also that "the bones [of dinosaurs] are clearly floated out to sea by the presence of considerable meat on them." There is thus an element of contradiction in Loomis's interpretation.

Hatcher (1903, 4) discussed the origin of the Morrison at some length. As his conclusions are closer to those of the present writer than those of any of the other workers mentioned, the important parts of his discussion will be quoted at this point.

"I can fully agree with Dr. White as to the necessity of assuming the existence in Jurassic times of a continental land-mass of the dimensions intimated in his paper. But it does not seem to me at all necessary to presuppose the existence of a Jurassic lake of even the smaller or more moderate dimensions assigned by him. While I do not wish to be understood as denying the possibility of the existence of a great lake in Jurassic times extending as Dr. White has suggested from the Arkansas River in Colorado to the Black Hills of South Dakota, it does appear to me that our present knowledge of the character of the faunas, both terrestrial and aquatic (fresh-water) as well as of the lithologic and stratigraphic features exhibited by the beds themselves is decidedly against such a presumption. If I properly understand Dr. White he finds nothing in the

character of the aquatic mollusca to preclude the possibility of their having lived and developed in smaller lakes. After a personal examination of the localities at Green River, Utah, at Grand River in western Colorado, Cañon City and Morrison in eastern Colorado, Como and Sheep Creek in southern Wyoming, at the Spanish Mines in eastern Wyoming, along the Bighorn Mountains in central Wyoming, about the Black Hills in South Dakota and in the country near Billings in southern Montana, in all of which localities the *Atlantosaurus* beds are exposed and exhibit in more or less abundance, the remains of those dinosaurs which are characteristic of them, I am convinced that neither the character of the vertebrate fauna nor the facts of stratigraphy at any one of these places can be taken as affording anything like conclusive evidence of the presence of a great body of water. At several of these localities, however, the occurrence at intervals of sandstones showing frequent examples of cross-bedding, ripple-marks and even occasionally exhibiting footprints is conclusive proof that such sandstones had not their origin in the midst of a great lake, while the presence almost everywhere of the remains of terrestrial reptiles and less frequently of mammals tells only too plainly of an adjacent land-mass. In all this region I know of no locality where any considerable extent of the *Atlantosaurus* beds occurs, in which remains of quadrupedal, terrestrial dinosaurs have not been found. . . . An hypothesis, which it appears to me is far more reasonable and more nearly in accordance with the facts as we now know them, is to consider this region as presenting in late Jurassic and early Cretaceous times the appearance of a low and comparatively level plain, with numerous lakes, both large and small, connected by an interlacing system of river channels."

Chamberlin and Salisbury (1907, 1) assign a fluvial origin to the Morrison formation.

Lee (1915, 2) considers the Morrison to be largely fluvial in origin.

DISCUSSION OF PREVIOUS THEORIES OF THE ORIGIN OF THE FORMATION

The theory of deposition of the Morrison in a great lake, as advanced by C. A. White, does not seem to be supported by evidence now available. The following list of characteristics of beds of lacustrine origin has been given by Johnson (1903, 8):

- 1). No great variations in texture and composition in vertical section.
- 2). No beds of conglomerate.
- 3). No marked and sudden variations in respect to the thickness and areal extent of the component beds.

- 4). Few unconformities of erosion.
- 5). No extensive cross-bedding at high angles.
- 6). A lacustrine rather than a land fauna or flora.

The Morrison departs widely from every one of these six characteristics except the last. The fauna might be considered lacustrine in part, but some of it, if not most of it, is strictly terrestrial, and much of the aquatic element may be fluviatile as well as lacustrine.

The series of events given by Riggs might fit very well a restricted area of the Morrison deposits. The Morrison is an extremely widespread formation, however, and this fact must be continually kept in mind in discussing its origin. There does not appear to be any evidence sufficient for concluding that the lower beds of the Morrison are marine, and deposition in estuaries is not in accord with the vast distribution of the formation.

There is abundant evidence for alternating lake and river conditions in restricted areas, however, and no doubt such conditions were common.

The statement by Loomis that the dinosaur bones had floated out to sea by means of meat on them is not supported by the known facts, as there is no evidence whatever of marine conditions in the Morrison formation itself.

Hatcher's theory of a low level plain, with lakes and interlacing streams, fits the observed conditions much better. The interpretation given in the present paper is in some senses an amplification of this idea.

PRELIMINARY STATEMENT OF PRESENT INTERPRETATION

To the present writer the best explanation of the origin of the Morrison formation appears to be that of a number of large streams issuing from a mountainous area and crossing a very broad flat plain. Such streams would deposit much of their loads on their flood-plains in the forms of very flat alluvial fans. Deposition by distributaries, aided by tributaries and aeolian action, would tend to unite these fans into a broad alluvial plain. The main streams and tributaries consequent on the plain would gradually extend such alluvial deposits over a very broad area. In local basins between the principal stream areas and in abandoned stream valleys lakes would probably form locally. In these lakes fine sediments would be deposited, with sandstones around the margins. Aeolian deposits would probably form to a certain extent between the main stream areas also.

The presence of a Comanchean sea in Texas and other areas east of the Morrison area, shown by the presence of marine sediments, indicates that part of the Morrison may be a true delta formation.

With conditions such as those above outlined kept in mind as a working hypothesis, it is desirable to consider the characteristics of large alluvial fans and river flood-plains of recent and Pleistocene origin.

CHARACTERISTICS OF RECENT ALLUVIAL PLAINS

Davis (1898, 6) describes the fan of the Hoangho River in China as follows: "One of the largest alluvial fans in the world is that of the Hoangho, in eastern China. This great river, bearing a heavy load of fine silt from the basins among the inner mountains, issues from its inclosed valley 300 miles inland from the present shore-line, and at a height of about 400 feet above sea-level, and then flows to the sea down the gentle slope of its extensive fan." The fan is fertile and is subject to overflow on a vast scale. A single flood in 1881 covered 50,000 square miles and drowned at least 1,000,000 people. The course of the river and its tributaries is constantly shifting.

The fan of the Yangtse-Kiang lies immediately south of that of the Hoangho and is more or less connected with it. The large rivers leave the mountains in valleys which resemble estuaries in their form and relation to the mountains. The mountains may be compared to the land and the plains and valley to the sea and estuary. The great rivers are bordered on either side by lakes, swamps and other streams, which often connect with each other in an intricate manner. The lakes vary in size from small ponds to large lakes 50 miles or so in length. They are usually situated in tracts along the borders of the large rivers, but are sometimes situated far from the latter. They extend from the mountains to the delta and are not especially characteristic of any one region. These features are well shown on the German government's land survey maps of eastern China (1903, 9, 10; 1904, 9, 10, 11).

Grabau (1914, 6) describes the dry delta of Cooper Creek as extending over an area of 185 x 170 miles. Grabau describes the great alluvial plain of the Indo-Gangetic region as follows:

"The Indo-Gangetic alluvial plain is an example of a river plain formed of many confluent dry deltas and carried forward by the two great rivers of northern India—the Indus on the west and the Ganges, with the tributary Brahmaputra, on the east. Numerous small streams feed these rivers from the south slope of the Himalayas, carrying an abundance of coarse and fine debris. . . . The great alluvial plain extends over an area of about 300,000 square miles, and comprises the richest and most populous portion of India. It varies in width from 90 to nearly 300 miles, and entirely separates the lower peninsula of India

from the Himalayas to the north. It rises 924 feet above the sea in its highest portion, and the deepest boring has located these deposits at a depth of nearly a thousand feet below the present sea-level. . . . It abounds in gravels and conglomerates near the sloping borders, but lutaceous or clayey deposits, more or less arenaceous, prevail over much of the plain, especially near the center, with only subordinate deposits of sand, gravel, and conglomerates. Beds of blown sand of great thickness are found in some regions. . . . Shells of river and marsh molluscs are occasionally found, and calcareous concretions and nodules of irregular shape, locally known as *kankar*, are frequent. . . . Calcareous tufas also form conglomerates in the stream beds by cementing pebbles derived from the hills. In the clays along the borders and in the shoals of the Jumna River a great variety of vertebrate remains has been found, including elephant, hippopotamus, ox, horse, antelope, crocodile and various fish." Grabau gives further descriptions of these deposits, much of which would apply to the Morrison.

Lakes are not especially abundant on these plains, though some are present. The large rivers are braided in a complicated manner. An interesting feature is shown in the delta portion of the Ganges, where a large tributary, the Brahmaputra, joins the main river *below* the point where one of its largest delta distributaries, the Hooghly, is given off. These features are shown on any large map of India.

Grabau also gives a description of the Nile flood-plain. Extracts from this description are here quoted.

"A striking example of a flood-plain is afforded by that of the Nile, which flows from a well-watered region through a desert country without receiving a tributary for a thousand miles, except a few small wet weather streams. Entrenched beneath the desert uplands this flood-plain holds its own for a length of 500 miles, and maintains a width of from 5 to 15 miles, broadening on the delta to over 100 miles. The annual inundation of the flood plain is caused by the northward movement of the belt of equatorial rains in summer. The flood begins in June and usually rises 25 feet or more at Cairo in the late summer or early autumn. The annual addition of the river silt causes a slow rising of the entire flood plain estimated to amount to $4\frac{1}{2}$ inches a century.

"This region furnishes an instructive example of widely varying contemporaneous deposits within the same general area. On the one hand occur the drifting, cross-bedded, well rounded and pure quartz sands of the desert, and, on the other, the extremely fine, well-stratified muds of the river flood plain."

Grabau makes the following statement regarding flood-plain sediments: "From the nature of the deposits on river flood plains, perfect and often very fine stratification is to be expected. This may be considered as characteristic of typical flood plains." The Po, Ganges and Hoangho are given as examples. Davis (1900, 9) states that the proportions of fine to coarse materials in these rivers is very great.

