

# **Article VII.—EOCENE AND OLIGOCENE OF THE WIND RIVER AND BIGHORN BASINS.**

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## INTRODUCTION.

The American Museum expedition of 1910 had, as its primary object, to study and collect from the Lower Eocene deposits of the Bighorn basin in northwestern Wyoming, but, at the beginning of the season, about a month was spent in reviewing the stratigraphy of the Wind River basin with special reference to the source of the sediments and their mode of deposition. A more careful study of the Beaver Divide section north of Hailey and east of Beaver Creek (Map, Fig. 1) than was possible last year has necessitated the publication of certain corrections and has brought out many new facts regarding the volcanic phenomena of the Eocene and Lower Oligocene. A short stop in the vicinity of Lost Cabin to reexamine the Wind River formation fully confirmed the fact of the superposition of the *Lambdotherium* beds east of Lost Cabin on the so-called Cottonwood Draw exposures, without *Lambdotherium* or *Systemodon*, as described by Mr. Granger in a former publication,<sup>1</sup> and afforded sufficient data for a subdivision of the rocks of the Wind River series. Early in July, the party reached the Bighorn basin. From various camps between Basin and St. Joe Post-office the richly fossiliferous Wasatch exposures south of the Grey Bull River were studied and collections secured from levels ranging from near the base of this formation on Elk and Antelope Creeks to the top on Tatman Mountain. Sufficient palæontological evidence was accumulated to demonstrate conclusively the presence of the *Lambdotherium* zone of the Wind River above the true Wasatch on this butte. Collections were made from three more or less well-defined fossiliferous zones in the Wasatch, all below the level of Dr. Loomis's upper and lower Tatman Mountain horizons.<sup>2</sup> These two horizons it was not found possible to trace in the area north of Tatman Mountain examined by the American Museum party, nor were we able to identify here more than a few of the subdivisions given in Dr. Loomis's section,<sup>3</sup> a circumstance explainable by the lens-like nature of the Wasatch strata and the change in the lithology of the sediments from the margin toward the center of the basin.

As the party was unprovided with surveying instruments, no accurate sections could be prepared. Those presented herewith are diagrammatic only, the profile in every case having been sketched and the elevations measured by hand level. The faunal horizons indicated in Fig. 2, B are, likewise, only approximately placed.

<sup>1</sup> Tertiary Faunal Horizons in the Wind River Basin, Wyoming, with Descriptions of New Eocene Mammals. Bulletin American Museum of Natural History, Vol. XXVIII, Art. XXI, pp. 235-251, 1910.

<sup>2</sup> Origin of the Wasatch Deposits. American Journal of Science, 4th Series, Article XXXIV, Vol. XXIII, No. 137, 1907.

<sup>3</sup> *Ibid.*, Fig. 1, p. 359.

## EOCENE AND POST-EOCENE BASINS OF ACCUMULATION.

The present Wind River-Bighorn drainage system is incised largely in Tertiary rocks constituting the filling of two great structural depressions of which the northerly or Bighorn basin, inclosed on the east and south by the Bighorn, Bridger and Owl Creek mountains and on the west by the Shoshone, Carter Mountains and other ranges still opens freely to the north, while the southerly or Wind River basin, rimmed about on the north and west by the Bridger, Owl Creek and Wind River ranges undoubtedly opened, originally, toward the east. The mountains are mainly anticlinal, involving formations ranging in age from pre-Cambrian to Fort Union, except in the Shoshone mountains where younger volcanic rocks occur. The basins or troughs which they inclose were filled during the Tertiary with detrital material deposited as river-borne muds, sands and gravels derived from the decay and erosion of older rocks, supplemented, locally, by volcanic tuffs and mud flows, wind-blown dust, limestone and spring deposits. In the Wind River basin sedimentation was continuous from the later Lower Eocene to the Lower Oligocene, with the exception of an interval of erosion at the close of the Upper Eocene. This was followed, in the Lower Oligocene, by volcanic outbursts of great violence. In the northerly basin accumulation began earlier in the Eocene with the deposition of the Wasatch and continued, probably, into the Oligocene, although this has not been fully established as the correlations presented on a later page are based on stratigraphic, lithologic and physiographic data and not on fossils. The difference in age of the earliest sediments in these adjacent basins was explained by Wortman,<sup>1</sup> adopting the now discredited lacustrine hypothesis, by the assumption that a lake existed in the Bighorn basin, while across the mountains to the south free drainage persisted, probably in an easterly direction. By the elevation of an eastern barrier of the Wind River basin, a later lake was formed in which the Wind River sediments were accumulated. This lake, on becoming filled, found an outlet to the north, excavating the gorge of the Wind River cañon. That this explanation is not in accord with recently ascertained facts will appear from the following section. The sedimentary record in both the Wind River and Bighorn basins closes with the formation of a gravel-strewn plain, the dissection of which is still in progress.

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<sup>1</sup> Geological and Geographical Sketch of the Bighorn Basin. In Article XI, Bulletin American Museum of Natural History, Vol. IV, p. 143, 1892.

## OLIGOCENE AND POST-OLIGOCENE EROSION.

*The Wind River Basin.*—On the crest of the divide between the headwaters of Beaver, Muskrat, Conant and Deer Creeks, northward-flowing tributaries of Wind River, and the easterly discharging Sweetwater drainage system, soft, limestone-capped ash beds and extensive gravel deposits occur, locally underlain by thick flows of andesitic agglomerate and tuff. As determined by associated fossils, these rocks are Lower Oligocene in age. They rest on the eroded surface of the Upper Eocene Uinta which is conformable with beds of supposed Middle Eocene age and these, in turn, conformable with the Wind River which rests discordantly on the upturned edges of the Cretaceous (Fig. 2, A).<sup>1</sup> South of Wagon-bed Spring the Oligocene limestone has preserved from erosion remnants of the once extensive ash beds beneath it, forming the buttes and mesas seen on the sky-line in Plate IV, Fig. 2. In the flat tops of these buttes and mesas are preserved remnants of the floor of the Wind River basin at the close of its depositional history in the Lower Oligocene. The beginning of the excavation of the present drainage system is, therefore, later Oligocene or post-Oligocene in age. Although physiographic studies were not pursued in detail, the erosional history of the Wind River basin is seen to involve all of the following stages:<sup>2</sup>

1. The plain represented by the flat tops of the buttes and mesas already described (Plate IV, Fig. 2).

2. A baselevel of erosion, 525 feet more or less below the old basin floor, controlled by the top of the Oligocene agglomerate (Fig. 2, A) or, where the agglomerate is absent, by the top of the Uinta sandstone. This is the level sagebrush-covered plain seen in the foreground of Plate V, Fig. 2, and in the even sky-line at the left hand side of the picture in Plate IV, Fig. 2.

3. Traces of another baselevel are preserved in the bench or terrace, mantled with landslides (Fig. 2, A, and Plate IV, Fig. 2, middle distance) at or near the top of the soft shales of the so-called Bridger. Although the landslides have had much to do with the formation of this terrace they are not entirely responsible for it.

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<sup>1</sup> Endlich's vaguely defined Sweetwater Group includes some of the formations mentioned above. Eleventh Annual Report of the United States Geological and Geographical Survey of the Territories, 1877, pp. 110-112.

<sup>2</sup> Stages 4, 5 and 6 below, agree in all essentials with the erosional history of the region south of Rock Springs, Wyoming, described by Rich. Physiography of the Bishop Mountain Conglomerate. Journal of Geology, Vol. XVIII, pp. 601-632, 1910. The great peneplain on which the Bishop conglomerate rests possibly corresponds to No. 1 of the series of stages mentioned in the text above.

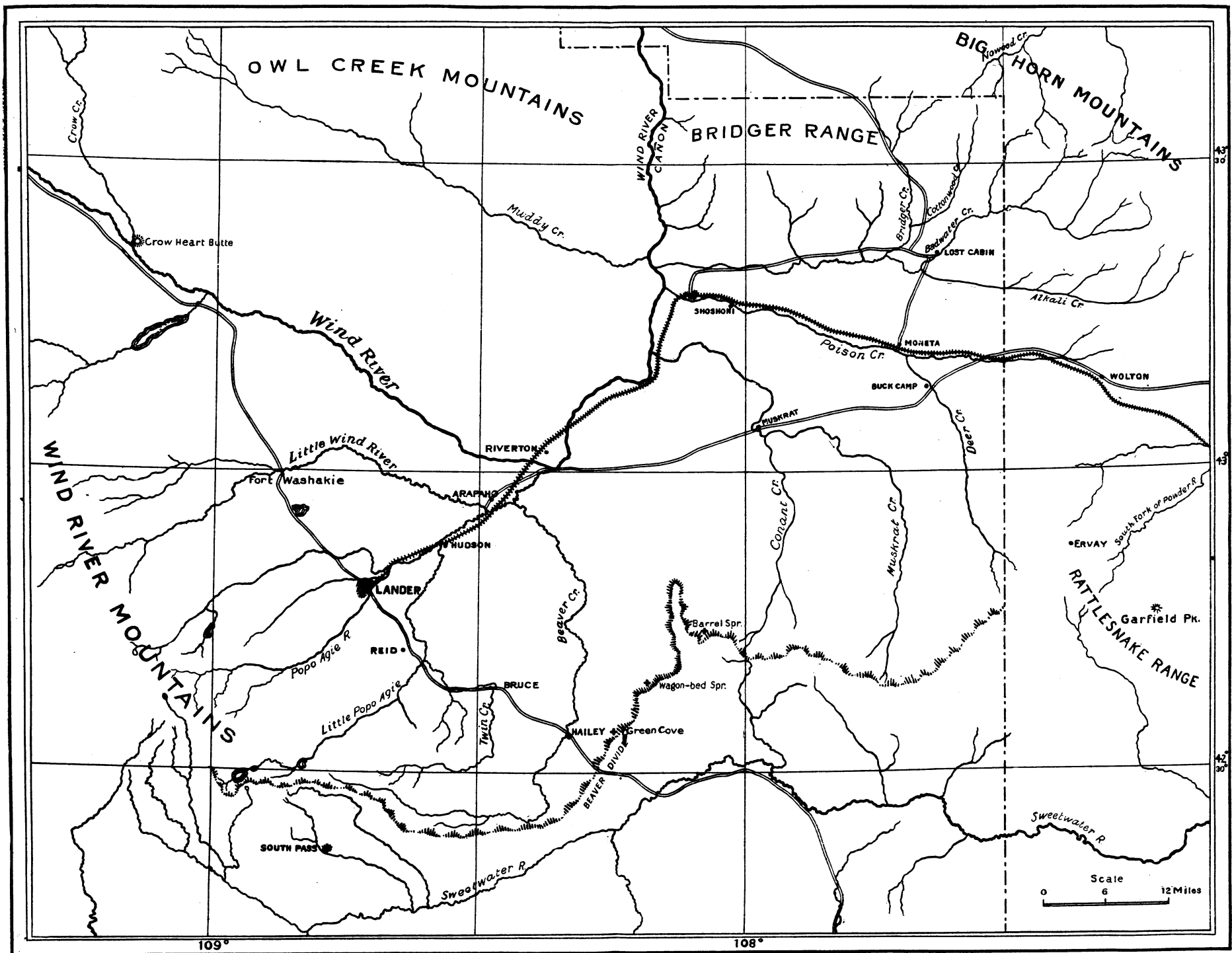


Fig. 1. Sketch map of the Wind River Basin. Based mainly on a map of Fremont County, by N. F. Brown. (After Granger.)



4. A long interval of erosion which resulted in the excavation of the present stream valleys. Probably several minor aggradational and degradational stages are here involved, as in all the modern stream valleys one or more gravel-strewn terraces occur above the level of the present valley floor. It is probable that some of these have been formed by the reëxcavation of deposits laid down in the valley troughs.

5. The silting up of the modern valleys, producing the broad flat floors through which the present streams have cut.

6. The cutting of the shallow trenches of the modern streams.

Wortman's suggestion, quoted above, regarding the easterly drainage of the Wind River trough during the Eocene is probably correct and, if we assume that erosion and transportation exceeded deposition, will account for the absence of the Wasatch (see page 85) which was then accumulating in the Bighorn basin across the mountains to the north. Such a direction for the drainage of the Wind River trough until after the lower Oligocene seems necessary from the position of the mountain barriers to the north, west and southwest, and from the extension of Oligocene sediments far to the east in the direction of Bates's Hole. Wortman's barrier (the Sweetwater-Wind River divide), which he supposed ponded the easterly flowing waters and so produced a lake, is not due to uplift, but to removal by erosion of Oligocene rocks accumulated in and beyond the same trough which had been receiving sediments since later Lower Eocene. More extensive physiographic studies than the writers have found opportunity to attempt will be necessary to explain the origin of the gorge through the Bridger-Owl Creek range by which the Wind River enters the Bighorn, but it does not seem beyond reason to suggest the possibility of the reversal and northward diversion of the early Oligocene Wind River drainage by the backward cutting of a tributary of the Bighorn at a time when the floors of both basins were considerably higher than they are to-day, previous to their reduction by erosion during later Tertiary and post-Tertiary time. The vigorous headwater cutting which has enabled Beaver, Muskrat, Conant and Deer Creeks to push back toward the Sweetwater and so maintain the steep north- and west-facing escarpment of the Beaver Divide<sup>1</sup> may possibly be traceable to this cause.

