

## OROGRAPHIC MOVEMENTS IN THE ROCKY MOUNTAINS.

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## INTRODUCTION AND HISTORICAL REVIEW.

That the vast succession of mountain ranges and elevated plateaus and valleys which go to make up the Cordilleran mountain system in the United States must be the final result of a number of orographic movements occurring at different periods of the earth's history was recognized in the earliest geological explorations in that region by Marcou, Newberry, Le Conte, and others. It was not, however, until systematic examination of large areas, both topographical and geological, had been instituted, which permitted the construction of geological maps of a substantial degree of accuracy, that any attempt could be made to determine the number and comparative importance of these movements and their relative position in the structural history of the region. Even then the conditions under which such examinations were conducted, necessitating the covering of large areas in a given time, which time was dependent more upon the geographical extent of the area than upon the complexity or relative importance of its geological structure, did not admit of an exhaustive study, and many significant facts were necessarily overlooked.

It will only be when the whole Cordilleran region shall have been accurately surveyed with much greater detail than has hitherto been practicable that its complete and accurate history can be written. Meantime much additional light can be thrown upon the subject by detailed examination of

especially disturbed districts, where in the limited time at their command the earlier explorers of necessity overlooked or but imperfectly studied many facts of importance in their bearing upon the general orographical history of the region. It has been my lot during the past ten years to make a number of such examinations, incidental to a study of the ore deposits of important mining districts in various parts of the Rocky Mountains in Colorado, and thus gradually to gather together a number of facts bearing upon this subject. Although these facts are not sufficiently complete for an exhaustive discussion of the subject, I have been led to attempt to construct from them, and from such information derived from the work of others in the region as seemed pertinent and trustworthy, a slight historical sketch of the orographic movements of the Rocky Mountains between Archæan and Tertiary times, with special reference to two important and hitherto not generally recognized movements, the one during the Carboniferous, the other during the Jurassic epoch.

Many of the conclusions at which I had arrived have to a certain extent been forestalled by my colleague, Dr. C. A. White, in his admirable address on the North American Mesozoic delivered at the last meeting of the American Association, at Toronto, Canada, but as they had been reached independently and from a somewhat different standpoint I have not thought it advisable on that account to modify what I had written.

Before presenting this sketch it may be well to review briefly the principal conclusions that have been arrived at by members of the various geological surveys that have examined this region. They will be taken as far as possible in the order in which the field work of each was done.

*Fortieth Parallel Survey.*—The orographic movements determined by the geologists of the Fortieth Parallel Survey\* are given by Mr. King† as follows:

1. Post-Laurentian.
2. Post-Archæan.
3. Post-Palæozoic.
4. Post-Jurassic.
5. Post-Cretaceous.
6. Post-Vermillion Creek [Wasatch] Eocene.
7. Post-Green River Eocene.
8. Post-Bridger Eocene.
9. Post-Eocene.
10. Post-Miocene.
11. Inter-Pliocene.
12. Post-Pliocene.
13. Faults of the Historical Period.

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\* Field work, 1867 to 1873, inclusive.

† Vol. I, Systematic Geology. Washington, 1878, p. 758.

Of these he considers that the work of the first movement was to throw the original crust of crystalline sediments into waves within the present provinces of the Wasatch and of the Rocky Mountains. His post-Archæan movements, which produced the land areas in the Cambrian seas and would now be designated post-Algonkian, extended over the whole breadth of the Cordilleras.

The post-Palæozoic or post-Carboniferous movement produced a continental elevation from the Wasatch westward to longitude  $107^{\circ} 30'$ . Its effects were most marked at the western edge of this area; and east of it, with the exception of slight unconformity by erosion in the Wasatch,\* no direct proof of movement was observed, though there is evidence of shallow water deposition in the succeeding Permian and Mesozoic sediments.