In general, levelness of surface is a characteristic of flood-plains: the material may vary from coarse to fine, the former usually occurring in greater abundance near the source and the latter at a distance from the



FIG. 94.—A tributary of the Grand River, near Mack, Colorado.

Streams of this character were probably abundant in the Morrison area during the deposition of the formation.

source; and overlap away from the source of supply is characteristic. The strata deposited will often approach horizontality over considerable areas. Thinning out and replacement of beds is common. Footprints and similar structures are often found.

COLOR OF SEDIMENTS

In moist or pluvial climates with moderate vegetation, the soil is apt to be bluish. Vegetation prevents a high degree of oxidation. "In seasons of dryness, when the amount of vegetation is small, the iron of the sediments of deltas and alluvial fans may become thoroughly oxidized.

Where dryness prevails for most of the year, and where vegetation is as a result scanty, such oxidation may be especially favored. Thus semiarid or even desert regions would furnish the best conditions for such oxidation. On river flood plains there is always sufficient moisture to result in the formation of hydroxides of iron, and hence the colors of such deposits will range from yellows to ocher and brown. It is only under conditions of intense heat that dehydration will result with a consequent change in color toward the reds. Such change of color may, however, take place as the result of aging of the deposits, as pointed out by Crosby" (Grabau, 1914, 6). Crosby's statement is as follows: ". . . the color of the deposit, so far as it is due to ferric oxide, is, other things being equal, a function of its geological age. . . . In other words, the color naturally tends with the lapse of time to change from yellow to red; and, although this tendency exists independently of the temperature, it is undoubtedly greatly favored by a warm climate" (1891, 3). Barrell has also discussed the causes of color combinations in continental sediments (1912, 10).

Without discussing the literature on this subject any further, the following conclusions may be made regarding the origin of beds of various colors in the Morrison formation. As noted above (p. 159), the coarser beds are usually gray or white, these beds often being cross-bedded, while the finer beds are green, gray, white, blue or red. The red and reddish-brown beds are not extremely fine, however, like the greenish clays. This is probably due to the prevalence in them of quartz grains, while the green clays are often composed largely of kaolinic material. There is a considerable amount of gradation of color in the finer beds. The coarser sands were probably deposited in the streams and as deltas in the lakes. The finer red, brown and gray grits were deposited in both lakes and streams, and also along river flood-plains. In most cases it would be difficult to assign one of these brownish-red grits to a precise origin. As noted above in discussing the petrographic characters of the formation, the green clays often grade into red and brown, and there is distinct evidence of the origin of some of the red color, at least, by the alteration of iron carbonate. It is possible, of course, that some of this oxidation may have taken place before the burial of the material. It is much more probable, however, that the process has been going on during a long period of time subsequent to the burial of the deposits, and in some cases is still going on. Many beds have been completely oxidized, there being little but quartz and red-stained clayey matter in the rock. This material is usually more abundant in the upper members of the formation than in the lower. Other beds show the operation to have progressed to a con-

siderable extent, but not completed. If the process is not interfered with by diastrophism, or other violent disturbance, it is probable that oxidation will continue and red color will be produced more and more, *up to the limits set by the nature of the material*. Pure quartz sands or kaolinic clays without iron cannot be oxidized to hematitic red beds under ordinary conditions. The iron will have to be introduced from outside. This probably accounts for the absence of red color in many of the very fine green clays.

INTERPRETATION OF THE MORRISON FORMATION

From the foregoing facts recorded concerning the Morrison formation, from the conditions which are known to prevail on modern flood-plains, alluvial fans and deltas, and from previous knowledge regarding the distribution of land and sea in western North America in Mesozoic times, an attempt will be made to interpret the Morrison formation and to trace the history of parts of western North America during middle Mesozoic time.

At the close of the Triassic period certain areas in western North America were elevated. This is shown by the presence of folding in Triassic rocks which are overlain unconformably by later beds and by disconformable contact with Jurassic beds. Large areas near the Pacific Coast were greatly affected and, as the effects are visible in eastern Colorado and New Mexico, the elevation was probably widespread. Erosion progressed over the greater part, at least, of the western United States until a peneplain was developed. Over this peneplain the sea advanced in late Jurassic time, as shown by Logan (1900, 10), coming from the Pacific through Alaska and western Canada, and extending south into the United States and covering practically the same areas that are occupied by the states of Montana, Wyoming and Utah, with very slight extensions into other states. The beds deposited at this time, or at any rate part of them, now constitute the Sundance formation. In areas where these marine deposits were not laid down, such as most of western Colorado, continental sediments were laid down. These continental sediments may be represented by parts of the La Plata sandstone. Beds with Sundance fossils overlie the La Plata in some areas, however, so it is not possible to correlate these formations directly.

As the deposits immediately overlying the Sundance are of continental origin in every area which has been described, possibly excepting the Unkpapa sandstone of the Black Hills region, and it is probable that this also is continental, it is evident that the sea withdrew from the Rocky

Mountain area before the deposition of the Morrison formation, or perhaps before the deposition of the Morrison formation of certain regions in the eastern part of its distribution area. Whether this retreat took place immediately after the deposition of the beds now constituting the highest members of the Sundance formation, or whether post-Sundance marine beds were deposited and eroded before the deposition of the Morrison, is a rather difficult question to decide. It is probable that there was a time interval between the deposition of the highest Sundance beds and lowest Morrison beds in the eastern area.

In the southwestern Morrison area the McElmo appears to overlie the La Plata sandstone conformably. In some localities, however, such as near Green River, Utah, and in northeastern Utah, the McElmo or its representative, the continental part of the Flaming Gorge, overlies the marine Jurassic of Sundance age. It is probable that the continental sedimentation which produced the larger part of the La Plata sandstone was interrupted by the invasion of the Sundance sea. If any area where the La Plata had been deposited was not covered by this sea, and there appears to be such, and if this area was in connection with the source of material to the westward, it is probable that continental deposition continued without any extensive break from La Plata into lower McElmo time. In areas in Colorado, east of the southern Sundance sea in Utah, the La Plata sedimentation was suspended for the time being; whether erosion of the Colorado area took place at this time is difficult to determine. The Colorado La Plata probably never extended very far to the east at any time. Possibly slight erosion took place over the Colorado area, but not enough to make any sharp erosion contact between the La Plata and McElmo.

From the distribution of the Sundance beds, it appears probable that the Sundance sea retreated in the direction from which it advanced, exposing the southern areas first. From the nature of the contact between the Sundance and Morrison formations in the eastern areas, it appears possible that post-Sundance beds were deposited and eroded before the deposition of the Morrison. Such an interpretation certainly fits the facts known in the case, and there does not appear to be any strong evidence against it.

When the southern Utah area was laid bare by the retreat of the Sundance sea, a broad practically flat plain seems to have been left, and as the sea retreated farther and farther this plain appears to have become larger and larger, until it occupied a considerable tract in the western portion of the United States. Continental sedimentation probably began immediately after the retreat of the sea. In the southwestern areas the

lowest beds of the McElmo formation probably represent this period of sedimentation. The exact geological age of these lower McElmo beds depends upon the decision of the question regarding the post-Sundance deposition and erosion. If these beds were deposited immediately after the highest Sundance, they are upper Jurassic in age; if they were deposited after a post-Sundance-pre-Morrison erosion interval, they may be upper Jurassic or basal Comanchean. To which of these two periods the lower beds of the McElmo really belong is not especially important from the point of view of the present paper.

From the greater thickness of the Morrison beds to the west, and from the larger amount of coarse material in the formation in its western occurrences, conditions which are distinctly shown in the descriptions of the formation, though there are local variations from them, it seems to the writer almost certain that the source of the materials comprising the Morrison came from mountain areas to the west of the present area of the formation.

After the lower beds of the McElmo phase of the Morrison were deposited, the formation was extended to the east, northeast and southeast. On such a plain as the one above indicated, it would be possible for a drainage system similar to that now existing in eastern China to develop. Such a drainage system, with large overloaded rivers, swamps, lakes and interlacing connecting streams was inaugurated. Aeolian sedimentation no doubt accompanied the stream deposition to a certain extent. As the formation increased in thickness it also spread farther out, the upper beds overlapping the lower ones. It seems probable that the lower beds of the Morrison formation in its eastern areas are not to be correlated in age with the lower beds of the McElmo in the western areas, but are later. This extension of the formation undoubtedly took a considerable length of time. The section shown in a given locality at present does not usually represent continuous deposition in that area, but in many cases at least represents an alternation of erosion and deposition, with deposition predominating in the long run. A given thickness laid down under such conditions may represent as long a time interval as a thickness three or four times as great, or more, deposited under conditions of continuous deposition.

The Unkpapa sandstone, in the Black Hills region, may represent an aeolian deposit laid down on the Morrison plain after the retreat of the Sundance sea and before the Morrison sediments had been extended to that point.

Under the conditions of alternating deposition and erosion indicated above, it would not be necessary for the beds in every section to corre-

spond, bed for bed, or even generally, with the beds in another section. It is also reasonable to suppose that some whole sections in certain areas are slightly younger or older than other whole sections in other areas. *It appears, then, that the Morrison commenced as a continental deposit in the western areas of its occurrence in early Comanchean time (or possibly latest Jurassic), and that it spread outward as it was built up, the uppermost and easternmost beds being laid down in Comanchean time.* The upper beds are generally fine-grained as compared with the lower ones. This suggests that the mountain areas to the west were being worn down and that the streams had only sufficient gradient, on the average, to carry fine material.