*The Bighorn Basin.*—That the Tertiary infilling of the Bighorn basin has been subjected to enormous erosion is at once apparent to an observer

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<sup>1</sup> A name locally applied to that part of the Sweetwater divide where it is crossed by the old Lander-Rawlins stage road. From the crest of the divide, there is a gentle slope southward to the Sweetwater, while to the north and west the descent is abrupt, in places precipitous, and is so maintained to the eastward along almost the whole southern border of the Wind River basin, due to the vigorous headwater erosion of certain northerly flowing streams, as explained in the text above.

standing on the flat-topped summit of Tatman Mountain and looking off over the great depression of Buffalo basin to the south or the valley of the Grey Bull to the north. Tatman Mountain, in reality only a residual butte spared by erosion, is capped by stream-worn andesitic gravels which may be of Oligocene age, as will be suggested later. The gravel sheet is underlain by about 600 feet of sandstone and lignitic shales in which no fossils have yet been found except leaf impressions, fresh-water molluscs and entomostraca. These rest conformably on the Wind River (Lambdotherium zone) and this, in turn, is in direct stratigraphic continuity with the Wasatch. As shown by remanic gravels at lower levels, derived from the deposit on Tatman Mountain, erosion has spared but a small part of this once extensive formation. As no fossils have yet been found in the gravels, their age is uncertain, but on the strength of certain lithologic similarities to be referred to later, they may be regarded as Oligocene and the dissection of the Tertiary deposits of the Bighorn basin fixed as later Oligocene and post-Oligocene. The flat top of Tatman butte is, therefore, correlated with Stage 1 (page 86) of the Wind River basin erosion cycle. Stage 2 of the latter finds its equivalent, apparently, in the well-marked bench or terrace some 525 to 550 feet, more or less, below the top of Tatman Mountain (see diagram, Fig. 2, B). Stage 3 has not been satisfactorily identified, but from the initiation of the great erosion, Stage 4, there is close equivalency in the two basins.

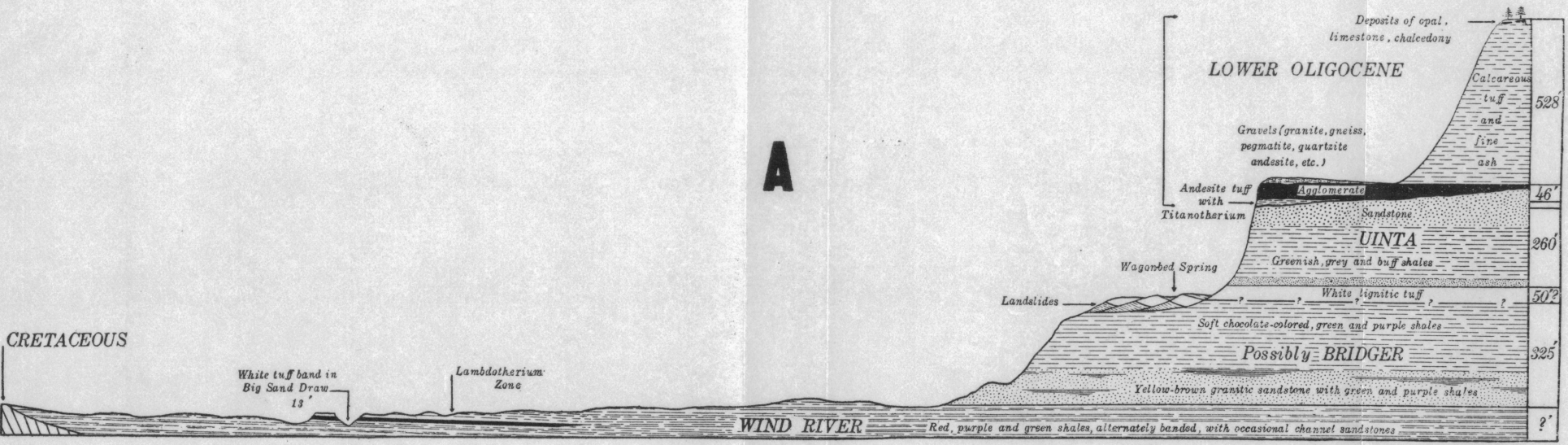
## THE EOCENE-OLIGOCENE SECTION OF BEAVER CREEK AND THE BEAVER DIVIDE.

From the Cretaceous<sup>1</sup> at Hudson to the top of the divide at Wagon-bed Spring a complete section of the Tertiary deposits of the Wind River basin may be studied from almost continuous exposures, especially on the east side of the valley of Beaver Creek, as shown in diagrammatic section (Fig. 2, A). Granger's figure,<sup>2</sup> showing a generalized section of the Tertiary of the Beaver Divide, differing in several respects from that published herewith, was based primarily on the succession of beds at Green Cove about four miles south of Wagon-bed Spring (map, Fig. 1), where several of the formations indicated in Fig. 2 A are absent and where considerable difference in the thickness of the remaining elements appears, probably due to thinning out toward the margin of the basin of accumulation. As shown in the diagram (Fig. 3) neither the white lignitic tuff nor the Oligo-

<sup>1</sup> Montana in age. Communicated by Mr. E. G. Woodruff through Dr. F. H. Knowlton.

<sup>2</sup> *Loc. cit.*, p. 238, fig. 1.

**A**



**B**

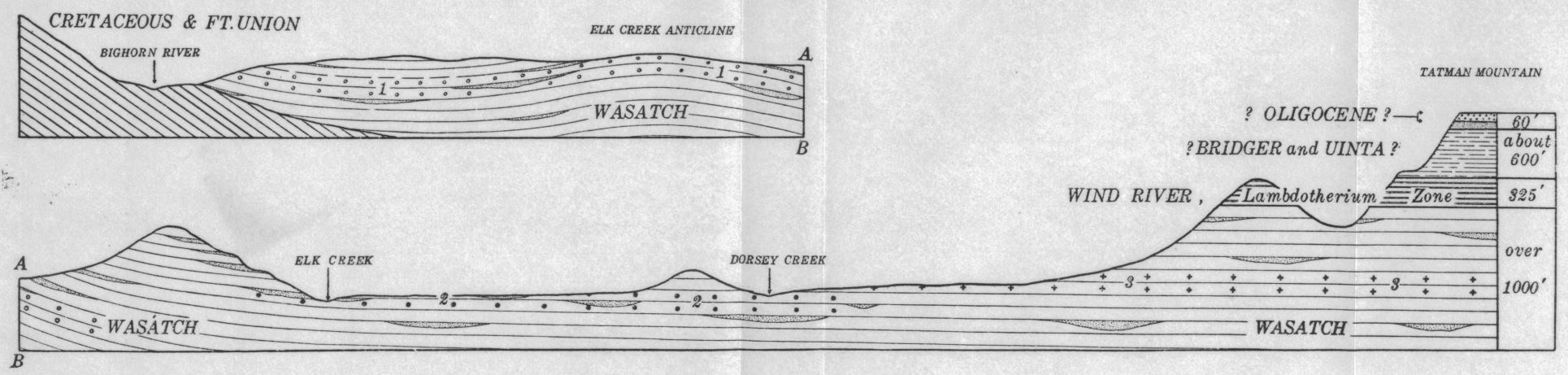


Fig. 2A. Diagrammatic section across the Wind River basin from the Cretaceous at Hudson to the top of the Beaver Divide at Wagon-bed Spring. Horizontally, not to scale; vertically, 500' = 1". Section from top of Wind River to top of lignitic tuff measured 1/2 mile north of Wagon-bed Spring; from top of tuff to top of Oligocene, 1/2 mile south of spring.

Fig. 2B. Diagrammatic section across the Bighorn Basin from the top of Tatman Mountain easterly to the Cretaceous and Fort Union opposite the mouth of Elk Creek. Not to scale either horizontally or vertically.



cene andesitic agglomerate studied at Wagon-bed Spring are present at Green Cove. The ash bed indicated in Granger's generalized section was inserted to conform with the stratigraphic succession at the first mentioned locality. So far as at present ascertained, the correlations between

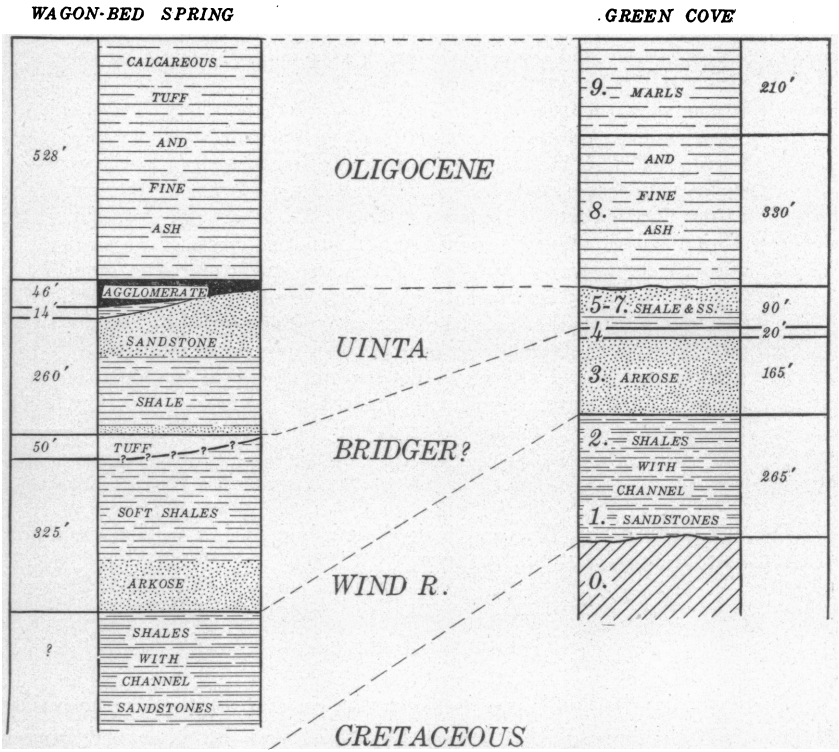


Fig. 3. Diagram showing the relations of the Wagon-bed Spring and Green Cove sections of the Tertiary deposits of the Beaver Divide.

the Wagon-bed Spring and Green Cove sections are indicated in Figure 3, and for convenience in comparison a detailed statement of the latter is here inserted. The beds to which the numbers refer are indicated in the diagram (Fig. 3) and in the photograph (Plate VI).

*Section through the Tertiary deposits of the Beaver Divide, about four miles east of Hailey.<sup>1</sup>*

*Top of Divide.*

- 9. Buff and gray calcareous marls with some coarse sandstone and a little sandy shale. Marls more highly calcareous than No. 8, and toward the top weather out into hard ledges . . . . . 210

<sup>1</sup> Granger, *loc. cit.*, pp. 237, 239.

8. Buff-colored calcareous marls, very uniform in nature except the lower 50 feet where the marls are interbedded with coarse sandy layers from one inch to two feet in thickness . . . . .	330
<i>Erosion Unconformity.</i>	
7. Coarse greenish sandstone . . . . .	10
6. Yellowish-green and olive coarse, loosely compacted sandy stones . . . . .	55
5. Gray and yellowish clay . . . . .	27
4. Blue-gray clay and sandstone, forming a prominent ledge along the face of the bluff; weathers nearly vertical . . . . .	20
3. Beginning at the base of the main bluff where there is a red stratum corresponding with the one at the top of the butte in No. 2, the rock is pale yellowish brown and alternates between sandy and clayey shales, with coarse sandy beds at intervals. Some layers weather out harder, forming rounded ledges . . . . .	165
2. A small outlying butte is composed of alternating layers of gray and purplish clays, gray-green sandy shales and strata of coarse sand. Some of the sandy layers weather out salmon-colored . . . . .	125
1. One mile out from the foot of the bluff, and resting nearly horizontally on upturned Cretaceous, are sandy clays, becoming more sandy toward the top, and with a two-foot stratum of calcareous sandstone midway. The clays are yellowish, greenish and purplish . . . . .	140
Total,	1082

*O. Cretaceous.*

The elements of the Beaver Creek-Wagon-bed Spring section may now be redescribed separately, in detail.

## THE WIND RIVER.

The extensive badland area between the outcrop of the Cretaceous at Hudson and the base of the Beaver Divide escarpment is carved from a series of red, reddish-purple, and bluish-green shales (the red and bluish-green colors alternating), unconsolidated arkosic sands with many water-worn pebbles of quartz and feldspar, and one prominent, though local, band of white tuff. These rest unconformably on the Cretaceous and dip beneath the Beaver Divide escarpment at a low angle (about  $1^{\circ} 15'$ ). From the few fossils (*Eohippus* sp., *Phenacodus* sp., *Coryphodon ? testis*) obtained during the summer of 1909, these beds were referred doubtfully by Granger to the Wasatch.<sup>1</sup> During the past summer, a typical Wind River fauna was found by Mr. George Olsen of the American Museum party in a small amphitheatre of low badlands to the east of the valley of Beaver Creek, some four or five miles above its intersection with Big Sand Draw (Plate

<sup>1</sup> *Loc. cit.*, pp. 239, 240.