The post-Jurassic movement was likewise considered by him to be mainly confined to the western part of the Cordilleran system, the evidence of unconformable deposition found at that time being too slight to justify the assumption of the general extension of the movement to the east of the Wasatch. It is to this movement that he ascribes the original formation of the peculiar parallel ranges of the geological province of the Great Basin—the Basin Ranges, as they are called—a movement due to tangential compression resulting in contraction and plication† which he distinguishes from the later movements in the same region, presumably Tertiary or later, in which there are few evidences or traces of tangential compression. The principal effect of this later movement has been the faulting and uplifting of irregular areas with little or no attendant plication. Where the effects of the earlier movements were not felt, or have been obscured by erosion and by later sediments and extensive flows of eruptive rock, only those due to the later movement are readily manifested. Hence a number of geologists, whose observations have been principally in such parts of the region, have considered it characteristic of the whole and given the name “Basin Range structure” to this later phase of its orography.

The post-Cretaceous movement was principally manifested east of the Wasatch, the Uinta uplift dating from this period, and the principal elevation of the Rocky Mountain region and the final shutting-out of ocean waters from the whole Cordilleran system east of the Sierra Nevada being due to it.

The subsequent movements during Tertiary and Recent times were foldings, upheavals, and subsidences within a continental area, to be measured not by their relations to sea level, but to that of adjoining land elevations or interior lakes. Thus, those numbered 6, 7, and 8 are shown in successive elevations of the Uinta mountains and in modifications in the adjoining Tertiary lakes whose sediments were largely derived from the abrasion of the broad crest of that range.

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\* Op. cit., p. 228.

† Op. cit., p. 744.

*Powell Survey.*—Major J. W. Powell,\* in his first account of the Colorado river, explains the tortuous nature of the upper portion of its course (the Green river) athwart the Uinta mountains on the hypothesis that the course being already determined previous to the uplift of these mountains its bed was deepened *pari passu* with the slow uplifting of the mountains, furnishing an illustration, which has been widely quoted in text books† and elsewhere, of the slow rate of mountain elevation. This hypothesis involves a conformable deposition of all the beds involved in or affected by the Uinta fold, since it is evident that sedimentation could not be going on in a region through which a river was running and cutting down or corradating its bed. Hence the Uinta fold should have commenced after the deposition of the latest sediments deposited along its flanks—that is, in Tertiary or Recent times. In his second volume, however, he recognizes the fact that the Uinta fold was formed at the close of Mesozoic time, and that during Tertiary times no less than four lakes were successively formed and drained during dry-land epochs, in which 8,000 feet of sediments were accumulated, largely from materials resulting from the degradations of the Uinta fold, and that these sediments did not arch over the crest of the Uinta fold. He found, what had not been observed by the geologists of the Fortieth Parallel, an unconformity by erosion between the Carboniferous and underlying Uinta sandstone, to which he assigned provisionally a Devonian age, showing that a land surface must have existed there during or previous to Carboniferous time. He also recognized, in accordance with the previous observations of the Fortieth Parallel geologists, the existence of a submerged cliff of Eozoic rocks at Red creek (Red Creek quartzites) against which 8,000 feet of Uinta sandstone were deposited. He considers Cenozoic time as the main mountain-building epoch, and regards the Park province or Rocky Mountains as of the Uinta type of structure—that is, that the sedimentary beds now resting against their flanks formerly formed a complete arch over their crests, or that they were completely submerged during the deposition of these beds.

*Wheeler Survey.*—Of the geologists of the Wheeler Survey,‡ Gilbert recognizes in Utah, Nevada, Arizona, and New Mexico the universality of the unconformity between Archæan and succeeding sediments, whether Cambrian or later. He accepts King's assignment of the Jurassic as the date of original formation of the Basin Ranges, but considers that the Plateau region was submerged from early Palæozoic to the close of Mesozoic time, though subjected to oscillations of level producing changes in depth of waters and consequently in character of sediments. While remarking upon the meager

\* U. S. Geol. Survey of the Rocky Mountain Region: Explorations of the Colorado River of the West, Washington, 1875 (field work, 1869 to 1872); Geology of the Eastern Portion of the Uinta Mountains, Washington, 1876 (field work, 1874 to 1875).