The exact relation of the Morrison to the marine Comanchean is not definitely known, except that Washita beds are known, in one or two cases, to overlie the Morrison. If the above interpretation of the Morrison be anything like the truth, it seems probable that the Morrison merged into the marine deposits in the southeastern areas, such as Texas, and that the Morrison in its southeastern and eastern areas consisted of true delta deposits.

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¹⁰ All important papers are listed, though the bibliography is not absolutely complete, especially in regard to very early papers. Works on the principles involved in the discussions in the present paper are included, as well as works dealing directly with the Morrison formation. The bibliography of the paleontology of the Morrison is not included, as it would add hundreds of titles which are of no value from the point of view of this work, being anatomical in nature. The original references to the various genera and species are given in the section on paleontology, with a few of the more important subsequent references.

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- 1887. 3.** WHITE, C. A.: "On the Cretaceous formations of Texas and their relation to those of other portions of North America." *Phila. Acad. Sci. Proc.*, vol. xxxix, pp. 39-47, 1887. [The Dakota in the Missouri Valley rests on Jurassic beds, which are absent in the Texas region.]
- 1888. 1.** COPE, E. D.: "Mesozoic realm." *Int. Cong. Geol. Amer. Comm. Rep.*, 1888, E, pp. 1-15, 1888. *Amer. Geol.*, vol. ii, pp. 261-268, 1888. [Notes of fauna and stratigraphy of Jurassic (Morrison).]

1888. 2. OSBORN, H. F.: "On the structure and classification of the Mesozoic mammalia." Phila. Acad. Nat. Sci., Journ., vol. ix, pp. 186-265, 30 figs., 2 pls., 1888. [Mammals from the Purbeck and Morrison formations described and discussed, the Morrison forms being referred to as Jurassic.]
1889. 1. HILLS, R. C.: [Address: The field for original work on the Rocky Mountains.] Colo. Sci. Soc., Proc., vol. iii, pp. 148-164, 1889. [Suggests collecting in the Atlantosaurus beds.]
1889. 2. STEVENSON, J. J.: "The Mesozoic rocks of southern Colorado and northern New Mexico." Amer. Geol., vol. iii, pp. 391-397, 1889. [Jurassic in southern Colorado consists of thin limestones; near Cañon City shales.]
1889. 3. WHITE, C. A.: "The lower Cretaceous of the southwest and its relation to the underlying and overlying formations." Amer. Journ. Sci., 3rd ser., vol. xxxviii, pp. 440-445, 1889. [Marine origin of the Dakota shown by fossils. No Jura or Lower Cretaceous in central New Mexico. No evidence of Triassic or Jurassic seas.]
1890. 1. CRAGIN, F. W.: "On the Cheyenne sandstone and Neocomian shales of Kansas." Washburn Coll. Lab., Bull., vol. ii, pp. 69-80, 1890. Amer. Geol., vol. vi, pp. 233-238; vol. vii, pp. 23-33, 1890. [The Cheyenne sandstone may be equivalent to the Atlantosaurus beds or to the Trinity series.]
1890. 2. HILLS, R. C.: "Additional notes on the eruptions of the Spanish Peaks region." Colo. Sci. Soc., Proc., vol. iii, pp. 224-227, 1890. [Notes the occurrence of Jurassic shales.]
1890. 3. EMMONS, S. F.: "Orographic movements in the Rocky Mountains." Geol. Soc. Amer., Bull., vol. i, pp. 245-286, 1890. [Atlantosaurus beds may be Cretaceous. Term "Jura-Dakota" used. The beds are of fresh-water origin. They were deposited around various "islands" in the Rocky Mountain region.]
1890. 4. LAKES, ARTHUR: "Extinct volcanoes in Colorado." Amer. Geol., vol. v, pp. 38-43, 2 pls., 1890. [Notes cutting of Jurassic strata by volcanoes.]
1890. 5. WHITE, C. A.: "The North American Mesozoic." Amer. Assoc. for the Adv. Sci., Proc., vol. xxxviii, pp. 205-226, 1890. [Atlantic Coast possesses upper Jurassic. The Potomac formation is divided. In "Interior Region" a few hundred feet of Jurassic lie conformably on the Trias: the upper part is non-marine and lower part marine. Jurassic disappears north and south, its distribution being less than that of the Trias.]
1891. 1. CANNON, GEORGE B.: "Notes on the geology of Perry Park." Colo. Sci. Soc., Proc., vol. iii, pp. 308-315, 1891. [Note on the Jura-Dakota hogback.]
1891. 2. MARSH, O. C.: "Geological horizons as determined by vertebrate fossils." Amer. Journ. Sci., 3rd ser., vol. xlii, p. 112, 1891 (abstract of paper read to the Intern. Geol. Congr.). [The Hallopus beds are Jurassic and older than the Baptonodon beds.]
1891. 3. CROSBY, W. O.: "On the contrast in color of the soils of high and low latitudes." Amer. Geol., vol. viii, pp. 72-82, 1891. [Color contrast is due partly to difference in climate under which deposits were formed and also to geologic age.]
1892. 1. WOOD, W. H.: "Two Montana coal fields." Geol. Soc. Amer., Bull., vol. iii, pp. 301-330, 13 figs., 1892. [Jurassic and Kootenai beds are both present at Great Falls, Montana.]

- 1893. 1.** CANNON, GEORGE L., JR.: "The geology of Denver and vicinity." Colo. Sci. Soc., Proc., vol. iv, pp. 235-270, 1893. [Account of the early dinosaur collecting and description of the section at Morrison, Colorado.]
- 1894. 1.** WOODWORTH, J. B.: "The relation between base-leveling and organic evolution." Amer. Geol., vol. xiv, pp. 209-235, 1894. [Review of the various theories concerning land erosion, discussion of the effect of river changes on organisms and their distribution, and the relation of the development of the Jura-Cretaceous peneplain with the contemporaneous fauna and flora, and general summary of the facts presented. Reptiles, and particularly the dinosaur group, correlated in development with the growth of the peneplain.]
- 1894. 2.** CROSS, WHITMAN: "Pike's Peak, Colorado, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 7, 7 pp., 5 maps, 1894. [Descriptions of the Morrison formation, including the Oil Creek locality. Proposal of the name Morrison.]
- 1894. 3.** ELDRIDGE, G. H., and EMMONS, S. F.: "Anthracite-Crested Butte, Colorado, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 9, 10 pp., 8 maps, 1 section sheet, 1894. [Description of the Gunnison formation and proposal of the name Gunnison.]
- 1895. 1.** MARSH, O. C.: "Restoration of some European dinosaurs, with suggestions as to their place among the reptilia." Amer. Journ. Sci., 3rd ser., vol. i, pp. 407-412, 1 fig., 4 pls., 1895. [Morrison equal to Wealden in age, and both are Jurassic. Restorations of Morrison dinosaurs.]
- 1896. 1.** EMMONS, S. F., CROSS, WHITMAN, and ELDRIDGE, G. H.: "Geology of the Denver basin in Colorado." U. S. Geol. Surv., Monograph, No. 27, 556 pp., 31 pls., 102 figs., 1896. [Morrison formation deposited in a depression following Jurassic movement. The formation is Lower Cretaceous in age.]
- 1896. 2.** MARSH, O. C.: "Vertebrate Fossils" [of the Denver basin.] U. S. Geol. Surv., Monograph, No. 27, pp. 473-527, pls. 21-31, figs. 23-102, 1896. [Notes on the *Hallopus*, *Baptanodon* and *Atlantosaurus* beds. The latter two are Jurassic in age.]
- 1896. 3.** WARD, L. F.: "Some analogies in the lower Cretaceous of Europe and America." U. S. Geol. Surv., 16th Ann. Rep., pt. 1, pp. 452-463, pls. 97-107, figs. 67-69, 1896. [Comparison in detail of the Potomac and Wealden. Discussion of origin and description of the flora.]
- 1896. 4.** WOODWARD, ARTHUR S.: "Note on the affinities of the English Wealden fish-fauna." Geol. Mag., decade iii, No. 380, pp. 69-71, 1896. [The Wealden estuary the last refuge of the Jurassic fish-fauna.]
- 1896. 5.** MARSH, O. C.: "Age of the Wealden." Amer. Journ. Sci., 4th ser., vol. i, p. 234, 1896. [From the evidence of the fossil fishes the Wealden is Jurassic.]
- 1896. 6.** MARSH, O. C.: "The geology of Block Island." Amer. Journ. Sci., 4th ser., vol. ii, pp. 295-298, 375-377, 1896. [Jurassic of the Potomac type present.]
- 1896. 7.** MARSH, O. C.: "The Jurassic formation on the Atlantic Coast." Sci., N. S., vol. iv, pp. 805-816, 1896. [Evidence for Jurassic age of the Potomac deposits.]