VII, Fig. 1). The entire fauna was obtained at or near the contact of a stratum of bluish-green shale resting on a red shale band, the fossiliferous zone not exceeding ten feet in thickness. The following association of forms was obtained:

*Glyptosaurus* (scutes).  
Gar pike (scutes).  
Crocodile (scutes, vertebræ and teeth).  
Turtles (numerous fragments).  
*Hyopsodus* sp. nov.  
*Hyopsodus* sp.  
*Didymictis* ? *altidens*.  
*Microsyops* sp.  
*Eohippus craspedotus*.  
*Eohippus* ? *venticolus*.  
*Heptodon calciculus*.  
*Heptodon ventorum*.  
*Heptodon* sp. nov.  
*Lambdotherium popoagicum*.  
*Coryphodon* sp.

The presence of fish and crocodiles in this fauna indicates plainly the fluviatile nature of the deposit in which they occur and goes far toward establishing a theory of flood plain origin for the Wind River shales, which is further supported by the presence of frequent channel fillings of coarse arkosic sandstone. Such a channel, a few feet above the horizon affording the fauna of the *Lambdotherium* zone, is shown in Plate VII, Fig. 2. It is filled with a coarse arkose containing water-worn, more or less kaolinized feldspar fragments, quartz and chlorite grains, foils of biotite and a small amount of clayey material associated with rounded grains and small pebbles of such pre-Tertiary rocks as quartzite, granite and gneiss, the whole slightly cemented with calcium carbonate. All the fossils from the shales are fragmentary and consist mostly of teeth with the roots worn off and only the crowns remaining, an indication that they have been transported in contact with abrasives.

Whether the entire thickness of banded beds between the horizon of the *Lambdotherium* fauna listed above and the outcrop of the Cretaceous at Hudson is to be regarded as Wind River cannot be positively stated and may be open to question in view of the discovery, in the Bighorn Basin, of the conformable superposition of the Wind River on the Wasatch without any lithologic dissimilarity between them.

1. *The Wind River Shales*.—These might with equal propriety be termed clays as they readily absorb water, swell and become more or less plastic. They occur in lenticular bands of variable extent and thickness and always highly colored, red or purplish red, mottled red and blue-green,

or blue-green, alternating with more or less regularity. Locally, an abundance of calcareous concretions of ball or star shape and radiate internal structure may be present, especially in the red clays, which may also be veined with the same material deposited along slipping planes and joint cracks. Anastomosing green lines traverse the red clays and spread along the joints where the color has been changed, perhaps by surface waters or organic acids from plant roots. Precisely similar green zones about undecayed roots were noted in a chocolate-colored Pleistocene or Recent clay exposed in an undercut bank on Beaver Creek. Under natural weathering, the clays break down into powder which becomes a sticky mud and flows down the badland slopes during every heavy rain. When dry, this is caked at the surface and extensively mud-cracked (Plate V, Fig. 1).

Of two samples examined in detail, the mottled red and blue-green variety possesses greater plasticity and finer grain while the red variety is less plastic and more gritty, due to the presence of small mineral particles, usually quartz and feldspar. Little can be determined microscopically regarding the origin of the clay. In addition to kaolin, an occasional minute feldspar fragment may be seen in the blue plastic clay. In the red and more gritty sample, larger grains of quartz and feldspar, some of them rounded, and an occasional round grain of chloritic material were observed.

A discussion of the origin of the color-banding in the clays may be deferred advantageously to a later page where it will be considered in attempting to explain a similar phenomenon in the Wasatch.

2. *The Wind River Sandstones.*—The Wind River sandstones in the vicinity of the Beaver Divide are stream channel deposits of predominantly arkosic character. A very perfect example has already been referred to and is figured in Plate VII, Fig. 2. It is a broad shallow trench cut in banded clays, traceable for a half mile or more, and filled with a barely coherent mass of coarse sandstone or even fine conglomerate composed of more or less water-worn grains or small pebbles of quartzite, granite and gneiss, quartz and feldspar, biotite foils and chlorite grains. Not all the sandstone beds are in such perfectly formed channels, but they are all more or less lenticular in cross section and may show slight erosional disconformity with the clays on which they rest although perfectly conformable above with the next succeeding stratum. In one instance small stems of petrified wood were noted, standing erect in the clay and abruptly truncated by the overlying sandstone. The sandstone here referred to lay directly beneath the white tuff described in the next section and contained scattered water-worn pebbles of a similar tuff in a matrix of small sharply angular fragments of feldspar, both orthoclase and plagioclase, often fresh but sometimes slightly kaolinized, quartz grains, biotite and muscovite foils, hornblende

needles, splinters of pink garnet, small, dark, opaque grains, probably iron ore and masses of kaolin, probably kaolinized feldspars, the whole cemented by calcium carbonate.

From these two average and quite typical examples, it would seem that the Wind River sandstones, in the region with which we are now concerned, represent deposits laid down in the channels of broad, shifting, low-grade streams flowing across clay-covered flats into which the channels were sunk or over which, in times of flood, the coarse detritus was spread. From the nature of the sediments composing these channel sandstones it is quite evident that they were derived from the decay of the granites and other pre-Tertiary rocks of the surrounding mountains. Absence of torrential streams is inferred from the fact that coarse conglomerates do not occur, although present in later formations in the same area.

3. *The Wind River Tuffs*.—Near the mouth of Big Sand Draw, referred to above in describing the position of the horizon affording the fauna of the *Lambdotherium* zone discovered by Olsen, and on the east side of the draw, a white tuff band, 13 feet thick, is interstratified with the Wind River clays and sandstones at a horizon considerably lower than that affording the fossils. It rests on a heavy brown sandstone containing rolled pebbles of tuff and is overlain by pale greenish shales. The upper four or five feet of tuff is highly pumiceous, containing grains of snow-white pumice varying in size from bird shot to small peas inclosed in a fine-grained gray matrix. The most abundant mineral constituent recognizable macroscopically is biotite, present in small cleavage foils inclosed in the white pumice grains, but not excluded from the matrix also. Occasionally a small fragment of feldspar may be found. In thin section both pumice grains and matrix are seen to be composed of a felt-like mass of wisps, needles and fine grains of isotropic glass inclosing in order of relative abundance: (1) orthoclase, often zoned, sometimes twinned on the Carlsbad law, either with recognizable crystallographic boundaries, more or less broken or in small laths, frequently with included apatite; (2) plagioclase (average extinction of pairs of twin lamellæ varying between  $15^{\circ}$  and  $18^{\circ}$ ); (3) foils of olive-green, pleochroic biotite, sometimes with hexagonal outline; (4) splinters of pale green hornblende; (5) black opaque grains, probably iron oxide. A flow structure is sometimes developed in the pumice grains.

An analysis of this tuff kindly prepared for us by Professor A. H. Phillips in the chemical laboratory of the Department of Geology of Princeton University shows a remarkably high water content, much of which must be secondary. Recalculation on a water-free basis gives a percentage composition approximating that of certain rhyolites. This is further supported by the acid character of the plagioclase, judging from the average values of the extinction angles.

*Pumiceous rhyolite tuff, Big Sand Draw, about twelve miles above the mouth of Beaver Creek, Fremont County, Wyoming.* A. H. Phillips, analyst, December, 1910.

	%
Si O <sub>2</sub> . . . . .	65.62
Al <sub>2</sub> O <sub>3</sub> . . . . .	13.07
Fe <sub>2</sub> O <sub>3</sub> . . . . .	1.89
Mg O . . . . .	.95
Ca O . . . . .	2.59
Na <sub>2</sub> O . . . . .	3.39
K <sub>2</sub> O . . . . .	1.13
*H <sub>2</sub> O below 110° . . . . .	2.71
*H <sub>2</sub> O above 110° . . . . .	7.39
CO <sub>2</sub> . . . . .	0.00
TiO <sub>2</sub> . . . . .	.18
P <sub>2</sub> O <sub>5</sub> . . . . .	.32
SO <sub>3</sub> . . . . .	.61
MnO . . . . .	.016
	99.866

\* No sharp distinction exists between water below and that above 110° in this analysis, as its emission was a continuous process.

The eight or nine feet of finer grained tuff beneath the pumiceous band just described is composed of a felt-like mass of glass granules and pumice wisps with flow structure inclosing many highly angular fragments of feldspar (both orthoclase and plagioclase), some quartz, olive-green biotite foils and splinters of green hornblende in greater abundance than in the pumiceous zone above, and many scattered black grains, probably magnetite. A few small apatite crystals were observed in the tuffaceous matrix, probably included originally in the biotite or feldspars. Many of the pumice grains have been infiltrated with secondary calcite, the presence of which is confirmed by treatment with dilute hydrochloric acid. Balls of hard green shale were observed in this tuff in the field. It is also traversed by channel fillings of contemporaneous origin, both indicative of fluvialite deposition.

#### THE SO-CALLED BRIDGER.

About 375 feet of sandstone, shale and tuff lying between the red-banded clays of the Wind River and the Uinta shales have been referred doubtfully by Granger<sup>1</sup> to the Bridger. Although repeatedly examined during two seasons, no fossils have been found in these beds, the age determination

<sup>1</sup> *Loc. cit.*, pp. 238, 239.

depending entirely on stratigraphic relationships. So far as has been determined, this so-called Bridger is conformable with the underlying Wind River. There may be an erosional disconformity with the Uinta, as the white lignitic tuff band and the soft clay shales beneath it, observed at Wagon-bed Spring (Fig. 3), are absent four miles farther south at Green Cove, their place being taken by a twenty foot layer of a peculiar sandstone and clay mixture (No. 4, Green Cove section, Fig. 3 and Plate VI).

1. *The Basal Arkose*.—The first formation overlying the Wind River clays at the base of the Beaver Divide escarpment (Figs. 2 A and 3; Plate VI, No. 3) is an unconsolidated or slightly consolidated pale yellow-colored arkose containing an abundance of water-worn gravels occurring both scattered through the finer matrix and in more or less well-defined lenses. Pegmatite pebbles two or three inches in diameter or even more abound in these gravels. Quartz, feldspar, black chert and sandstone are also represented. The matrix is composed of subangular quartz and feldspar grains, with a few foils of biotite, rather numerous particles of chlorite and a little kaolinized material. The harder layers, which always weather out in relief, show minor disconformities with the softer beds on which they rest (Plate VI, No. 3). From the lenticular character of these harder beds, the local disconformities and the abundance of stream gravels throughout the mass it seems evident that we are dealing with the coarser detritus of a series of confluent alluvial fans deposited by streams draining from some granitic area near by, probably the Sweetwater Mountains. Occasional interstratified layers of shale represent, undoubtedly, the fine clays washed out of the arkose by the streams in which the latter was transported.

2. *Shales of the So-called Bridger*.—In the Wagon-bed Spring section, the gravels and arkose pass upward into olive-green sandy shales with some coarser sand layers. Above these are exceedingly soft, chocolate-colored, greenish and purplish-tinted shales or clays which readily absorb water and slip, producing the numerous landslides found everywhere throughout the middle portion of the Beaver Divide escarpment (Fig. 2 A, and Plate IV, Fig. 2).

3. *The White Lignitic Tuff*.—Owing to these landslides, the contact between the variegated shales or clays and a bed of white lignitic tuff which overlies them has been either concealed or so dislocated at every exposure discovered that we have not been able to ascertain whether it rests conformably on the clays or not. From its absence in the Green Cove section, and also to the northeast about the headwaters of Muskrat Creek, the tuff bed is evidently lens-shaped. Exposures were examined for a mile and a half or more north of Wagon-bed Spring which issues from the tuff in a land-slipped block, and for about a half mile to the south of the spring,

beyond which the tuff is concealed by talus and probably thins out and disappears. Various measurements of the thickness gave values ranging from 25 feet to 75 feet which have been averaged in constructing the section (Fig. 2 A). The tuff is a white, thin-bedded harsh-feeling rock varying in degree of cementation from pulverulent to compact, and contains frequent lignite beds varying in thickness from six inches to a foot. It shows no admixture of fluvial material such as clay, sand or gravel and is possibly a lacustrine deposit. On chemical analysis, a sample of the pulverulent variety shows the following composition:

*Tuff, half mile south of Wagon-bed Spring, Beaver Divide escarpment, Fremont County, Wyoming.* A. H. Phillips, analyst, December, 1910.

	%
SiO <sub>2</sub> . . . . .	83.12
Al <sub>2</sub> O <sub>3</sub> . . . . .	7.16
Fe <sub>2</sub> O <sub>3</sub> . . . . .	.63
MgO . . . . .	.09
CaO . . . . .	.39
Na <sub>2</sub> O . . . . .	.25
K <sub>2</sub> O . . . . .	5.64
H <sub>2</sub> O below 110° . . . . .	.51
H <sub>2</sub> O above 110° . . . . .	1.52
CO <sub>2</sub> . . . . .	0.00
TiO <sub>2</sub> . . . . .	.15
P <sub>2</sub> O <sub>5</sub> . . . . .	.05
SO <sub>3</sub> . . . . .	.37
MnO . . . . .	.01
	99.89

As the silica percentage in this analysis is rather above the average for even the most acid tuffs, the presence of diatoms was suspected, but repeated microscopic examinations have failed to reveal more than one and the possibility of its accidental introduction was not fully guarded against. Perhaps the tuff has been secondarily enriched in silica, deposited in colloidal form by springs, but the only occurrence of opaline silica in the vicinity is at a much higher horizon in the Oligocene.