† J. LeConte: Elements of Geology. New York, 1878, p. 244. A. Galkie: Text book of Geology. London, 1882, p. 920.

‡ Explorations West of the 100th Meridian: Vol. III, Washington, 1875 (field work, 1871, 1872, and 1873); vol. III, Supplement, Washington, 1881 (field work, 1878 and 1879).

representation of the Upper Silurian and Devonian both in fossils and in strata, he finds no evidence to prove that the region was lifted above water during these times, but considers that the general movement of the land during Palæozoic time was a subsidence, and that where Carboniferous limestone rests directly upon the Archæan there were islands in the early Palæozoic seas which became submerged in Carboniferous time.

J. J. Stevenson, in the course of his explorations in Colorado and New Mexico in 1873, noted several unconformities and drew the following conclusions:

"The Rocky Mountain system, therefore, is the result of four especially marked upheavals, the first, at the close of the Carboniferous; the second, at the close of the Trias; the third, at the close of the Cretaceous, and the fourth, during the Tertiary. Of these, the first and the third were the most general in their effect."

He also recognized the unconformity of overlying beds with the Archæan. In his subsequent more detailed work in southern Colorado and northern New Mexico he does not seem to have found reason to modify these general conclusions.

*Hayden Survey.*—The beautiful geological atlas of Colorado,\* showing the result of the combined labors of the various members of the Hayden Survey, furnishes a most valuable record of the geology of the Rocky Mountain region. Unfortunately no systematic discussion of their field observations has yet been made to present the final orographical conclusions which would be drawn with the consensus of all who were engaged in the work. In the absence of such a discussion inferences must necessarily be drawn from the graphic representation of facts given by the maps, where personal verification in the field has not been possible. Such verifications as have been made have proved the substantial accuracy of the geological outlines laid down on these maps, except in southeastern Colorado and in the San Juan mountains, where at the various points examined the facts of nature show such wide divergence from these outlines, as laid down by Mr. Endlich, as to throw serious discredit upon all of his field work.

Dr. A. C. Peale, of this Survey, has since summarized the results of his own observations in Colorado as follows:†

"1st. In very early times in Colorado there was Archæan land rising above the Palæozoic sea. As the Carboniferous age progressed this land diminished by encroachment of the sea, due to subsidence of the land. This subsidence continued through Triassic, Jurassic, and Cretaceous time into the early Tertiary.

"2nd. At the close of the Lignitic, there was a physical break followed by subsidence (at least locally), and subsequently by elevation after the deposition of the Miocene strata.

\* Field work 1873, 1874, 1875, 1876.

† Amer. Jour. Sci., 3d Ser., Vol. XIII, Mar. 1877, p. 181.

"3rd. The elevation of the Rocky Mountains, as we now see them in Colorado, is the result of an elevation commencing in early Tertiary time and continuing through the period, accelerated perhaps at the close of the Lignitic and after the deposition of at least lower Miocene strata."

This was written at the time when Dr. Peale, in accordance with the views of his chief, Dr. F. V. Hayden, regarded the Lignitic (Laramie) as of Tertiary age.

*Black Hills Survey.*—In the Black Hills of Dakota\* Newton and Jenney recognized two distinct series of crystalline schists, with some faint evidence of unconformity between them. The great breaks determined by them were between these crystalline schists and the Cambrian (Potsdam sandstone). More recently W. O. Crosby† has found evidence of an uplift of the region at the close of the marine Jurassic.

*Colorado Plateau Region.*—Gilbert, in his *Geology of the Henry Mountains*,‡ remarks on the physical break at the close of the Cretaceous, and notes three unconformities by erosion, one at the close of the Carboniferous and two within the series called by him Jura-Trias.