1896. 8. MARSH, O. C.: "The Jurassic formation on the Atlantic Coast." Amer. Journ. Sci., 4th ser., vol. ii, pp. 433-447, 2 figs., 1896. [Description of the Buptanodon and Atlantosaurus beds of the west. Description of the Pleurocelus beds and the Potomac formation. Discussion of the relative importance of fossils, the age of the Wealden and the position and character of the Jurassic.]
1896. 9. GILBERT, G. K.: "Age of the Potomac formation." Sci., N. S., vol. iv, pp. 875-877, 1896. [Discusses the methods of correlation used by Marsh in his paper on the Jurassic formation of the Atlantic Coast. Slightly favors Cretaceous age for the Potomac beds.]
1896. 10. HILL, R. T.: "A question of classification." Sci., N. S., vol. iv, pp. 918-922, 1896. [Equivalents of the Potomac extend along the Atlantic Coast and westward into Texas. Tuscaloosa equals Lower Trinity. The whole is Cretaceous. Discussion of Marsh's evidence of the Jurassic age of these beds.]
1896. 11. MARCOU, JULES: "The Jura in the United States." Sci., N. S., vol. iv, pp. 945-947, 1896. [Potomac formation Jurassic in age.]
1897. 1. HAWORTH, ERASMUS: "Underground waters of southwestern Kansas." U. S. Geol. Surv., Water Supply Paper, No. 6, 63 pp., 12 pls., 2 figs., 1897. [Map and discussion of Jura-Trias beds. Red beds were deposited in ocean water.]
1897. 2. GILBERT, G. K.: "Pueblo, Colorado, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 36, 7 pp., 16 figs., 6 maps, section sheet, illustration sheet, 1897. [Discussion and sections of Mesozoic strata, including the Morrison.]
1897. 3. CLARK, WM. B.: "Outline of present knowledge of the physical features of Maryland, embracing an account of the physiography, geology and mineral resources." Md. Geol. Surv., vol. i, pp. 141-228, pls. 6-13, 1897. [Upper Jurassic and Lower Cretaceous deposited in brackish water.]
1897. 4. CLARK, WM. B., and BIRNINS, ARTHUR: "The stratigraphy of the Potomac group in Maryland." Journ. Geol., vol. v, pp. 479-506, 1897. [Descriptions of the Patuxent, Arundel, Patapsco and Raritan formations. Discussions of the relations and age of the deposits and the views of other writers. Patuxent and Arundel are Jurassic? Patapsco is Lower Cretaceous. The whole series deposited in brackish water.]
1897. 5. SCOTT, WM. B.: An introduction to geology. 1st ed., xii + 573 pp., 169 figs., 13 pls., Macmillan Co., 1897. [Name "Como" given to the Morrison in southern Wyoming. The formation is assigned to the Lower Cretaceous period.]
1898. 1. PURINGTON, C. W.: "Preliminary report on the mining industry of the Telluride quadrangle, Colorado." U. S. Geol. Surv., 18th Ann. Rep., pt. 3, pp. 751-848, pls. 103-158, figs. 66-74, 1898. [Notes on the La Plata and Gunnison formations.]
1898. 2. SPURR, J. E.: "Geology of the Aspen mining district, Colorado, with atlas." U. S. Geol. Surv., Monograph, No. 31, 260 pp., 43 pls., 11 figs., 30 atlas sheets, 1898. [Description of the Gunnison formation, part of which is correlated with the Atlantosaurus beds.]
1898. 3. MARSH, O. C.: "Jurassic formation on the Atlantic Coast." Supplement, Amer. Journ. Sci., 4th ser., vol. vi, pp. 105-115, 1 fig., 1898. [Re-

- ply to Gilbert's criticism and restatement of evidence for Jurassic age of the Potomac beds.]
- 1898. 4.** TOMM, JAMES E.: "Section along Rapid Creek from Rapid city westward. South Dak. Geol. Surv., Bull., No. 2, pp. 27-40, pls. 2-5, 1898. [Notes on the Black Hills Jurassic.]
- 1898. 5.** MARSH, O. C.: "Cycad horizons in the Rocky Mountains." Amer. Journ. Sci., 4th ser., vol. vi, p. 197, 1898. [Notes on the Mesozoic strata of the Black Hills.]
- 1898. 6.** DAVIS, W. M.: "Physical geography," xviii + 432 pp., 9 pls., 261 figs., frontsp., Ginn & Co., N. Y., 1898. [Discussion of river deposits. Description of the Hoangho alluvial plain.]
- 1899. 1.** MARSH, O. C.: "Footprints of Jurassic dinosaurs." Amer. Journ. Sci., 4th ser., vol. vii, pp. 229-232, 3 figs., 1899. [Footprints found in the Morrison of the Black Hills region.]
- 1899. 2.** DARTON, N. H.: "Jurassic formations of the Black Hills of South Dakota." Geol. Soc. Amer. Bull., vol. x, pp. 383-396, 3 pls., 1899. [Description and history of the Black Hills Jurassic beds. Beulah shales equivalent to the Morrison.]
- 1899. 3.** CROSS, WHITMAN: "Telluride, Colorado, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 57, 18 pp., 4 maps, section sheet, 3 illustration sheets, 1899. [Sections and descriptions of the La Plata and McElmo formations. These names are proposed for divisions of the Gunnison formation.]
- 1899. 4.** CROSS, WHITMAN, SPENCER, A. C., and PURINGTON, C. W.: "La Plata, Colorado, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 60, 14 pp., 4 maps, 2 illustration sheets, 1899. [La Plata and McElmo formations described and discussed.]
- 1900. 1.** KNIGHT, W. C.: "The Wyoming fossil fields expedition of July, 1899." Nat. Geog. Mag., vol. xi, pp. 449-465, 8 pls., 1900. [Description of Como Bluff and other Morrison localities.]
- 1900. 2.** KNIGHT, W. C.: "Jurassic rocks of southeastern Wyoming." Geol. Soc. Amer. Bull., vol. xi, pp. 377-388, pl. 23, 1900. [Detailed sections, map, descriptions and faunal lists.]
- 1900. 3.** KNIGHT, W. C.: "A preliminary report on the artesian basins of Wyoming." Wyo. Exp. Station. Bull. No. 45, pp. 107-251, 14 pls., 15 figs., map, June, 1900. [Brief description of the Morrison formation.]
- 1900. 4.** CROSS, WHITMAN, and SPENCER, A. C.: "Geology of the Rico Mountains, Colorado." U. S. Geol. Surv., 21st Ann. Rep., pt. 2, pp. 15-165, pls. 1-22, 1900. [The La Plata is correlated with the lower part of the Gunnison, and the McElmo with the upper part, and in part with the Morrison.]
- 1900. 5.** LOGAN, W. N.: "The stratigraphy and invertebrate faunas of the Jurassic formation in the Freezeout Hills of Wyoming." Kans. Univ. Quart., vol. ix, pp. 109-134, pls. 25-31, 5 figs., 1900. [Descriptions, detailed section and descriptions of new species of invertebrate fossils.]
- 1900. 6.** WARD, L. F.: "Description of a new genus and twenty new species of fossil cycadean trunks from the Jurassic of Wyoming." Wash. Acad. Sci. Proc., vol. i, pp. 251-300, pls. 14-21, 1900. [Stratigraphic notes and descriptions of the cycads, which form the principal element of the Morrison flora.]

1900. 7. HILLS, R. C.: Walsenberg, Colorado, quadrangle. U. S. Geol. Surv., Geol. Atlas, Folio No. 68, 6 pp., 3 figs., 6 maps, 2 section sheets, 1900. [Description of the Morrison formation. It varies from 100 to 270 feet.]
1900. 8. WARD, L. F. (with the collaboration of Wm. Fontaine, Atreus Wanner and F. H. Knowlton): "Status of the Mesozoic floras of the United States. First paper: Older Mesozoic." U. S. Geol. Surv., 20th Ann. Rep., pt. 2, pp. 211-430, pls. 21-179, 1900. [Description of the occurrence and character of the strata and plant remains of the Trias and Jura at different localities in the United States and the characters of the genera and species.]
1900. 9. DAVIS, W. M.: "The fresh-water Tertiary formations of the Rocky Mountain region." Amer. Acad. Arts and Sci., Proc., vol. xxxv, pp. 345-373, 1900. [Discussion of flood-plain deposits and short description of Huangho and Indo-Gangetic flood-plains.]
1900. 10. LOGAN, W. N.: "A North American epicontinental sea of Jurassic age." Journ. Geol., vol. viii, p. 241, 4 figs., 1900. [Section of the Morrison and Sundance formations, map of distribution of the Sundance, summary of sequence of events concerning the advance and retreat of the Sundance sea.]
1901. 1. DARTON, N. H.: "Preliminary description of the geology and water resources of the Black Hills and adjacent regions in South Dakota and Wyoming." U. S. Geol. Surv., 21st Ann. Rep., pt. 4, pp. 497-599, 55 pls., 28 figs., 1901. [Sections, descriptions, etc.; Beulah shales equal the Morrison.]
1901. 2. DARTON, N. H.: "Comparison of the stratigraphy of the Black Hills with that of the Rocky Mountain front range." Geol. Soc. Amer., Bull., vol. xii, p. 478, 1901. [General comparison, Morrison included.]
1901. 3. WILLISTON, S. W.: "The Dinosaurian genus *Crococaurus* Marsh." Amer. Journ. Sci., 4th ser., vol. xi, pp. 111-114, 1 fig., 1901. [Name "Atlantosaurus Beds" replaced by "Como."]
1901. 4. RIGGS, ELMER S.: "The dinosaur beds of the Grand River Valley of Colorado." Field Col. Mus. Pub. 60, Geol. Ser., vol. i, no. 9, pp. 267-275, 6 pls., 1901. [General section and description of beds. They were deposited by a combination of stream and lake deposition.]
1901. 5. HATCHER, J. B.: "The Jurassic dinosaur deposits near Cañon City, Colorado." Carn. Mus., Ann., vol. i, pp. 327-341, 5 figs., 1901. [Description of section, discussion of origin and correlation.]
1901. 6. LOOMIS, F. B.: "On Jurassic stratigraphy in southeastern Wyoming." Amer. Mus. Nat. Hist., Bull., vol. xiv, pp. 189-198, 2 pls., 1901. [Detailed sections and descriptions of the Morrison at Como Bluff and near-by localities.]
1901. 7. LEE, W. T.: "The Morrison formation of southeastern Colorado." Journ. Geol., vol. ix, pp. 343-352, 4 figs., 1901. [Detailed section and discussion of correlation of the beds in the canyons in southeastern Colorado.]
1901. 8. DARTON, N. H., and KEITH, A.: "Washington, Maryland-Virginia-District of Columbia, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 70, 7 pp., 8 maps, 1901. [Notes on the Potomac beds.]
1902. 1. DARTON, N. H.: "Norfolk, Virginia-North Carolina, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 80, 1 pp., 4 maps, section sheet,