Under the microscope, the pulverulent tuff, of which the chemical composition has just been given, is seen to be made up almost entirely of exceedingly fine isotropic granules which appear structureless even under a 370 diameter magnification. A few splinters of clear feldspar may also be observed which the analysis shows to be orthoclase. The more compact variety, when examined with a hand lens, is found to contain many foils of olive-green biotite scattered through the white matrix. In thin section

hosts of minute feldspar fragments are seen, water-clear and highly angular. The feldspars are both untwinned and twinned (extinctions of pairs of twin lamellæ ranging from  $15^{\circ}$  to  $26^{\circ}$ ). Foils of olive-green biotite are also present and, occasionally, light green hornblende in splinters and needles. Rusty opaque grains, probably iron oxide, and an occasional pumice fragment complete the list.

As mentioned above, the white tuff and underlying soft shales are absent at Green Cove, their place being taken by a twenty-foot blue-gray stratum of arkose, clay pellets and clay (No. 4, Fig. 3 and Plate VI). This is harder than the beds below it, from which it is separated by a slight disconformity, and weathers out in relief as a prominent cliff and terrace. Its superior hardness is not due to a calcareous cement (present in small amount), but seems rather to have resulted from a setting process. Under a low power, the hand specimen is seen to be traversed by numerous irregular tubules ( $\frac{1}{2}$  mm. to 1 mm. in diameter), perhaps root-canals, lined with a white waxy clay. Small interstratified clay lenses and numerous clay pellets form a considerable part of this hard stratum. The remaining material is coarse arkose mixed with fine clay and minute isotropic grains (glass particles?). This stratum may, therefore, owe its superior hardness to the presence of ash which was deposited, apparently, under lacustrine conditions at Wagon-bed Spring, but elsewhere must have been more or less widely distributed by the wind and mixed with such terrestrial formations as were in process of accumulation. The clay-lined root-tubules, if such they be, may indicate a certain amount of leaching by surface waters either during or after the consolidation of this stratum. Possibly the clay lining may have been formed by organic acids from the roots themselves.

#### THE UINTA.

In the field, the plane of demarcation between the so-called Bridger and the Uinta was arbitrarily placed at the top of the white lignitic tuff in the Wagon-bed Spring section, as no structural break could be detected between it and the overlying shales with *Amymodon* and other Uinta fossils.

Wherever exposed, the lignitic tuff is conformably overlain by a rust-colored, fine-grained silt, frequently concretionary, owing its color to the yellow staining of multitudes of cottony grains, doubly refracting, silvery white in color, between crossed nicols and evidently representing kaolinized or sericitized material. Much finely divided feldspar, both orthoclase and plagioclase, small fragments of biotite and hornblende and considerable magnetite are also present. If quartz occurs, it could not be distinguished from the small water-clear feldspars.

The formation just described is overlain conformably by the so-called "joint-clays"<sup>1</sup> of the Uinta with *Amynodon*, etc., light cream-colored to pale greenish shales with the same association of minerals as in the yellow silts below, but with the kaolinized material of finer grain. As the specimen examined showed no tendency to become plastic when soaked in water, even after the large amount of calcium carbonate present had been removed by treatment with acid, the term "clay" is hardly applicable. The shales are irregularly jointed (Plate VIII, Fig. 1, lower margin of picture), readily crumbling, when exposed to the weather, into small fragments forming the steep talus slope below the escarpment of the Uinta sandstone (Plate VI, Figs. 1 and 2).

The sandstone (Plate IV, Fig. 2) is a medium-grained, greenish-colored rock which, in addition to vast numbers of kaolinized fragments ranging in size from fine dust to particles a third of a millimeter in diameter or thereabouts, white, rusty red or purplish pink in color (probably kaolinized feldspar though some few suggest pumice in texture), contains abundant angular fragments of orthoclase, water clear or slightly cloudy, an occasional plagioclase (average extinction on twin lamellæ varying from 15° to 26°), quartz grains, hornblende splinters, biotite foils and abundant magnetite sand. The association of glassy feldspars with weathered and kaolinized grains suggests their derivation from granitic rocks by temperature changes causing shattering of the unweathered minerals. That the sandstone is of granitic origin seems beyond question, for, locally, it becomes a coarse arkose with siliceous cement. Great blocks of this, fallen from the cliff controlled by the Uinta sandstone and Oligocene agglomerate strew the land-slipped area south of Wagon-bed Spring (Plate IV, Fig. 2). In the silicified arkose, large angular fragments of orthoclase, microcline and plagioclase (extinctions on albite twin lamellæ ranging from 17° to 21°) both absolutely water clear and also dull white, abundant and large grains of quartz and a few splinters of green hornblende are firmly cemented together by a siliceous paste, both opaline and chalcedonic. The resulting rock is so hard that it readily breaks across the quartz grains when a hand specimen is trimmed. The opaline silica of the paste is gray-white in color in transmitted light and absolutely isotropic between crossed nicols. Until the nicols are crossed, the chalcedonic silica cannot be distinguished from the clear quartz grains, but between crossed nicols it appears as a spherulitic aggregate, some of the spherulites showing the central black cross distinctly. No calcite is present as a cementing substance.

At Green Cove, the medium-grained green sandstone of the Uinta, con-

<sup>1</sup> *Loc. cit.*, p. 238, Fig. 1.

taining many quartz and feldspar pebbles (Plate VI, No. 7) can be readily identified. Uinta Number 6 of this section is very much like the arkose of the so-called Bridger (No. 3) and like it contains abundant quartz and feldspar pebbles, while Number 5 shows, in superficial appearance at least, some resemblance to the cream-colored shales of the Uinta already described. In the section at the head of Muskrat Creek a fine-grained, bluish-gray shale occupies the position of the Uinta below the Oligocene gravels which here rest upon it.

As shown in the diagram (Fig. 3) the total thickness of the Uinta varies much as does that of the individual elements which, also, change in character from place to place.

### THE OLIGOCENE.<sup>1</sup>

1. *The post-Uinta Erosion.*—After the close of Eocene deposition, broad shallow valleys, indicative of a fairly mature topography, were excavated in the Uinta sediments (Plate IV, Fig. 1). Ripple marks and mud-pellet conglomerate observed at the bottom of the channel, of which a part is seen in Plate IV, Fig. 1, show that the valleys were, at times, occupied by running water.

2. *Volcanic Mud Flows.*—Shortly after the cutting of the valleys, explosive volcanic eruptions broke out somewhere in the vicinity, and the first deposit laid down in these troughs was a fine-grained, buff-colored tuffaceous shale (Plate IV, Fig. 1, O1). It was in this tuff that the American Museum party of 1909 found a skull of *Titanotherium heloceras* which, with other vertebrate fossils<sup>2</sup> from higher levels, determines the age of all the beds above the post-Uinta erosion cycle as Lower Oligocene.

Vulcanism soon became extremely violent, ejecting great blocks of hornblende andesite which, with ash, pumice, lapilli, and pebbles and cobbles of pre-Tertiary rocks, were swept down the valleys as mud-flows. The vents from which this material came have not yet been located. They continued in eruption during the whole of the Lower Oligocene, as here represented, showering the surrounding region with dust. The agglomerate resulting from these mud-flows attained a thickness of 46 feet in the vicinity of Wagon-bed Spring. As its distribution was controlled by the then-existing valleys, it can readily be understood why it is not present at Green Cove. The Wagon-bed Spring flow thins out toward the south and, for some distance north of the lone butte seen on the sky-line in Plate IV,

<sup>1</sup> Possibly the same beds which are referred to vaguely by Endlich, *loc. cit.*, pp. 112, 113, as Pliocene.

<sup>2</sup> Granger, *loc. cit.*, faunal list, p. 240.

Fig. 2, the Uinta sandstone is at the level of the top of the agglomerate. A second flow is seen in the face of the escarpment below the distant mesa at the extreme right of the picture but thins out also before reaching Green Cove. The agglomerate may rest on the buff-colored tuffaceous shale already mentioned or on the Uinta sandstone (Plate IV, Fig. 1; Plate VIII, Fig. 1), often with a basal conglomerate inclosing pebbles of the sandstone. It is a light gray, harsh-feeling, coarse-grained tuff crowded with fragments of hornblende andesite of a size up to three or four feet in diameter, both angular and worn round and smooth, abundant pebbles of pumice and, locally, pebbles and even cobbles of quartz, granite and gneiss, or of the tuff itself. About a half mile south of Wagon-bed Spring, a five-foot bed of coarse fragments of white pumice occurs near the top of the flow. This may be traced southerly along the crest of the escarpment for some distance. Probably there were repeated mud-flows down the same valley, as what looks like a channel of contemporaneous erosion, filled with andesite cobbles imbedded in gray ash, was seen in the agglomerate about two miles south of Wagon-bed Spring.

Thin sections taken from the lava pebbles in the agglomerate show that these are hornblende andesite containing phenocrysts of beautifully zoned plagioclase (average maximum extinction of twin lamellæ as high as  $33^\circ$ ), untwinned but sometimes zoned feldspars (perhaps orthoclase), golden brown, intensely pleochroic biotite, dark, olive-green hornblende (the proportions of biotite to hornblende varying greatly in different slides), a subordinate amount of hypersthene and, finally, abundant black, opaque grains in a ground-mass of fine needles of feldspar and glass. Flow structure is commonly observable, the needles orienting themselves parallel to the margins of the phenocrysts or curving about the ends of the latter. In some slides, large patches of calcite are seen filling cavities (gas cavities). In one highly pumiceous section wisps of glass may be observed penetrating the calcite which has evidently been introduced by secondary infiltration.

As already stated, the agglomerate is absent at Green Cove (Plate VI and Fig. 3). In a third section at the head of Muskrat Creek, small patches of andesitic gravel in an ashy-appearing matrix were found overlying fine-grained bluish-gray shale (Uinta?) on the slope and capping isolated buttes in advance of the main exposures of the Oligocene which here abound in coarse gravels containing some andesite but mostly pebbles of granite, various schists, quartzite, etc.

3. *Oligocene Gravels from pre-Tertiary Rocks.*—Such gravels abound throughout the Oligocene beds capping the Sweetwater-Wind River divide at the head of Muskrat Creek and thickly strew the remnant of the old alluvial plain (page 87) at its summit. At Wagon-bed Spring on the great

terrace (page 95) above the agglomerate flow and extending for perhaps a mile north of the spring is a deposit of gravel and cobbles of granite, pegmatite, hornblende and other gneisses, quartzite, quartz, hornblende andesite and other volcanic rocks in a matrix of coarse sand resembling an arkose, mixed with and overlain by soft ash (Fig. 2 A and Plate IV, Fig. 1, O3). At first it was suspected that the gravels were contemporaneous in origin with the terrace on the surface of which they are exposed, but further study showed that their areal extent was limited, that they were, in places, firmly cemented and, finally, that many large cobbles of granite at the base of the gravel sheet were imbedded in the tuff at the top of the agglomerate flow. Apparently, we are dealing with a channel deposit of Oligocene age, perhaps formed by a stream which had been diverted from its course by the mud flows. As already noted, similar gravels abound in and to the very top of the Oligocene on the divide at the headwaters of Muskrat Creek. Granite pebbles have also been found in the limestone capping of the Oligocene in the Wagon-bed Spring section and further south. The earlier andesitic eruptions may have been followed (perhaps even caused) by an elevation about the headwaters of the streams crossing this portion of the basin of deposition, enabling them to transport coarse gravel and large cobbles which far exceed in size any of those in the conglomerates of earlier age in this vicinity, so far as known, with the exception of the andesite boulders in the agglomerate. Perhaps the Oligocene conglomerates were spread over the floor of the Wind River basin by torrential intermittent streams under more arid climatic conditions than prevailed during the Eocene.

4. *Wind-blown Ash and Dust.*—That explosive vulcanism was still in progress is indicated by the great thickness of fine buff-colored ash and dust above the gravels at Wagon-bed Spring, where 528 feet of such material is found, increasing to 540 feet at Green Cove (Fig. 3). Locally, the ash is still quite unconsolidated, but usually shows considerable calcareous cementation, especially toward the top of the section where it may pass into a tuffaceous limestone. Angular fragments of more or less devitrified pumice, in which a flow structure is beautifully defined, and sharp splinters of isotropic glass make up more than fifty percent of the soft ash. The remainder consists of abundant angular fragments of plagioclase (average extinction of twin-lamellæ ranging from  $11^{\circ}$  to  $23^{\circ}$ ), water-clear or slightly cloudy orthoclase sometimes including apatite, in one slide a small feldspar granule with cross-twinning resembling that characteristic of microcline, hornblende both dark green and blue-green, olive-green and golden-brown biotite, small fragments of quartz, an occasional particle of hypersthene, and many black opaque grains, probably iron oxide. The harder phase of

the ash, after removal of its calcareous cement by treatment with acid, differs in no respect from the softer material with which it is interstratified. From the abundance of green hornblende, brown biotite and the occasional presence of hypersthene, no doubt is entertained regarding the andesitic character of this ash. The presence of quartz and microcline-like feldspars can readily be accounted for when it is remembered that great quantities of granite and other quartz-bearing rocks were being swept into the basin of deposition from the surrounding mountains and, from the surfaces of these alluvial fans, the wind could readily carry away fine dust to mingle it with material of volcanic origin.