In the preface to Captain Dutton's work on the High Plateaus,§ Major Powell states with regard to the Plateau province—

"A marked unconformity exists between the Silurian and Devonian rocks; another between the Devonian and Carboniferous; another, but not so well marked, between the Carboniferous and Mesozoic, and lastly an unconformity between Cretaceous and Tertiary is usually well defined."

In the region of the Grand Cañon of the Colorado,|| Captain Dutton notes, besides the universal unconformities at the close of the Archæan and the Cretaceous, that the Carboniferous rests unconformably upon the Silurian or Devonian, as the case may be. He also finds unconformities by erosion between Carboniferous and Permian, between Permian and Trias, between Trias and Jura, and between Jura and Cretaceous. He considers that the Carboniferous was deposited in deep waters, but that during the Permian and Mesozoic, shallow-water conditions prevailed; also that the Eocene was a fresh-water deposit, that a slow elevation began about the middle of this epoch, and that the Colorado river commenced as a drainage channel of the Eocene lake in early Tertiary times, gradually eating its way back until it reached its present extension, and cutting across any elevations produced during subsequent movements as they rose without changing its already determined course.

I find it difficult to reconcile my own observations in the Uinta mountain

\* *Geology of the Black Hills of Dakota*. Washington, 1880 (field work, 1876).

† *Proc. Boston Soc. Nat. Hist.*, Vol. XXIII, March, 1888.

‡ *Washington*, 1877, p. 10 (field work, 1875 and 1876).

§ *Geology of the High Plateaus of Utah*. Washington, 1880, p. vii (field work, 1875, 1876, and 1877).

|| *Mon. II, U. S. Geol. Survey: Tertiary History of the Grand Cañon*. Washington, 1882 (field work, 1879-1880).

region with the views of either Powell or Dutton, with regard to the determination of the course of the Colorado river; and I am inclined to think that future investigation will prove that they have placed it at too early a date. I have already shown\* that the Wyoming conglomerate (Bishop Mountain conglomerate of Powell), which has escaped erosion along the flanks of the Uinta mountains, is so situated as to prove that it must once have extended over the entire eastern end of the mountains through which the cañon of the Green river is now cut, forming a nearly level surface at an altitude corresponding to a present elevation of between 9,000 and 10,000 feet, and that the river must have initiated its present meandering course over this surface as a superimposed valley. This conglomerate is considered by all who have examined the region to be of very late age, either Pliocene or Quaternary, though no fossils have yet been found in it. It is everywhere horizontal and undisturbed, showing no stratification planes, but at one exposure shows a thickness of 200 feet of rounded pebbles derived from the Uinta quartzite, cemented into hard rock by an abundant lime cement. The situation of its remaining exposures is such that I cannot conceive of the possibility of the existence of the cañon of the Green river during its formation. While in the Plateau province south of the Uinta mountains no beds have yet been discovered that are known to be of later than Eocene age, the region has not yet been examined with sufficient detail to make it certain that they have not existed there. Such beds would have been the first to be affected by the enormous erosion to which the entire region has been subjected, and the present limited extent of the Wyoming conglomerate (which has doubtless been exceptionally protected by its position along the flanks of the range), as compared with that it must once have had, proves how thoroughly such recent deposits could have been carried away by recent erosion.

In more recent observations in northern New Mexico,† Captain Dutton found upper Carboniferous beds resting directly on the Archæan in the Zuñi plateau and the Nacimiento mountains, the Cambrian, Silurian, and Devonian being wanting.

In more detailed studies of previously examined sections in the Grand Cañon of the Colorado, Mr. C. D. Walcott‡ has recognized a great thickness of comparatively unaltered sandstones, shales, and limestones (the Chuar and Grand Cañon series), which he considers of Algonkian age, and which rest unconformably upon sandstones and eruptive granites of undetermined age. A distinct unconformity of angle exists between the Algonkian and upper

\* Descriptive Geology: Vol. II, Fortieth Parallel reports. Washington, 1887, pp. 194 and 206 (field work, 1871).

† Mount