- illustration sheet, 1902. [The Potomac series Cretaceous in age and estuarine in origin.]
1902. 2. DARTON, N. H.: "Oelrichs, South Dakota-Nebraska quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 85, 6 pp., 4 maps, 2 figs., section sheet, illustration sheet, 1902. [The Lakota immediately overlies the Unkpapa near Hot Springs, South Dakota. The Morrison is absent in this locality.]
1902. 3. RIGGS, E. S., and FARRINGTON, O. C.: "The dinosaur beds of the Grand River Valley of Colorado." Sci. Amer., Supp., vol. llii, pp. 22061-22062, 2 figs., 1902. [Description and discussion of the Grand River beds. They were deposited in a system of streams and lakes.]
1902. 4. FRAAS, E.: "Geologische Streifzüge durch die Prärien und Felsengebirge Nordamerikas." Württemberg, Jahreshfte des Vereins für vaterlandische Naturkunde, Stuttgart, Jahrg. lviii, pp. 65-68, 1902. [Observations on the Jurassic beds of Wyoming and their invertebrate fossils.]
1902. 5. LEE, W. T.: "The Morrison shales of southern Colorado and northern New Mexico." Journ. Geol., vol. x, pp. 36-58, 7 figs., 1902. [Detailed descriptions of the southern Morrison occurrences. The Morrison extends eastward into Oklahoma.]
1902. 6. LEE, W. T.: "Canyons of southeastern Colorado." Journ. Geol., vol. i, pp. 357-370, 12 figs., 1902. [Sections, descriptions, etc., of the Morrison and adjacent beds.]
1902. 7. LOOMIS, F. B.: "On Jurassic stratigraphy on the west side of the Black Hills." Second paper on American Jurassic stratigraphy. Amer. Mus. Nat. Hist., Bull., vol. xvi, pp. 401-407, 1 pl., 1902. [Detailed descriptions and sections.]
1902. 8. DARTON, N. H.: "Stratigraphy of the Bighorn Mountains." Sci., N. S., vol. xv, p. 823, 1902. [Brief abstract of fuller paper.]
1902. 9. HATCHER, J. B.: "Structure of the foreleg and manus of *Brontosaurus*." Carn. Mus., Ann., vol. i, pp. 356-376, 2 pls., 1902. [Notes on the levels of different quarries.]
1902. 10. SHATTUCK, GEORGE B.: "Development concerning the physical features of Cecil County." Md. Geol. Surv., vol. Cecil Co., pp. 31-62, 2 pls., 1902. [Extensive bibliography.]
1902. 11. SHATTUCK, GEORGE B.: "The geology of the coastal plain formations." Md. Geol. Surv., vol. Cecil Co., pp. 149-194, 5 pls., 2 figs., 1902. [Patuxent is Jurassic; Patapsco is Cretaceous; Arundel is absent or not differentiated.]
1903. 1. REAGAN, A. B.: "Geology of the Jemez-Albuquerque region, New Mexico." Amer. Geol., vol. xxxi, pp. 67-111, 7 pls., 1903. [Cretaceous rests directly upon Red Beds; apparently no Morrison present.]
1903. 2. LEE, W. T.: "The canyons of northeastern New Mexico." Journ. Geol., vol. ii, pp. 63-82, 14 figs., 1903. [Sections, descriptions etc. of country where the Morrison is present.]
1903. 3. DARTON, N. H.: "Preliminary report on the geology and water resources of Nebraska west of the 100th meridian." U. S. Geol. Surv., Professional Paper No. 17, 69 pp., 43 pls., 23 figs., 1903. [Sections, etc.]
1903. 4. HATCHER, J. B.: "Osteology of *Haplocanthosaurus*, with description of a new species and remarks on the probable habits of the sauropod"

- and the age and origin of the *Atlantosaurus* beds." *Can. Mus. Mem.*, vol. ii, pp. 1-72, 6 pls., 28 figs., 1903. [The *Atlantosaurus* beds, or Morrison, are Jurassic in age. They represent the result of combined erosion and deposition, the latter process being the dominant one.]
1903. 5. SMITH, W. S. TANGIER: "Hartville, Wyoming, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 91, 6 pp., 2 maps, 2 section sheets, 1 illustration sheet, 1903. [Short description of the Morrison formation.]
1903. 6. STANTON, T. W.: "A new fresh-water molluscan fauna from the Cretaceous of Montana." *Amer. Philos. Soc., Proc.*, vol. lxii, pp. 188-189, 1 pl., 1903. [Discussion of the age of the Morrison formation.]
1903. 7. WARD, L. F.: "Correlation of the Potomac of Maryland and Virginia." *Abst., Sci., N. S.*, vol. xvii, pp. 941-942, 1903. [General discussion.]
1903. 8. JOHNSON, D. W.: "Geology of the Cerillos Hills, New Mexico. Pt. I. General Geology." *Sch. Mines Quart.*, vol. xxiv, pp. 303-350, 7 figs., 7 pls.; pp. 450-500, 6 figs., 10 pls., 1903. [Discussion of origin of sediments and their criteria.]
1903. 9. Tsi nan fu Sheet. Kartographische Abtheilung der Königl. Preuss. Landes-Aufnahme. Karte von Ost-China, 1901? [Pub. 1903]. [Detailed map of part of the alluvial plain in eastern China. Shows streams interlacing in a complicated manner, many lakes and swamps on the fan.]
1903. 10. Nanking Sheet. Kartographische Abtheilung der Königl. Preuss. Landes-Aufnahme. Karte von Ost-China [Pub. 1903]. [Map of the delta of the Yangtse Kiang. Many lakes and swamps are on it. Some of the lakes are 50 miles or more in length.]
1904. 1. HATCHER, J. B.: "An attempt to correlate the marine with the non-marine formations of the Middle West." *Amer. Philos. Soc., Proc.*, vol. xliii, pp. 341-365, 2 figs., 1904. [The *Atlantosaurus* beds and the Dakota, considered as the possible equivalents of the marine Jurassic and Lower Cretaceous.]
1904. 2. JAGGAR, THOMAS A.: "Economic resources of the northern Black Hills, pt. 1, General Geology." U. S. Geol. Surv., Professional Paper No. 26, pp. 13-41, pl. 1, 1904. [Section and short description of the Morrison.]
1904. 3. PECK, FRED. B.: "The *Atlantosaurus* and *Titanotherium* beds of Wyoming." *Wyoming Hist. and Geol. Soc., Proc. and Col.*, vol. viii, pp. 25-41, 5 pls., 1904. [Sections, stratigraphical descriptions and faunal lists.]
1904. 4. DARTON, N. H.: "Newcastle, Wyoming-South Dakota, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 107, 9 pp., 4 maps, 6 figs., section sheet, illustration sheet, 1904. [Description of the Morrison.]
1904. 5. DARTON, N. H., and SMITH, W. S. T.: "Edgemont, South Dakota-Nebraska, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 108, 10 pp., 4 maps, 5 figs., section sheet, illustration sheet, 1904. [Description and section of Morrison.]
1904. 6. SPENCER, A. C.: "The copper deposits of the Encampment district, Wyoming." U. S. Geol. Surv., Professional Paper No. 25, 107 pp., 2 pls., 40 figs., 1904. [Notes 400 feet of fresh-water Jurassic beds with limestones.]
1904. 7. LEE, W. T.: "Age of the *Atlantosaurus* beds." *Geol. Soc. Amer., Bull.*, vol. xiv, pp. 531-532, 1904. [These beds can be correlated with the Lower Cretaceous of Texas.]