5. *Limestone and Spring Deposits.*—Toward the top of the Oligocene section at Wagon-bed Spring, the ash becomes increasingly calcareous and gives place to sheets of tuffaceous limestone or layers of white nodular masses, calcareous without, but, when broken open, found to contain more or less silica, both opaline and chalcedonic. Pipes of siliceous material are also seen penetrating the limestone. South of the road-crossing known as Government Slide, the limestone forms the rim-rock of several buttes and mesas seen in the background, at the right-hand side of the picture, in Plate IV, Fig. 2 and, closer at hand, in Plate V, Fig. 2. In the last-mentioned view, an angular unconformity is shown between the limestone and the tuff below, the latter dipping to the west or northwest. This appears to be local. Many quartz, feldspar and pink granite pebbles may sometimes be found in the limestone. It weathers into irregular slabs and honey-combed masses deeply etched by solution. When treated with hydrochloric acid, it dissolves readily leaving a fine gray dust and many delicate, moss-like aggregates of snow-white, isotropic silica. The gray dust, when examined microscopically, is found to be ash, abounding in glass splinters, pumice wisps, and the same association of minerals as occurs in the soft, wind-blown ash already described.

In Granger's preliminary report,<sup>1</sup> the limestone is referred to as "marl," interbedded with sandstones and shales (see section page 89) which have since proved to be ash beds. The term marl, in so far as it implies organic origin from fragments of fresh-water shells, is, probably, inapplicable. While careful search might show the presence of such shells in this limestone, none have yet been found. It seems more probable that it has been formed by waters carrying carbonates in solution, the evaporation of which, at or near the surface, has produced the limestone. A somewhat similar occurrence is described by Rogers and Du Toit in Cape Colony, South Africa,<sup>2</sup>

<sup>1</sup> *Loc. cit.*, section, p. 237.

<sup>2</sup> An Introduction to the Geology of Cape Colony, 2nd Edition, pp. 401-404, 1909.

in which local replacement of the carbonate by opal and agate has taken place. Such replacement by opal and chalcedony was repeatedly observed in the limestones of the Beaver Divide. Cylindrical pipes of silica were seen cutting through the limy layers and delicate moss-like aggregates of opaline silica were dissolved out of the massive limestone on treating the latter with acid. Probably the source of both limestone and silica is to be sought in the thick beds of ash from which they were brought to the surface by percolating waters. The silica may, perhaps, have been deposited by springs.

The formation of the limestones of the Beaver Divide by the method suggested above may imply a dryer climate during the Oligocene, with more intense evaporation of waters brought to the surface by capillarity, than prevailed during the Eocene. In the latter, stream-channel deposits and fine water-laid clays are abundant. No clays have yet been found in the Oligocene, but only wind-laid ash and coarse gravels, perhaps to be regarded as alluvial fan deposits formed by torrents during occasional heavy rains. It is desirable to point out, however, that we are familiar with but small fragments of a once extensive formation, and that generalizations regarding Oligocene climate which are based on these have a necessarily insufficient foundation.

### THE LOST CABIN SECTION OF THE WIND RIVER.

In contrast with the arkoses which characterize the Wind River in the Beaver Creek and Beaver Divide areas, the extensive exposures of this formation at the northerly margin of the basin of accumulation, south of the Bridger Range, in the valleys of Poison, Alkali, Badwater, Bridger and Lysite Creeks (map, Fig. 1) are, so far as the coarse sediments are concerned predominantly quartzose. The beds consist of the usual highly-colored clays, often alternately banded red and blue, interstratified with pale greenish, buff and yellow-brown sandstones in more or less continuous lenses. The clays show no appreciable difference from those already described from the Wind River. The red clays are often mottled with green or show green zones along joints or as irregular lines branching through the clay. Both red and blue clays may be fine-grained and highly plastic or gritty from mixture with quartz and feldspar grains. They abound in small, irregular, calcareous concretions which weather out and strew the badland slopes. The sandstones interstratified with the clays are composed largely of quartz sand, highly angular to subangular, with subsidiary feldspar and a little chlorite and biotite. In only a few of the specimens ex-

amined was feldspar in excess of quartz. Fragments of pre-Tertiary rocks are rare. Only one conglomerate was seen, composed of highly angular fragments of white quartzite and chert, small round pebbles of coarse sandstone and many round grains of quartz sand with their surfaces roughened by secondary growth. A fragment of a silicified fossil shell was also found among the rock fragments and sand grains.

Granger<sup>1</sup> has separated certain beds exposed along Cottonwood Creek (see map, Fig. 1) north of Lost Cabin, characterized by the absence of *Systemodon* and *Lambdotherium*, from the typical Wind River along Alkali Creek where *Lambdotherium* is abundant. They comprise yellow, gray and brick-red shales or clays with interstratified buff, pale blue, yellow-brown and gray sandstones, dipping at a low angle away from the Bridger Range and passing *beneath* the bluish shales and gray and yellow sandstones with *Lambdotherium* along Alkali Creek. These, in turn, lie *below* the red and blue banded beds, also with *Lambdotherium*, forming the divide between Alkali and Poison Creeks north of Moneta. Throughout there is conformable superposition.

With regard to the faunistic basis for separating the Cottonwood Creek exposures from the rest of the Wind River Granger<sup>2</sup> writes: — “A preliminary study of this fauna shows two points of interest. *First*. All of the genera from these beds are common to the *Lambdotherium* zone and to the *Coryphodon* zone of the Bighorn Wasatch. *Second*. The affinities of the species are, in general, closer to those of the latter than of the former zone. The absence in these collections of *Lambdotherium*, one of the most common forms, and of *Eotitanops*, a not uncommon genus of the Alkali Creek beds but a few miles distant, clearly indicates that these Cottonwood Creek beds belong to a faunal horizon distinct from the *Lambdotherium* zone. On the other hand, the absence of the equally common *Systemodon* of the Bighorn Wasatch makes it difficult to correlate the beds with the *Coryphodon* zone. They appear to be intermediate between the two zones with none of the characteristic faunal features of either.”

As the beds on Cottonwood Creek lie below and are faunally distinct from the *Lambdotherium* zone, it seems desirable that they should have a formation name, and, as Cottonwood is preoccupied, we propose **Lysite**, from Lysite Creek where the beds are well exposed. For the *Lambdotherium* zone which has hitherto been synonymous with Wind River, we propose the formation name **Lost Cabin**, from the village of that name to the east of which are the main exposures of the beds affording *Lambdotherium*.

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<sup>1</sup> *Loc. cit.*, p. 245.

<sup>2</sup> *Loc. cit.*, pp. 245, 246.

Both the Lysite and Lost Cabin are grouped as stages of the Wind River series, as they are conformable.

The type area of the Lysite formation is on Lysite and Cottonwood Creeks, north of Lost Cabin. The beds comprise in descending order:<sup>1</sup>—

- Yellowish and gray sandy shales covered with a heavy mantle of pebbles from the older rocks of the mountains.....50 ft.
- Alternating buff sandstones (1 ft. to 5 ft. in thickness) and red and blue-gray shales.....200 ft.
- Gray and dark brick red sandy shales (red predominating) and gray sandstones.....100 ft.
- Dull colored, deeply disintegrated clays with some feldspathic sandstone and much gypsum.....thickness undetermined.

Pre-Tertiary rocks of Bridger Range.

The type area of the Lost Cabin formation is to the east of Lost Cabin along Alkali Creek and on the divide between Alkali and Poison Creeks. The Wind River of the Beaver Divide from the level of the *Lambdotherium* fauna (Fig. 2 A) to the base of the yellow arkose which may be referable to the Bridger belongs to the Lost Cabin stage, as does also the Wind River of the Bighorn basin (see page 108).

#### DEFORMATION OF THE WIND RIVER.

Between Lysite and Cottonwood Creeks north of Lost Cabin the slight southerly dip of the Lysite formation suddenly changes to north, producing a narrow syncline, of which the southerly limb dips to the north at an angle estimated at 10°. The beds soon flatten out and continue with their usual low southerly dip beneath the Lost Cabin formation (*Lambdotherium* zone). This syncline does not seem to be due to irregularities in the surface of the depositional basin and may have resulted from a post-Wind River elevation of the Bridger Range.

#### THE EOCENE-? OLIGOCENE SECTION OF THE BIGHORN BASIN.

##### THE FLOOR OF THE EOCENE BASIN.

The Bighorn Wasatch occupies a structural depression, the floor of which was modified by erosion subsequent to the main uplift of the Bighorn Mountains, occurring after the deposition of the Fort Union. At several

<sup>1</sup> Section measured by Granger. *Loc. cit.*, p. 245.

points where the pre-Wasatch basin floor can be seen, the basal conglomerate or sandstone of the Wasatch rests on a level surface carved across the uptilted edges of Fort Union beds. A splendid section, showing the contact, may be examined on Antelope Creek, about two miles southwest of the town of Basin (Plate IX, Fig. 1). At this locality, the Fort Union shales and sandstones dip to the west at an angle of  $35^{\circ}$ . The Wasatch contact plane also dips westerly, but at an angle of  $1^{\circ}$ , increasing to  $8^{\circ}$  toward the easterly margin of the basin. A yellow-brown quartzose sandstone forms the basal member of the Wasatch, succeeded by yellow-weathering blue clays, frequently lignitic, interstratified with narrow, pale pink clay bands and occasional sandstone lenses. The bedding planes of the Wasatch parallel the slope of the contact plane, increasing with it in dip toward the east. This has probably been produced by an uplift of the Bighorn Range subsequent to the deposition of the Wasatch. More conclusive evidence favoring this assumption is presented in the discussion of the great anticline on Elk Creek discovered by the American Museum party (p. 108). Fisher<sup>1</sup> figures a similar unconformable contact between the Wasatch and "Laramie" (probably Fort Union) at the head of Dry Cottonwood Creek, at the western margin of the Bighorn basin. In southwestern Wyoming, Veatch<sup>2</sup> recognizes "a period of folding and erosion of great magnitude" separating the Coryphodon Wasatch (Knight formation) from the Evanston, Almy and Fowkes formations, also regarded as Eocene and perhaps to be correlated with the Fort Union.

#### THE BIGHORN WASATCH.

Owing to a lack of the necessary instruments, no measurement of the thickness of the Wasatch was attempted, but it is probably in excess of a thousand feet.<sup>3</sup> In the area studied, this formation is composed largely of clays varying in texture from fine and unctuous to slightly gritty from intermixture with quartz sand, and in color from pale blue-green through mottled pink and blue to pale pink, bright red and faded purple. Interstratified with the clays are lenses of yellow-brown, blue and gray quartzose sandstone, usually with a calcareous cement but often quite unconsolidated, crumbling at the slightest touch. The lower levels are of a predominantly bluish to yellowish tone owing to the prevalence there of yellow-weathering

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<sup>1</sup> Geology and Water Resources of the Bighorn Basin. Professional Paper, U. S. G. S. No. 53, pl. x, fig. B.

<sup>2</sup> Geography and Geology of a Portion of Southwestern Wyoming. Professional Paper, U. S. G. S. No. 56, p. 88.

<sup>3</sup> Fisher estimates the thickness of the Bighorn Wasatch at 2000-3000 feet. *Loc. cit.*, p. 8.

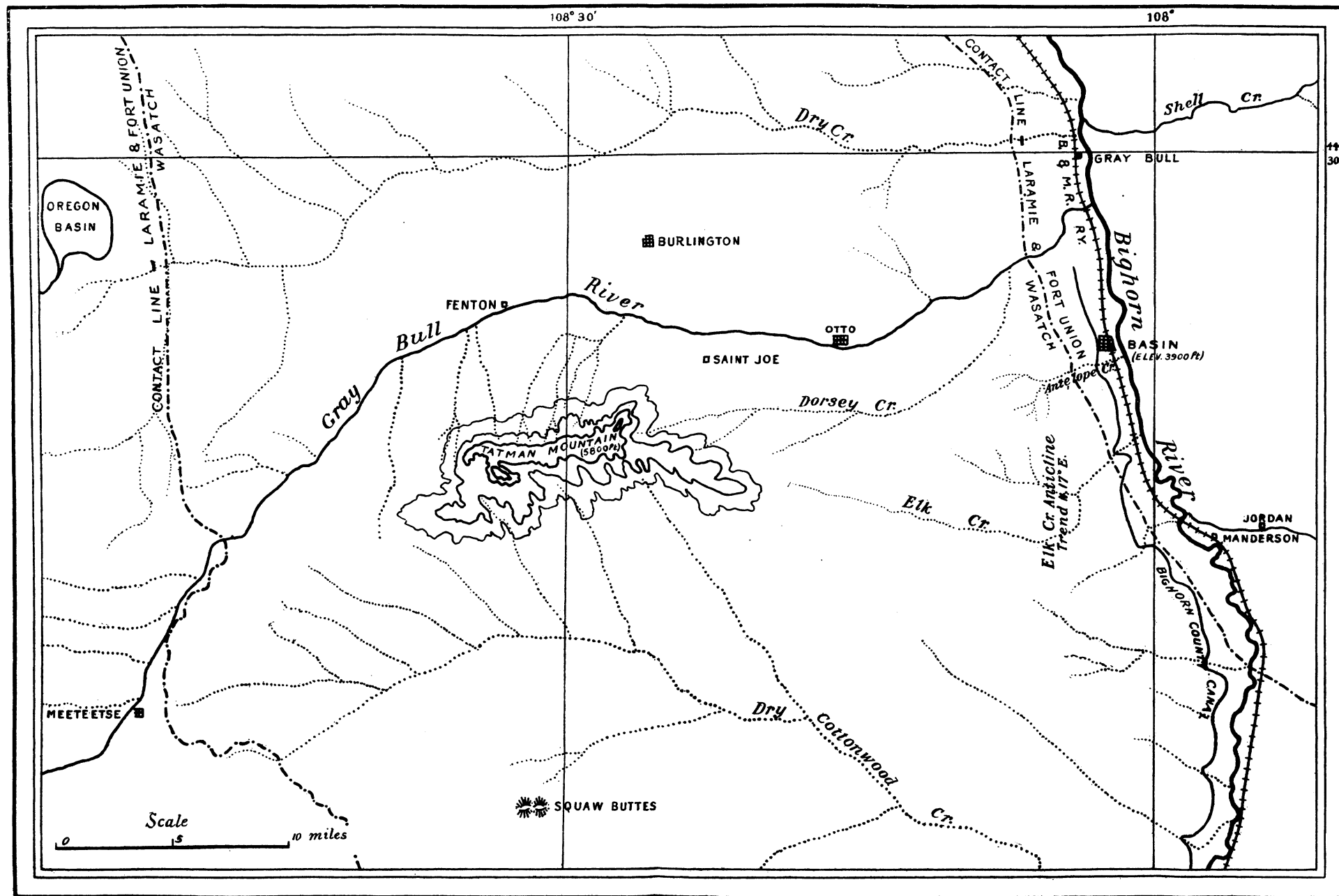


Fig. 4. Sketch map of a portion of the Bighorn basin studied by the American Museum expedition of 1910. Based on a Geologic map of the Bighorn basin by C. A. Fisher.



blue-green clays, but pink, red and purple banding is by no means absent. At higher levels the red banding predominates, occurring in regular alternation with blue-green or mottled (red and blue) clays, or with lenses of yellow-brown to gray sandstone. The blue clays and, occasionally, the sandstones may be lignitic, but no lignite has been found in the red, purple and pink bands.

The color of the Wasatch clays is due entirely to differences in chemical combination of the iron and not to its state of oxidation. Microscopic examination of both the red and blue-green varieties shows practically no difference between them. In addition to kaolin, varying in color from pearl-gray to rusty red or brown, all contain more or less fine grit consisting of minute angular fragments of quartz. Sometimes a little chlorite is present. Calcareous concretions are exceedingly abundant, especially in the red clays, and strew the badland slopes in countless numbers (Plate V, Fig. 1). Concretionary hematite is quite common in the blue-green clays, either in isolated nodular masses of irregular shape or in association with fossil bones, either coating the fossils or occurring in their immediate vicinity, but not deposited on the bones. It is sometimes found also on bones from the red and mottled clays.

Without exception, the Wasatch sandstones are predominantly quartzose, the quartz grains varying in shape from angular to round and, in almost every case, having their surfaces roughened by secondary quartz growths oriented in conformity with the crystallographic axes of the original grains, producing crystal facets and even complete crystals with double rhombohedral terminations with or without the prism zone. This secondary growth seems to have taken place after the deposition of the sandstone as the crystal facets show no signs of abrasion. Owing to the secondary quartz, it is difficult to determine whether the round grains owe their shape to wind or water wear. In addition to quartz, much feldspathic material is present, usually in an advanced state of kaolinization. Decomposed mica foils, chlorite grains and small angular fragments of dark-colored shale, black chert and brown quartzite may also be found, but in less abundance.

Although conglomerates and gravels are known to occur in the Bighorn Wasatch,<sup>1</sup> both at the base and higher up in this formation, none were found within the limits of the area studied with the exception of a few flattened shale pebbles near the base of a large sandstone lens.

*Faunal Horizons.*—In the diagram (Fig. 2 B) three faunal horizons in the Wasatch are indicated by conventions and numbered consecutively

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<sup>1</sup> Fisher, *loc. cit.*, p. 33 and pl. x, fig B. Loomis, *loc. cit.*, p. 360, No. 12 of section.

from 1 to 3. These are based on series of levels where fossils were particularly abundant, but apart from the assistance they afford to the collector and palæontologist, have little additional interest. For reasons stated on an earlier page, it was not possible to ascertain their thickness nor can their stratigraphic limits be strictly defined. The facts regarding superposition, indicated in the diagram, are, however, well established. Horizon 1 is exposed on both sides of the lower valley of Elk Creek, and passes over the Elk Creek anticline (p. 106). Horizon 2 extends from Dorsey Creek above Hal Blakesley's ranch to Elk Creek and is known to be higher than Horizon 1. The third horizon is best exposed in the badlands south of Saint Joe P. O. and is but little higher than Horizon 2.

#### THE BIGHORN WIND RIVER.

The presence of *Lambdotherium* in the Bighorn Basin was ascertained by one of the early Princeton expeditions.<sup>1</sup> Five specimens of *Lambdotherium primævum* (= *L. popoagicum*) were collected by Dr. Loomis in Buffalo basin at a level higher than those affording the typical Wasatch fauna. He, therefore, suggests that the uppermost 1000 feet of the section belongs to the Wind River.<sup>2</sup> It remained for the American Museum expedition to definitely establish the presence of the Lost Cabin stage (*Lambdotherium* zone) of the Wind River in direct stratigraphic conformity above the true Wasatch in the area of high badlands north and northeast of Tatman Mountain (Plate IX, Fig. 2), where the following species were secured from horizons ranging from the top of the alternately red and blue banded clays, immediately beneath the lignitic shales described in the following section, to a point 320–325 feet below this level: —

<i>Lambdotherium popoagicum</i>	2 specimens.
<i>Heptodon ventorum</i>	several specimens.
<i>Eohippus</i>	2 species, both primitive.
<i>Hyopsodus</i> cf. <i>powellianus</i>	2 specimens.
? <i>Stylinodon</i>	1 “
<i>Paramys</i> sp. a	1 “
<i>Paramys</i> sp. b.	1 “
Crocodile	1 “

Of the two specimens of *Lambdotherium popoagicum* secured, one was found about 25 feet below the top of the Wind River as defined above and the other about 319 feet below the top. It would seem, therefore, that

<sup>1</sup> Unpublished data communicated by Professor W. B. Scott.

<sup>2</sup> Loomis, *loc. cit.*, p. 357, 362.

Loomis's<sup>1</sup> figures for the thickness of the Wind River in the Bighorn Basin (325 feet) are, approximately, correct.

Were it not for the presence of *Lambdotherium* and *Heptodon*, of which no specimens were found by the American Museum party in the Wasatch, it would be impossible to differentiate the Wind River from the Wasatch either lithologically or stratigraphically. At present, the line of separation is determined by the vertical range of *Lambdotherium*. The fauna of the Lysite stage has not been identified in the Bighorn Basin but may occur in the 600 feet of sparingly fossiliferous beds between the *Lambdotherium* zone and the richly fossiliferous Wasatch bench indicated by the asterisks in Plate IX, Fig. 2.

There is no lithologic difference by which the Wasatch and Wind River can be separated. Sedimentation seems to have been a continuous process, the fauna alone changing. A coarse-grained pebbly sandstone occurring at a level above the second specimen of *Lambdotherium* secured by us is worthy of special mention from the insight it affords regarding the source of the Wind River sediments. It is a feebly coherent rock with much calcium carbonate cement, composed of small pebbles and angular fragments of brown and salmon-pink quartzite, white and black chert, banded chalcedony, micaceous sandstone, quartz-feldspar and mica-feldspar pegmatite, a few fragments of what seem to be a much decayed igneous rock, several flattened pebbles of light-colored shale with dendrites, a small silicified gastropod shell (pre-Tertiary), mica foils, numerous quartz grains angular to round with crystal facets and often doubly terminated, secondary quartz obscuring the original surface of the round grains, abundant feldspar, dull white but not soft and crumbly, many deeply kaolinized particles, and a few splinters of pink garnet, an association of materials derived manifestly, in greater part, from the Palæozoic rocks of the Bighorn or Bridger-Owl Creek Mountains.

#### POST-WIND RIVER LIGNITIC SHALES.

On the north and northeast sides of Tatman Mountain, the Wind River is capped by a bed of buff-colored sandstone overlain conformably by about 600 feet (730 feet according to Loomis's aneroid readings) of yellowish-brown lignitic shales and sandstones containing sufficient carbonaceous matter to have induced some little prospecting.

Fisher<sup>2</sup> refers to these beds as follows:

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<sup>1</sup> Numbers 4-11 of Loomis's section, *loc. cit.*, p. 360 are Wind River.

<sup>2</sup> *Loc. cit.*, p. 34.

"Capping some of the highest areas in the central part of the Bighorn basin, especially that part lying south of the Grey Bull River, are brown, leaf-bearing, sandy shales and gray sandstones, which have a total thickness of about 600 feet. Thin coal seams sometimes occur in these beds, and in one locality on the southern side of Tatman Mountain some prospecting has been done in a seam which has a thickness of about 18 inches. A number of fossils were collected from the sandstones of this formation in the vicinity of Squaw Buttes. These have been examined by Dr. T. W. Stanton, who makes the following report:

"The small collection contains many internal casts of fresh-water fossils belonging to the genera *Unio*, *Viviparus* and *Goniobasis*. Of the last named there are imprints of the exterior which permit identification with *G. tenera* Hall, an Eocene species. The *Unio* has about the size and proportions of *U. haydeni* Meek and the *Viviparus* resembles *V. wyomingensis* Meek, but in neither case can positive identification be made with such material, as there are Laramie species so closely resembling these that they could not be discriminated from the casts alone. I think that the horizon is Eocene, but I am unable to determine from these fossils whether it is Wasatch or Bridger.

"These beds are extensively exhibited in Tatman Mountain and Squaw Buttes."

Poorly preserved remains of ostracods and phyllopods have been found by Professor G. van Ingen in a specimen of pale pink shale collected near the base of this formation on Tatman Mountain. The possibility of these beds being Wasatch is ruled out by their stratigraphic position above the Wind River. That they may correspond to the Bridger is possible, and they are, perhaps, to be correlated with the so-called Bridger of the Beaver Divide section. They are separated from the gravels capping Tatman Mountain (Fig. 2 B) by about 30 feet of unconsolidated, highly micaceous, greenish sandstone containing abundant foils of chloritized biotite, decomposed muscovite, many quartz grains and both fairly fresh and kaolinized feldspar. From its stratigraphic position this sandstone may possibly be Uinta, but the assumption is entirely unconfirmed by palæontological data. Only small remnants of both the lignitic shales and the greenish sandstone capping Tatman Mountain, Squaw Buttes and other high points have been spared by erosion. So far as at present observed, the sandstone seems to be conformable with the lignitic shales. The latter are usually conformable with the *Lambdotherium* zone, but on the northwest side of Tatman Mountain local dips in the Wind River were observed which did not conform with the flat-lying shales above. Their significance has not yet been fully ascertained.

### TATMAN MOUNTAIN GRAVELS.

Tatman Mountain is capped by about 30 feet of stream gravels resting unconformably (?) on the lignitic shales below. While the majority of the pebbles are of volcanic rocks, no particularly careful search is necessary to demonstrate the presence of vein quartz and quartzite. Four of the volcanic pebbles, gathered at random, have been sectioned. All prove to be hornblende-augite andesite in which the lath-shaped plagioclase phenocrysts (average maximum extinctions ranging from  $26^{\circ}$ – $36^{\circ}$ ) have their long axes similarly oriented due to flowage of the mass before cooling. The few large hornblende phenocrysts are encircled by heavy resorption wreaths which sometimes inclose masses of chlorite. Much chlorite and fine black dust is present in the ground-mass in certain of the slides. Augite is moderately abundant. The ground-mass is composed largely of fine feldspar needles. These lavas differ from the andesite of the Beaver Divide Oligocene in the presence of augite instead of hypersthene, in the absence of biotite and in the scarcity and evident decomposition of the hornblende. They have been more decomposed and may be older. As no fossils have yet been found in the Tatman Mountain gravels and nothing in the shales below but traces of plants and a few invertebrates, their age cannot be fixed, and the questionable assumption that they are Oligocene (diagram, Fig. 2 B) is based entirely on their stratigraphic position above beds which may correspond to the so-called Bridger and perhaps also the known Uinta of the Wagon-bed Spring section in the Wind River basin. The exposures on Tatman Mountain are but fragments of a formation at one time more extensive, but now almost entirely destroyed by erosion.

### DIASTROPHIC MOVEMENTS INVOLVING THE EOCENE IN THE WIND RIVER AND BIGHORN BASINS.

Attention has already been called (p. 105) to a narrow marginal syncline involving beds of the Lysite stage in the Wind River basin north of Lost Cabin. A marginal anticline of much greater extent was discovered by the American Museum party (see map, Fig. 4) trending across the lower valley of Elk Creek about four miles from its mouth, in a direction  $N. 17^{\circ}$  East (true meridian) and at least four miles across between the steepest dipping portions of the east and west limbs which are inclined respectively at angles of  $7^{\circ}$  and  $5^{\circ} 30'$ , flattening out to the east and west. This fold may be known as the Elk Creek anticline. It has probably been produced in the same way as the oversteepened dips on the margin of the Wasatch

basin (Plate IX, Fig. 1) on Antelope Creek by a post-Wasatch uplift of the Bighorn Range with compression of the marginal portions of the adjoining intermontane trough. As the Wind River sediments have been eroded from the area including the Elk Creek anticline, it is not possible to say whether the folding was an event of Wasatch or Wind River time. About the periphery of the basin, the dips of the Wasatch are usually at low angles toward the center of the trough where the beds are, with few exceptions, practically horizontal.