1904. 8. DARTON, N. H.: "Comparison of the stratigraphy of the Black Hills, Bighorn Mountains and Rocky Mountain front range." *Geol. Soc. Amer., Bull.*, vol. xv, pp. 379-448, 14 pls., 1904. [Many sections, descriptions and discussions. The Morrison is considered as Cretaceous in age.]
1904. 9. Peking Sheet. Kartographische Abtheilung der Königl. Preuss. Landes-Aufnahme. Karte von Ost-China, 1901 [Pub. 1904]. [Map of part of the alluvial plain of China. Many lakes are present on it.]
1904. 10. Yi tschang fu Sheet. Kartographische Abtheilung der Königl. Preuss. Landes-Aufnahme. Karte von Ost-China, 1901? [Pub. 1904]. [Map of part of the alluvial plain of China near the inland mountains. Lakes are present on it.]
1904. 11. Hankau Sheet. Kartographische Abtheilung der Königl. Preuss. Landes-Aufnahme. Karte von Ost-China, 1902 [Pub. 1904]. [Map of the portion of the alluvial plain of China which includes the divide between the Hoangho and Yangtse rivers. Many lakes, from small ponds to lakes 25 miles or more in length, are present in broad belts each side of the main rivers. They connect more or less by small streams.]
1904. 12. OSBORN, HENRY F.: "Fossil wonders of the West, the dinosaurs of the Bone-Cabin Quarry, being the first description of the greatest 'find' of extinct animals ever made." *Century Mag.*, vol. lxxviii, pp. 680-694, 18 figs., 1904. [General account of the discovery and description of the occurrence of the remains, with some descriptions. Good figures of Morrison outcrops.]
1905. 1. CROSS, W., and HOWE, ERNST: "Red Beds of southwestern Colorado and their correlation." *Geol. Soc. Amer., Bull.*, vol. xvi, pp. 447-498, 4 pls., 4 figs., 1905. [The McElmo, 300 to 900 feet thick, equivalent to the upper Gunnison or Morrison.]
1905. 2. KEYES, CHARLES R.: "The Jurassic horizons around the southern end of the Rocky Mountains." *Amer. Geol.*, vol. xxxvi, pp. 289-292, 1 fig., 1905. [Diagram of relations of beds in the southern Rocky Mountain region.]
1905. 3. DARTON, N. H.: "Preliminary report on the geology and underground water resources of the central great plains." *U. S. Geol. Surv., Professional Paper No. 32*, 433 pp., 72 pls., 18 figs., 1905. [Extensive discussion of the Morrison and other Mesozoic formations, with many sections.]
1905. 4. WILLISTON, S. W.: "The Hallopus, Baptonodon and Atlantosaurus beds of Marsh." *Journ. Geol.*, vol. xiii, pp. 328-350, 1905. [Hallopus beds are Triassic, Baptonodon beds are Jurassic and Atlantosaurus beds probably Cretaceous. Historical notes.]
1905. 5. DARTON, N. H.: "Sundance, Wyoming-South Dakota, quadrangle." *U. S. Geol. Surv., Geol. Atlas, Folio No. 127*, 12 pp., 5 maps, 3 figs., 1905. [Sections and descriptions. The Morrison is Cretaceous.]
1905. 6. DARTON, N. H., and O'HARRA, C. C.: "Aladdin, Wyoming-South Dakota, Montana, quadrangle." *U. S. Geol. Surv., Geol. Atlas, Folio No. 128*, 8 pp., 4 maps, 1 fig., 1 section sheet, 1905. [Short description of the Morrison formation.]
1905. 7. WARD, L. F.: "Status of the Mesozoic floras of the United States." Second paper. *U. S. Geol. Surv., Monograph No. 48*, pt. 1, text, 616 pp.;

- pt. 2, plates, 119 pls., 1905. (Includes papers by Fontaine, Bibbins and Wieland. Stratigraphic notes by Wieland.) [Complete descriptions of Mesozoic plants and discussions and descriptions of their occurrence.]
1905. 8. DARTON, N. H.: "Discovery of the Comanche fauna in southeastern Colorado." *Sci., N. S.*, vol. xxii, p. 120, 1905. [Brief note.]
1905. 9. FENNEMAN, N. M.: "Geology of the Boulder district, Colorado." *U. S. Geol. Surv., Bull.*, No. 265, 101 pp., 5 pls., 11 figs., 1905. [Detailed description of the Morrison at this locality.]
1905. 10. CROSS, W.: "Rico, Colorado, quadrangle." *U. S. Geol. Surv., Geol. Atlas, Folio No. 130*, 20 pp., 5 maps, illustration sheet, 1905. [Sections and descriptions of the La Plata and McElmo formations.]
1905. 11. STANTON, T. W.: "The Morrison formation and its relations with the Comanchic series and the Dakota formation." *Journ. Geol.*, vol. xiii, pp. 657-667, 1905. [Statement of existing knowledge of the Morrison in southern Colorado. Upper Comanchean fossils found above the Morrison at Cañon City.]
1905. 12. HUNTINGTON, ELLSWORTH: "The basin of eastern Persia and Sistan." *Carn. Inst. Wash., Pub.* 26, pp. 217-317, figs. 149-174, 1905. [Observations on the deposition of shales of various colors.]
1906. 1. FRAAS, E.: "Vergleichung der amerikanischen und europäischen Jura-formation." *Intern. Amerikanisten Kongress, Tag.* 14, pp. 41-45, Stuttgart, 1906. [General comparison.]
1906. 2. DARTON, N. H.: "Geology of the Bighorn Mountains." *U. S. Geol. Surv., Professional Paper No. 51*, 129 pp., 47 pls., 14 figs., 1906. [Many sections and descriptions, etc. The Morrison is Cretaceous; good distribution map.]
1906. 3. DARTON, N. H.: "Geology and underground waters of the Arkansas Valley in eastern Colorado." *U. S. Geol. Surv., Professional Paper No. 52*, 90 pp., 27 pls., 2 figs., 1906. [Section, descriptions and discussion of the Mesozoic strata.]
1906. 4. FISHER, CASSIUS A.: "Geology and water resources of the Bighorn basin, Wyoming." *U. S. Geol. Surv., Professional Paper No. 53*, 72 pp., 16 pls., 1 fig., 1906. [Many sections and descriptions; the Morrison is Cretaceous; good distribution map.]
1906. 5. MILLER, BENJAMIN L.: "Dover, Delaware-Maryland, quadrangle." *U. S. Geol. Surv., Geol. Atlas, Folio No. 137*, 10 pp., 2 maps, 1 fig., 1906. [Patuxent is present and is Lower Cretaceous in age; Arundel and Patuxent may underlie the Patuxent.]
1906. 6. DARTON, N. H.: "Bald Mountain and Dayton, Wyoming, quadrangles." *U. S. Geol. Surv., Geol. Atlas, Folio No. 141*, 15 pp., 7 maps, 6 figs., 1 cross-section and 2 illustration sheets, 1906. [Sections, maps, descriptions, etc., including the Morrison.]
1906. 7. DARTON, N. H.: "Cloud Peak and Fort McKinley, Wyoming, quadrangles." *U. S. Geol. Surv., Geol. Atlas, Folio No. 142*, 16 pp., 7 maps, 1 cross-section and 2 illustration sheets. [Sections, maps, descriptions, etc., including the Morrison.]
1906. 8. CLARK, W. B., and MILLER, B. L.: "A brief summary of the geology of the Virginia coastal plain." *Va. Geol. Surv., Geol. Ser., Bull.*, No. 2, pp. 11-24, 1906. [Patuxent and Arundel provisionally referred to the Jurassic.]

- 1906. 9.** DARTON, N. H.: "Geology of the Owl Creek Mountains, with notes on resources of adjacent regions in the ceded portion of the Shoshone Indian reservation." 59th Cong., 1st Sess., Sen. Doc. no. 219, 48 pp., 19 pls., 1 fig., 1906. [Section, descriptions and distribution map of the Morrison and other formations.]
- 1906. 10.** DARTON, N. H.: "The hot springs at Thermopolis, Wyoming." Journ. Geol., vol. xiv, pp. 194-200, 4 figs., 1906. [The Morrison is present at Thermopolis.]
- 1906. 11.** CLARK, W. B., and MATHEWS, E. B.: "Report on the physical features of Maryland, together with an account of the exhibits of Maryland mineral resources made by the Maryland Geological Survey." Md. Geol. Surv., vol. vi, pts. 1 and 2, pp. 27-281, 30 pls., 19 figs., map, 1906. [Patuxent and Arundel are Jurassic. Both were deposited in swampy areas.]
- 1906. 12.** WIELAND, G. R.: "American fossil cycads." Carn. Inst. Wash., Pub. 34, 266 pp., 50 pls., 137 figs., 1906. [Notes on the occurrence of the cycads in the Morrison beds, with complete discussion of their morphology and relationships.]
- 1907. 1.** CROSS, W.: "Stratigraphic results of a reconnaissance in western Colorado and Utah." Journ. Geol., vol. xv, pp. 634-679, 11 figs., 1907. [Description of the McElmo formation. Correlation table. McElmo equivalent to the Morrison.]
- 1907. 2.** WEEKS, F. B.: "Stratigraphy and structure of the Uinta range." Geol. Soc. Amer., Bull., vol. xviii, pp. 427-448, 6 pls., 3 figs., 1907. [600-800 feet of Jurassic present, of which 200-300 feet is limestone.]
- 1907. 3.** FISHER, C. A.: "The Great Falls coal field, Montana." U. S. Geol. Surv., Bull., No. 316, pp. 161-173, 1 pl., 1907. [Morrison and Kootenie beds present.]
- 1907. 4.** DARTON, N. H., and O'HARRA, C. C.: "Devil's tower, Wyoming, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 150, 9 pp., 3 maps, cross-section and structure sheet, 1907. [Sections, maps, descriptions, etc., of the Morrison and other beds.]
- 1907. 5.** SHATTUCK, G. B., MILLER, B. L., and BABBINS, ARTHUR: "Patuxent," Maryland, quadrangle. U. S. Geol. Surv., Geol. Atlas, Folio No. 152, 12 pp., 3 maps, 2 figs., section sheet, 1907. [Patuxent and Arundel provisionally classed as Jurassic and Patapsco as Cretaceous.]
- 1907. 6.** CROSS, W., HOWE, E., and IRVING, J. D.: "Ouray, Colorado, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 153, 19 pp., 3 maps, 4 figs., illustration sheet, 1907. [Descriptions and maps, La Plata, McElmo and other formations.]
- 1907. 7.** CHAMBERLIN, T. C., and SALISBURY, R. D.: Geology, Volume III. 624 pp., 269 figs. [Good description of the Morrison formation and fluvial origin given for it.]
- 1908. 1.** DARTON, N. H.: "Paleozoic and Mesozoic of central Wyoming." Geol. Soc. Amer., Bull., vol. xix, pp. 403-470, 10 pls., 1908. [Many sections and descriptions. Morrison is Cretaceous.]
- 1908. 2.** KEYES, CHARLES R.: "Geotectonics of the Estancia plains." Journ. Geol., vol. xvi, pp. 434-451, 12 figs., 1908. [The Morrison is present in eastern New Mexico.]

1908. 3. FISHER, C. A.: "Southern extension of the Kootenai and Montana coal-bearing formations in northern Montana." *Econ. Geol.*, vol. iii, no. 1, pp. 77-99, 1908. [The Kootenie lies apparently with perfect conformity on the Morrison.]
1908. 4. BARRELL, JOSEPH: "Relations between climate and terrestrial deposits. Pt. II. Relation of sediments to regions of deposition." *Journ. Geol.*, vol. xvi, pp. 255-295, 1908. [Discussion of types of sediment deposited under various conditions; notes on colors in sediments and discussion of their origin.]
1909. 1. MARTIN, G. C.: "The Niobrara limestone as a source of Portland cement material." *U. S. Geol. Surv., Bull. No. 380*, pp. 314-326, 1 fig., 1909. [The Morrison is of fresh-water origin.]
1909. 2. GILMORE, C. W.: "A new Rhynchocephalian from the Jurassic of Wyoming; with notes on the fauna of 'Quarry 9.'" *U. S. Nat. Mus., Proc.*, vol. xxxvii, pp. 35-42, 1 pl., 3 figs., 1909. [Lists of the fauna of the Morrison formation.]
1909. 3. SPURR, J. E.: "Scapolite rocks of America." *Amer. Journ. Sci.*, 4th ser., vol. xxv, p. 154, 1909. [Description of the Gunnison formation.]
1909. 4. LEE, W. T.: "The Grand Mesa coal field, Colorado." *U. S. Geol. Surv., Bull., No. 341*, pp. 316-334, 1 pl., 1909. [Section including the Gunnison formation.]
1909. 5. DARTON, N. H.: "Geology and water resources of the northern part of the Black Hills and adjacent regions in South Dakota and Wyoming." *U. S. Geol. Surv., Professional Paper No. 65*, 105 pp., 24 pls., 15 figs., 1909. [Many sections and descriptions of Sundance, Unkpapa, Morrison and other beds.]
1909. 6. DARTON, N. H., and O'HARRA, C. C.: "Bellefourche, South Dakota, quadrangle." *U. S. Geol. Surv., Geol. Atlas, Folio No. 164*, 9 pp., 4 maps, 1 fig. (field edition, 67 pp., 5 maps), 1909. [Descriptions, sections, etc. of Morrison and associated formations.]
1909. 7. GILMORE, C. W.: "Osteology of the Jurassic reptile *Cumtosaurs*, with a review of the species of the genus and descriptions of two new species." *U. S. Nat. Mus., Proc.*, vol. xxxvi, pp. 197-332, 15 pls., 47 figs., 1909. [Description of quarry and copies of Loomis's sections.]
1909. 8. WILLIS, BAILEY: "Paleogeographic maps of North America." *Journ. Geol.*, vol. xvii, pp. 203-208; 253-256; 286-288; 342-343; 403-405; 406-409; 424-428; 503-505; 506-508; 600-602; 15 figs., 1909. [Pp. 408-409; 424-425, Jura-Cretaceous maps and descriptions.]
1909. 9. STANTON, T. W.: "Succession and distribution of later Mesozoic invertebrate faunas in North America." *Journ. Geol.*, vol. xvii, pp. 410-423, 1909. [Jurassic of the Rocky Mountain region equals Oxfordian and perhaps Callovian. The Morrison is overlain by the Kootenie at the north and by the Comanchean at the south.]
1909. 10. HENDERSON, JAMES: "The foothills formations of north central Colorado." *Colo. Geol. Surv., 1st Ann. Rep. for 1908*, pp. 145-188, 6 pls., 1909. [General descriptions of the Morrison and other formations.]
1909. 11. FISHER, C. A.: "Geology of the Great Falls coal field, Montana." *U. S. Geol. Surv., Bull., No. 356*, 85 pp., 12 pls., 2 figs., 1909. [Correlation tables. The Morrison is present, overlain by the Kootenie.]

- 1909. 12.** DARTON, N. H., and SIEBENTHAL, C. E.: "Geology and mineral resources of the Laramie basin, Wyoming." U. S. Geol. Surv., Bull., No. 364, 81 pp., 8 pls., 1 fig., 1909. [Sections, description and distribution map of the Morrison and other formations.]
- 1909. 13.** FISHER, C. A.: "Geology and water resources of the Great Falls region, Montana." U. S. Geol. Surv., Water Supply Paper, No. 221, 89 pp., 7 pls., 1909. [Cretaceous, Morrison (60-120 feet thick) and Ellis formations appear to be conformable throughout.]
- 1909. 14.** DARTON, N. H.: "Geology and underground waters of South Dakota." U. S. Geol. Surv., Water Supply Paper, No. 227, 156 pp., 15 pls., 7 figs., 1909. [Sections, discussions and illustrations. Sundance and Unkpapa are Jurassic; Morrison is Cretaceous.]
- 1909. 15.** LEE, W. T., and Girty, G. H.: "The Manzano group of the Rio Grande Valley, New Mexico." U. S. Geol. Surv., Bull., No. 389, 120 pp., 12 pls., 9 figs., 1909. [The Morrison is probably present.]
- 1909. 16.** HENNING, KARL J.: "Streifzüge in den Rocky Mountains. IV. Morrison und die Morrisonformation." Globus, Bd. xvi, pp. 344-349, 5 figs., 1909. [Description of the Morrison formation, with discussion as to its age.]
- 1910. 1.** LULL, R. S.: "Dinosaurian distribution." Amer. Journ. Sci., 4th ser., vol. xxix, pp. 1-39, 10 figs., 1910. [Correlation tables and discussion of the Morrison and other faunas.]
- 1910. 2.** LARKIN, PIERCE: "The occurrence of a sauropod dinosaur in the Trinity Cretaceous of Oklahoma, with an introductory note by S. W. Williston." Journ. Geol., vol. xviii, pp. 93-98, 4 figs., 1910. [A morosauroid coracoid found in the Trinity sands.]
- 1910. 3.** SCHUCHERT, CHARLES: "Paleogeography of North America." Geol. Soc. Amer., Bull., vol. xx, pp. 427-606, 56 pls., 1910. [Paleogeographic maps and discussions.]
- 1910. 4.** CROSS, WHITMAN: "Engineer Mountain, Colorado, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 171, 13 pp., 3 maps, 1 section sheet, 2 illustration sheets, 1910. [La Plata is lower Jurassic and equivalent to the lower part of the Gunnison. The McElmo is in general equivalent to the Morrison.]
- 1910. 5.** DARTON, N. H., BLACKWELDER, ELIOT, and SIEBENTHAL, C. E.: "Laramie and Sherman, Wyoming, quadrangles." U. S. Geol. Surv., Geol. Atlas, Folio No. 173, 17 pp., 7 maps, 1 section sheet, 1 illustration sheet, 1910. [Sections of Sundance and Morrison formations.]
- 1910. 6.** GALE, HOYT S.: "Coal fields of northwest Colorado and northeast Utah." U. S. Geol. Surv., Bull., No. 415, 265 pp., 22 pls. and figs., 1910. [Description of the Flaming Gorge formation.]
- 1910. 7.** O'HARRA, CLEOPHAS: "The Badland formations of the Black Hills region." S. D. Sch. Mines, Dept. Geol., Bull., No. 9, 152 pp., 50 pls., 20 figs., Nov., 1910. [Sections and descriptions of the Jurassic.]
- 1910. 8.** CLARK, W. B.: "Results of a recent investigation of the coastal plain formations in the area between Massachusetts and North Carolina." Abst., Geol. Soc. Amer., Bull., vol. xx, pp. 646-654, 1 pl., 1910. [Patuxent, Arundel and Patapsco are all Lower Cretaceous.]
- 1911. 1.** WOODRUFF, ELMER G.: "The Lander oil field, Wyoming." U. S. Geol. Surv., Bull., No. 452, pp. 7-36, 6 pls., 1 fig., 1911. [Section of Sundance, Morrison and Cloverly formations.]

1911. 2. STONE, R. W.: "Geological relations of ore deposits in the Elkhorn Mountains, Montana." U. S. Geol. Surv., Bull., No. 470, pp. 75-98, 1 pl., 1911. [Geologic section and map. Morrison is present at this locality.]
1911. 3. VON HUENE, F.: "Kurze Mitteilung über Perm, Trias, und Jura in New Mexico." Neues Jahrb., Beilage-Bd. xxxii, H. 3, pp. 730-739, 1 pl., 2 figs., 1911. [Sections at Morrison, Colorado, and Mesa Prieta.]
1911. 4. JAMISON, C. E.: "Geology and mineral resources of a portion of Fremont County, Wyoming." Wyoming [Geol. Surv.] ser. B, Bull. No. 2, 90 pp., 14 pls., map, 1911. [Section and description of the Morrison.]
1911. 5. CLARK, W. R., BIBBINS, A., and BERRY, E. W.: "The lower Cretaceous of Maryland." Md. Geol. Surv., vol. Lower Cretaceous, pp. 23-98, 10 pls., 1911. [The lower portion of the Potomac is Lower Cretaceous in age. Descriptions and sections of the members of the Potomac formation.]
1911. 6. BERRY, EDWARD W.: "The lower Cretaceous floras of the world." Md. Geol. Surv., vol. Lower Cretaceous, pp. 99-151, 1 fig., 1911. [Discussion of Lower Cretaceous floras and map of their distribution.]
1911. 7. BERRY, EDWARD W.: "Correlation of the Potomac formation." Md. Geol. Surv., vol. Lower Cretaceous, pp. 153-172, 1911. [Correlation table. Patuxent-Arundel equal to the Morrison-Kootenie and in part to the Wealden.]
1911. 8. LULL, R. S.: "The reptilia of the Arundel formation." Md. Geol. Surv., vol. Lower Cretaceous, pp. 173-187, 1911. [The Arundel fauna is Lower Cretaceous, rather than Jurassic in age.]
1911. 9. MILLER, B. L.: "Development of knowledge concerning the physical features of Prince George County." Md. Geol. Surv., vol. Prince George Co., pp. 24-33, 1911. [Note on the Lower Cretaceous, and extensive bibliography.]
1911. 10. MILLER, B. L.: "Geology of Prince George County." Md. Geol. Surv., vol. Prince George Co., pp. 83-136, 7 pls., 1911. [Descriptions of the various members of the Potomac formation. They are all considered as Lower Cretaceous in age.]
1912. 1. WEGEMANN, C. H.: "The Powder River oil field, Wyoming." U. S. Geol. Surv., Bull., No. 471, pp. 56-75, 1 pl., 1 fig., 1912. [Short description of the Morrison formation.]
1912. 2. CALVERT, W. R.: "The Electric coal field, Park County, Montana." U. S. Geol. Surv., Bull., No. 471, pp. 406-422, 1 map, 1912. [Description of Ellis, Morrison and Kootenie formations. Detailed section.]
1912. 3. LEE, W. T.: "The Tijeras coal field, Bernalillo County, New Mexico." U. S. Geol. Surv., Bull., No. 471, pp. 574-578, 1 pl., 1912. [Notes the presence of the Morrison formation.]
1912. 4. STONE, R. W.: "Coal near the Black Hills, Wyoming-South Dakota." U. S. Geol. Surv., Bull., No. 499, 66 pp., 7 pls., 8 figs., 1912. [Short description of the Morrison formation.]
1912. 5. WILLIS, BAILEY, and STOSE, G. W.: "Index to the stratigraphy of North America," accompanied by a geologic map of North America, compiled by the United States Geological Survey, in cooperation with the Geological Survey of Canada and the Instituto Geológico de Mexico, under the supervision of Bailey Willis and George W. Stose. U. S. Geol. Surv.,