Minor gravity faults were noted occasionally. Their presence can frequently be detected by small vertical ledges of hard slickensided shale standing up in relief an inch or so above the crumbling, mud-cracked surface of the Wasatch clays.

Perhaps to be correlated with the accumulation of the deformative stresses producing faulting and folding is the occurrence in the Wasatch of numerous sandstone dykes (Plate VIII, Fig. 2). These are similar lithologically, in all respects, to the Wasatch sandstones already described. In one instance, a narrow dyke, cutting clays, was traced downward to confluence with an underlying sandstone lens. They appear to have been forced up as quicksands through cracks produced by earthquakes. As suggested above, the earthquakes which produced the dyke fissures may have been associated with the action of mountain-making stresses or they may have been due merely to the settling down of unconsolidated sediments.

## LIFE CONDITIONS IN THE WIND RIVER AND BIGHORN BASINS DURING THE EOCENE AND OLIGOCENE.

### ORIGIN AND MODE OF DEPOSITION OF THE SEDIMENTS.

From the foregoing discussion it may readily be gathered that the Eocene sediments represent materials derived by erosion from the older rocks of the mountains and deposited in the intermontane basins. This is particularly well shown in the association of rock species found in the coarser sandstones and arkoses of the Wind River and Bridger (?), where Archæan granites and Palæozoic quartzites are readily recognizable. The well-rounded gravels found in some of the arkoses point with equal certainty to running water as the transporting agent while fluvial deposition is shown by the frequent channels filled with coarse sandstone which cut irregularly across the finer clays, by the frequent interstratification of sandstone lenses with the clays and by the presence in the latter of fish, crocodiles and turtles, and occasional beds of *Unio*. Local swamps are

indicated by lignites in the blue clays and sandstones, but never in the red clays.

As the source of the detrital materials remained constant, increase in the size of the constituent particles in the sediments must have been due either to climatic causes affecting the volume and transporting power of the streams or to steepening of the stream grades as a result of uplift, while differences in color must be due to chemical changes acting within the basin of accumulation and, accordingly, local in character, or to variations in climate affecting the region as a whole. It is not always possible to determine whether one factor has acted to the exclusion of the others; for instance, the coarse, frequently cross-bedded arkose forming the lower member of the so-called Bridger of the Beaver Divide appears to represent a series of conjoined alluvial fans spreading out over the banded clays of the Wind River, but it is not possible to say whether the gravels and sands were transported by torrential streams under a dry climate or by streams whose carrying capacity had been increased by uplift. From the freshness and high degree of angularity of many of the feldspar fragments in the arkoses and sandstones described in the pages preceding, it seems permissible to deduce the following inferences:—*First*. It may be assumed from the angularity of the fragments that they have not been transported far. Archæan granites are exposed in the mountains at no great distance from the basin floors. *Second*. From the freshness of the feldspars, it may be assumed that they have not been leached by carbonated waters, such as might be expected to occur if they were deposited in a region of high humidity, and that they have not been derived from the parent granite by ordinary weathering processes, but rather by temperature changes which would shatter the minerals without affecting their freshness. The condition of the feldspars, therefore, does not favor the idea of luxuriant Eocene tropical forests and a warm, humid climate, with the formation of a deeply decayed regolith, but suggests a dry, not necessarily arid, climate with rapid changes of temperature to splinter the parent ledges, rapid transportation of the fragments for short distances and their burial beyond the reach of carbonated waters.

In the Wind River basin, wash from the mountains continued to be spread over the basin floor by streams until the close of the Uinta. The interposition of two small ash beds found in the Wind River and Bridger (?) respectively did not affect the character of the depositional cycle in the least. After the erosion of the broad valleys in the Uinta (p. 86) wind rather than water seems to have been the chief transporting agent. The Oligocene tuffs are, in part, wind laid. Such turtle remains as were found in them were confined to the ashy filling of the post-Uinta valleys below

the agglomerate flow. Above the level of the agglomerate, wind transportation assisted by occasional torrents heading in the mountains where granites and Palæozoic quartzites are exposed were the principal agents responsible for the 525-540 feet of beds above the agglomerate layer. The rolled boulders and pebbles in the latter indicate aqueous transportation, but the source of the waters which carried them is probably to be found in the deluges of rain which accompany volcanic eruptions, due to condensation from the steam clouds. Neither the Oligocene ash nor the associated gravels show evidence of having been weathered to any appreciable extent since their deposition and we are inclined to believe that they were accumulated under a dryer climate than prevailed during the Eocene. The most reliable piece of evidence favoring this view is to be found in the limestones which cap the Beaver Divide. No fresh-water shells have been found in these so far, but ash is always present and gravels frequently so. We regard these limestones as having been formed by evaporation, at the surface, of calcareous waters rising in response to capillarity. Remnants of the old basin floor at the close of Oligocene sedimentation are preserved in the flat gravel-strewn summits of the Beaver Divide. Whatever fine silt may have originally been mixed with the gravels has been largely removed by the wind. The cobbles still show the bruises produced by their striking together in the torrential streams which swept them over the Oligocene basin floor.

In the Bighorn basin, fluvial deposition is indicated for the entire Eocene. The lignitic shales which cap the *Lambdotherium* zone, from their fresh-water molluscs, entomostraca and plant traces, are quite certainly both fluvial and palustrine. The Tatman Mountain gravels are, with equal certainty, of stream origin, but whether deposited under moist or dry climatic conditions is not apparent.

#### SOURCE OF THE COLOR-BANDING.

Frequent reference has been made to color-banding in the Wasatch and Wind River clays. This consists in a more or less regular alternation of beds of red and blue-green clay or of red with mottled clay (red and blue-green). The red clays are frequently streaked with blue-green color along joint cracks or are traversed by anastomosing green lines along what may have been the courses of roots. The beds are lenticular in shape, varying from a few inches in thickness, with little horizontal extent, to strata from 18 inches to 50 feet in thickness, traceable sometimes for several hundred yards to a mile or more. One persistent purplish band, passing over the Elk Creek anticline may be followed for several miles. Lignite is never

found in the red clays but may be present in the blue. In the Wasatch, where fossils were obtained at many horizons in the red, blue and mottled clays, it is noticeable that those from the red clays, while at times abundant, are always fragmentary, the more resistant parts such as jaws and teeth predominating. In the blue and mottled clays associated skeletons may be expected and many of *Coryphodon* were found.

So far as mineralogical composition is concerned, the microscope has failed to reveal any essential difference between the variously colored clays. Chemical examination by Professor A. H. Phillips has produced some unexpected results regarding the chemical condition of the iron content of the clays, to which alone the color is due. The results of the analyses with respect to iron may be tabulated as follows:

*Iron determinations. Wasatch and Wind River clays, from Natrona and Bighorn Countries, Wyoming. A. H. Phillips, analyst, March, 1911.*

HORIZON	PHASE	TOTAL IRON CALCULATED AS $\text{Fe}_2\text{O}_3$	TOTAL IRON	
			$\text{FeO}^*$	$\text{Fe}_2\text{O}_3$
		%	%	%
1. Mottled (red and blue) clay, Lost Cabin stage, Wind River formation, east of Lost Cabin.	Red	8.16	0.19	7.91
	Blue	6.67	0.38	6.24
2. Blue clay, Wasatch, south of St. Joe P. O., in badland area northeast of Tatman Mountain. Headwaters of Dorsey Creek.	Blue	3.34	0.52	2.77
3. Red clay, Wasatch, south of St. Joe P. O., in badland area northeast of Tatman Mountain. Headwaters of Dorsey Creek.	Red	4.82	0.58	4.18

\*By sealed tube method.

In all the samples examined, the *total iron* in the red clays is in excess of that present in the blue by 1.48 % to 1.49 %. The amount of *ferrous iron* in the blue Wasatch clay is less than that present in the red while in the mottled Wind River clay it is slightly greater in the blue than in the red phase, but in neither case does it seem possible to ascribe the blue color to ferrous oxide as this substance is far exceeded in amount by *ferric iron*,

evidently occurring in the blue clay in some other form than ferric oxide (hematite), perhaps as a hydrous silicate. In the Wasatch clay the red contains 1.41 % more  $\text{Fe}_2\text{O}_3$  than the blue; in the Wind River clay,  $\text{Fe}_2\text{O}_3$  in the red phase is 1.67 % greater than in the blue. If this excess of iron is present in the form of hematite, as the red color seems to show, it is possible that the remaining iron in the red clay may be in the same form as in the blue (a hydrous silicate?) and that the blue color has been masked by the red pigment.

The results of analysis seem to show that the blue color has not been derived from the red by reduction of the iron as ordinarily understood. The red color may have been from the blue by conversion of the hypothetical silicate into carbonates by meteoric waters and the subsequent oxidation of these salts, or by the introduction of iron compounds in solution and their concentration and oxidation possibly under dryer climatic conditions than existed during the deposition of the blue clays. We favor the latter alternative and regard the coloration of the clays as a phenomenon controlled by conditions active during the deposition of each individual stratum (red or blue as the case may be) and not by subsequent or secondary changes. Under the arid conditions which exist at present over most of the Wind River and Bighorn basins, the blue clays show no tendency to weather red. The layer of weathered, mud-cracked clay on the surface of badland slopes cut in the blue clays is yellow from the hydrous oxide limonite.

Similar alternations of red and blue clays have been described by Huntington in the desert basins of Lop and Seyistan and the colors associated with a recurrence of moist and arid climatic cycles, the iron salts oxidizing during the arid cycles, producing the red colors. We ascribe the color-banding of the Wasatch and Wind River clays to a similar cause, the alternation of moist and dry climatic conditions, but have not found any evidence of excessive aridity, the fauna of the red and blue bands being the same. The clays cannot owe their color to different sources of supply for they are microscopically the same and the alternation of color bands is too regular and of too frequent recurrence to permit this inference. The red clay cannot represent upland oxidized wash, for waters swift enough to carry the bone fragments found in the clay would also transport rock fragments of some size, and these are not found. From the fact that the blue clays of the Wasatch are sometimes lignitic and often afford associated skeletal remains, we are disposed to regard them as having been formed during cycles of more abundant rain fall when the surface of the intermontane basin was prevented from drying out rapidly. The red clays, we believe, were formed during the dryer cycles when the carbonaceous matter

of decaying plants was completely oxidized, concentration and oxidation of iron compounds occurred, and animal bones exposed at the surface were weathered and broken before entombment. That these conditions were not local is shown by similar color-banding in the Wasatch in other localities than the Bighorn basin.

#### OCCURRENCE OF ORGANIC REMAINS.

The collections secured from the Wasatch (about 3000 individuals) have shown that vertebrate fossils are particularly abundant at certain levels. In many of the red clay bands or at the contact of red and blue strata, great numbers of fragmentary jaws and scattered teeth were found. Such levels undoubtedly represent portions of the basin floor as it was when these creatures died and their bones were scattered and weathered before being buried. Associated skeletons have been mentioned as of quite common occurrence in the blue clays. These are the remains of animals which were either drowned and rapidly covered beneath fluvial sediments or were mired in the soft clays. In the Wind River area, where fragmentary material is the rule, the teeth usually have the roots worn away and only the harder enamel-covered crowns preserved. Where *Unio* beds occur in the Wasatch, they are always of limited extent and, so far as we can recall, have never been found in the red clays. The lignite layers in the blue clays are usually mere dirt bands, but some, in the Wind River basin, along Alkali Creek have considerable thickness.



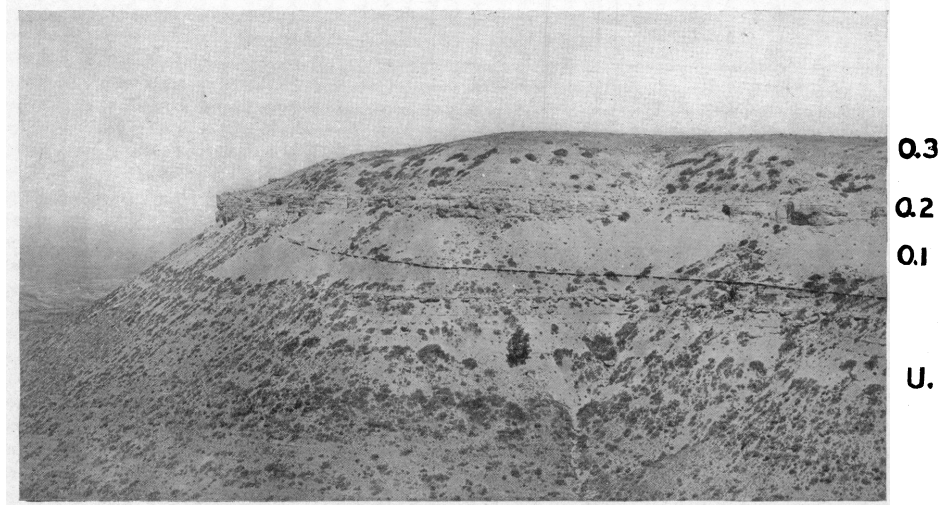


Fig. 1. Beaver Divide north of Wagon-bed Spring showing broad channel cut in the Uinta (U) and filled with Oligocene tuff (O.1) overlain by agglomerate (O.2) and gravels (O.3).

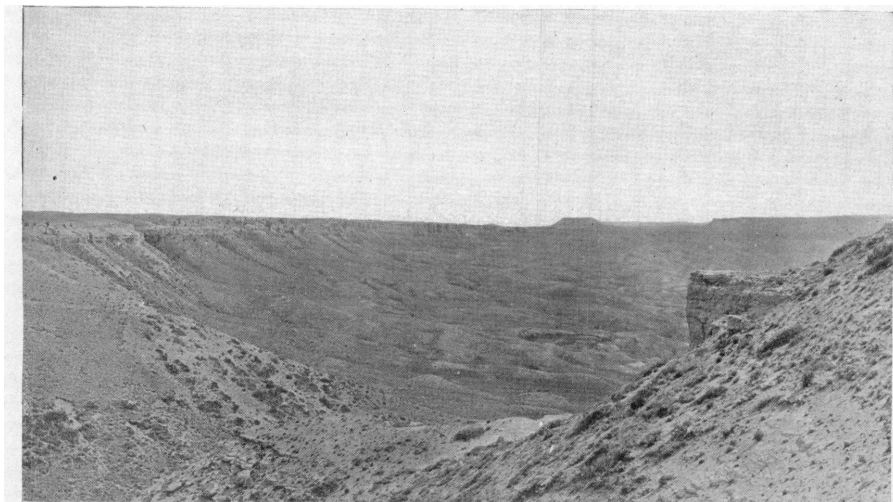


Fig. 2. Looking south along Beaver Divide above Wagon-bed Spring.





Fig. 1. Mud-cracked, concretion-strewn surface of Wasatch clays, three miles south of Otto, Bighorn Co., Wyo. Weathered *Coryphodon* bones in the foreground.

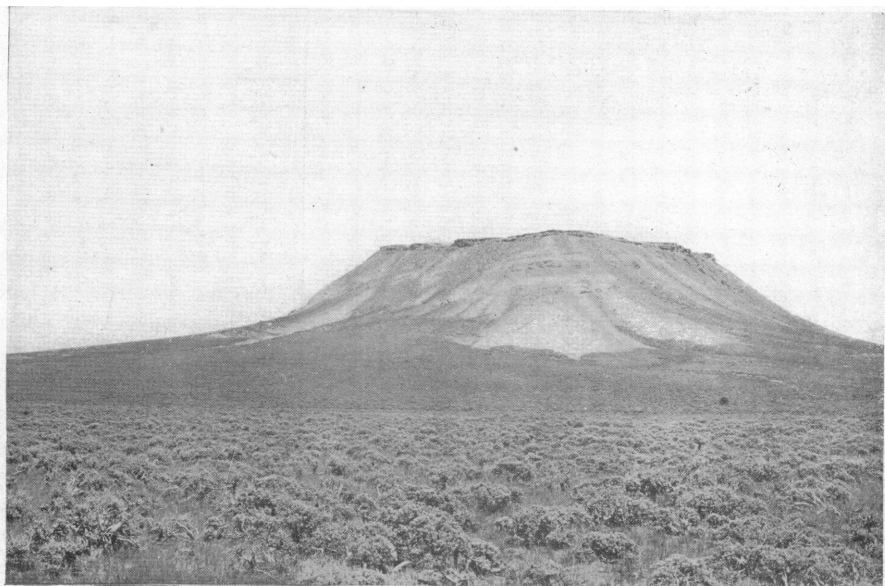


Fig. 2. Pumiceous limestone unconformably overlying slightly consolidated ash. Oligocene. Lone Butte, south of Government Slide road, Beaver Divide. Shows first and second Oligocene-post-Oligocene baselevels.





Eocene-Oligocene section at Green Cove about four miles east of Hailey, numbered to correspond with the section on p. 89 and the diagram (Fig. 3).



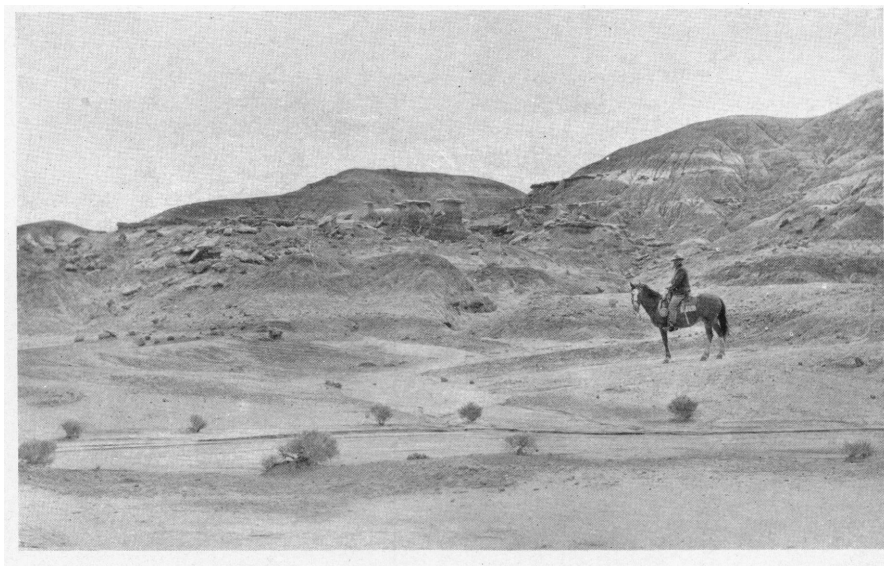


Fig. 1. *Lambdaotherium* zone, Wind River badlands, between Beaver Creek and Big Land Draw. The horse stands on the fossiliferous bench.

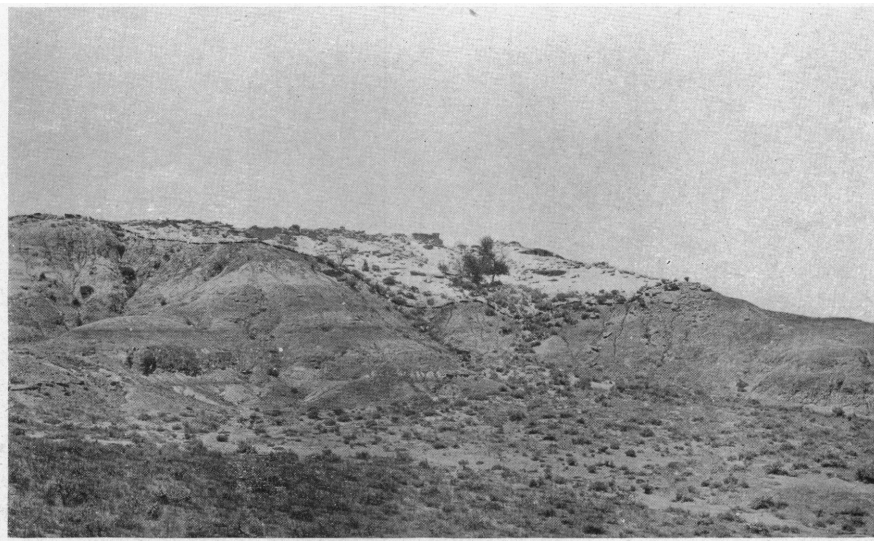


Fig. 2. Arkose-filled stream channel in banded Wind River clays between Beaver Creek and Big Land Draw. The fauna of the *Lambdaotherium* zone occurs in the clays at the foot of the bluff.



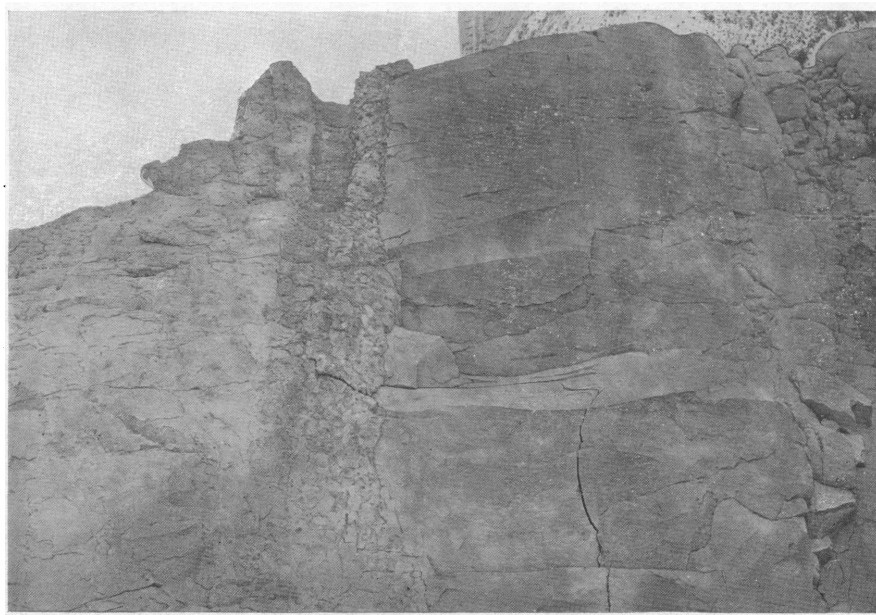


Fig. 1. Contact of the Oligocene andesitic tuff (O) and the Uinta sandstone (U) showing the basal tuff conglomerate. Above Wagon-bed spring, Beaver Divide.

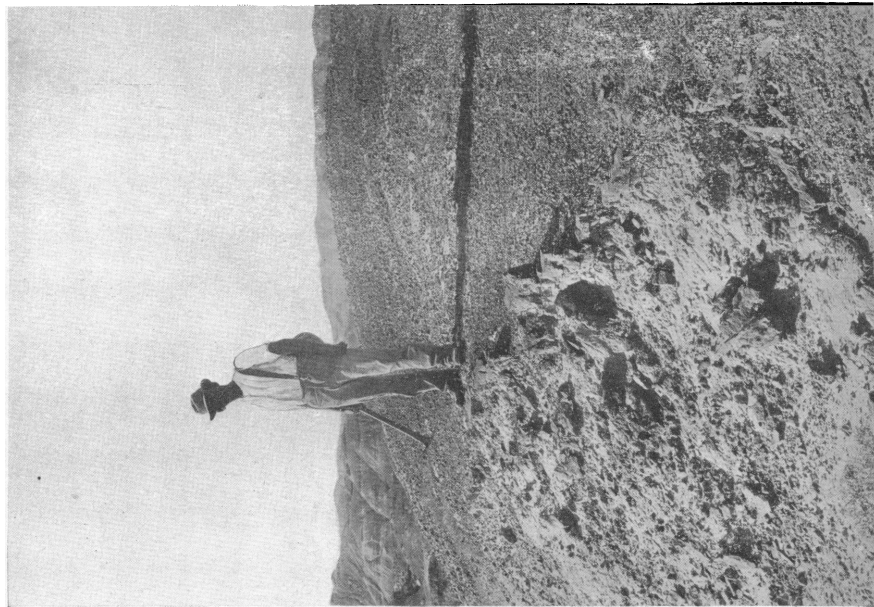


Fig. 2. Sandstone dyke cutting Wasatch clays. Badlands south of Elk Creek.





Fig. 1. Unconformable contact of Wasatch on Fort Union. Antelope Creek, about two miles southwest of Basin, Bighorn Co., Wyoming. Showing the floor of the Eocene basin of accumulation.

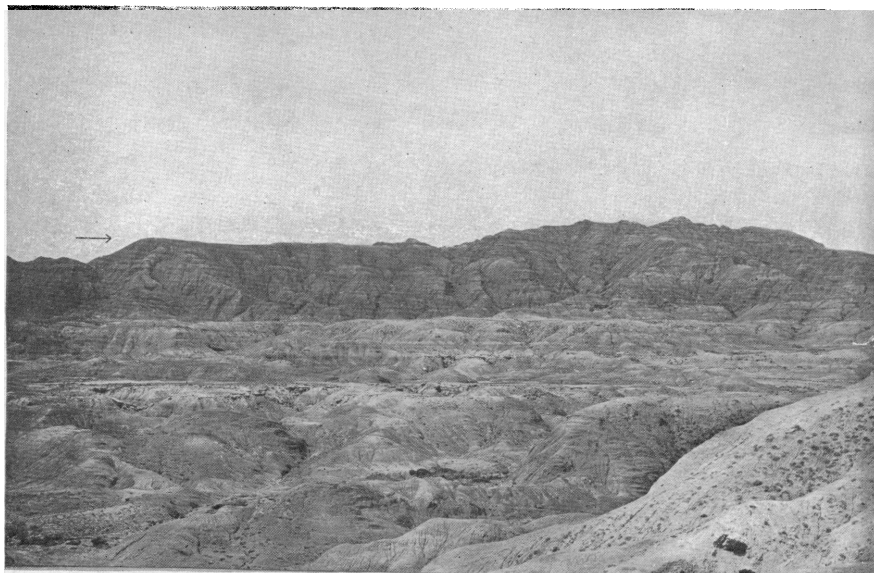


Fig. 2. Wasatch-Wind River badlands north of Tatman Mountain. The arrow points to the contact of the Wind River. The dark bands are red clays. Remains of 30 individuals of *Eohippus* were collected in one day from the Wasatch bench marked by asterisks.