- Professional Paper, No. 71, 894 pp., 19 figs., large map in sections, 1912. [Descriptions and bibliographies of all important North American geological formations; correlation tables etc.]
1912. 6. LEE, W. T.: "Coal fields of Grand Mesa and the West Elk Mountains, Colorado." U. S. Geol. Surv., Bull., No. 510, 237 pp., 21 pls., 37 figs., 1912. [Map of the Grand Mesa region, with description and section of the Gunnison formation in that region.]
1912. 7. STOSE, G. W.: "Apishapa, Colorado, quadrangle." U. S. Geol. Surv., Geol. Atlas, Folio No. 186, 12 pp., 3 maps, 1 illustration sheet, 1912. [Description of the Morrison formation.]
1912. 8. JAMISON, C. E.: "The Douglas oil field, Converse County, Wyoming." Wyoming [Geol. Surv.], Bull., No. 3, ser. B, 50 pp., 8 pls., 1912. [Notes the presence of the Morrison formation.]
1912. 9. JAMISON, C. E.: "The Salt Creek oil field, Natrona County, Wyoming." Wyoming [Geol. Surv.], Bull., No. 4, ser. B, 75 pp., 16 pls., 1 map, 1912. [Notes the presence of the Morrison formation.]
1912. 10. BARRELL, JOSEPH: "Criteria for the recognition of ancient delta deposits." Geol. Soc. Amer., Bull., vol. xxiii, pp. 377-446, 4 figs., 1912. [Discussion of deltas and criteria for recognizing their origin and criteria for the determination of the marine, lacustrine and fluvial origin of sedimentary deposits.]
1913. 1. GROUT, F. F., WORCESTER, P. G., and HENDERSON, JUNIUS: "Reconnaissance of the geology of the Rabbit Ears region." Colo. Geol. Surv., Bull., No. 5, pt. 1, pp. 1-57, 1 pl., 1 fig., 1913. [Brief description of the Morrison formation.]
1913. 2. BUTTERS, R. M.: "'Permian' or 'Permo-Carboniferous' of the eastern foothills of the Rocky Mountains in Colorado." Colo. Geol. Surv., Bull., No. 5, pt. 2, pp. 61-94, 1913. [Discussion of the Morrison formation.]
1914. 1. BARNETT, V. H.: "The Douglas oil and gas field, Converse County, Wyoming." U. S. Geol. Surv., Bull., No. 541-C, pp. 3-42, 1 pl., 1 fig., 1914. [Brief discussion of the Morrison formation and section.]
1914. 2. HEWETT, D. F.: "The Shoshone River section, Wyoming." U. S. Geol. Surv., Bull., No. 541-C, pp. 43-67, 1 pl., 1 fig., 1914. [Description and discussion of the Morrison formation. It is 580 feet thick, which is very unusual in the northern areas.]
1914. 3. LUTON, CHARLES T.: "Oil and gas near Green River, Grand County, Utah." U. S. Geol. Surv., Bull., No. 541, pp. 115-133, 1 pl., 1 fig., 1914. [The McElmo formation is over 1,000 feet thick near Green River.]
1914. 4. SCHUCHERT, CHARLES: "Climates of geologic time." Carn. Inst. Wash., Pub. 192, pp. 263-298, figs. 87-90, 1914. [Discussion of the prevailing climates of the various geologic periods. Morrison dinosaurs lived in a warm and moist climate.]
1914. 5. TROWBRIDGE, ARTHUR C.: "A classification of common sediments and some criteria for identification of the various classes." Journ. Geol., vol. xxii, pp. 420-436, 12 figs., 1914. [Descriptions of modern sediments of various modes of origin and criteria for recognizing the same in older deposits.]
1914. 6. GRABAU, A. W.: Principles of stratigraphy. 1185 pp., 264 ill., A. G. Sellen and Co., N. Y., 1914. [Extensive discussion of sedimentary processes.]

1914. 7. CROSS, WHITMAN, and LARSEN, E. S.: "Contributions to the stratigraphy of southwestern Colorado." U. S. Geol. Surv., Professional Paper 90-E, pp. 37-50, figs. 2, 3, pl. viii, 1914. [Description of McElmo formation and discussion of geological history of region concerned.]
1914. 8. BARNETT, V. H.: "The Moorcroft oil field, Crook County, Wyoming." U. S. Geol. Surv., Bull., No. 581-C, pp. 83-104, 1 fig., 1 plate (map), 1914. [Separates only; bulletin not yet issued, Mar. 4, 1915.] [Section of the Morrison formation in this locality, with brief description.]
1914. 9. BARNETT, V. H.: "Possibilities of oil in the Big Muddy Dome, Converse and Natrona counties, Wyoming." U. S. Geol. Surv., Bull., No. 581-C, pp. 105-117, 1 plate (map). [Separates only; bulletin not yet issued, Mar. 4, 1915.] [Note on the Morrison.]
1914. 10. CROSS, WHITMAN, and LARSEN, ESPER S.: "The stratigraphic break below the Jurassic sandstone in southwestern Colorado." Abstract. Wash. Acad. Sci., Journ., vol. iv, p. 237, 1914. [The Dakota does not overlap the McElmo in Gunnison Canyon, as indicated by Peale's map of Colorado.]
1915. 1. BEBBY, EDWARD W.: "Paleobotanic evidence of the age of the Morrison formation." Geol. Soc. Amer., Bull., vol. xxvi, pp. 335-342, 1915 (read before the Paleontological Society December 30, 1914). [Discussion of the floras of the Potomac, Wealden and Kootenie formations and the relation of these to the Morrison. Favors Lower Cretaceous (Comanchean) age for the Morrison.]
1915. 2. LEE, WILLIS T.: "Reasons for regarding the Morrison as an introductory Cretaceous formation." Geol. Soc. Amer., Bull., vol. xxvi, pp. 303-314, 1915 (read before the Paleontological Society December 30, 1914). [Diastrophic criteria applied to the study of the Morrison. The formation is considered as the non-marine forerunner of the marine Cretaceous deposits.]
1915. 3. LULL, RICHARD S.: "Sauropoda and Stegosauria of the Morrison of North America compared with those of Europe and eastern Africa." Geol. Soc. Amer., Bull., vol. xxvi, pp. 323-334, 1915 (read before the Paleontological Society December 30, 1914). [The Morrison partly at least homologous with the Tendaguru dinosaur beds. The latter are not older than uppermost Jurassic and probably are early Comanchean.]
1915. 4. MOOK, CHARLES C.: "Origin and distribution of the Morrison formation." Geol. Soc. Amer., Bull., vol. xxvi, pp. 315-322, 4 figs., 1915 (read before the Paleontological Society December 30, 1914). [The Morrison the product of alternate deposition and erosion; it may be both Jurassic and Comanchean in different parts.]
1915. 5. OSNORN, H. F.: "Close of Jurassic and opening of Cretaceous time in North America." Geol. Soc. Amer., Bull., vol. xxvi, pp. 295-302, 1915 (read before the Paleontological Society, December 30, 1914). [Paleontologic evidence considered as of greater value than diastrophic in correlation; the Morrison probably both Jurassic and Lower Cretaceous.]
1915. 6. STANTON, T. W.: "Invertebrate fauna of the Morrison formation." Geol. Soc. Amer., Bull., vol. xxvi, pp. 343-348, 1915 (read before the Paleontological Society December 30, 1914). [Evidence of the invertebrates is not conclusive, but seems to indicate Jurassic age for the Morrison.]

PLATE VI

MAP SHOWING THE DISTRIBUTION OF THE MORRISON FORMATION

Heavy black lines indicate actual outcrops. Cross-hatching indicate areas where the Morrison probably lies buried beneath younger beds. Dashes indicate areas where the Morrison may or may not underlie younger beds.

NOTE.—Since the preparation of this map, Dr. W. T. Lee has informed the writer of additional outcrops in New Mexico.



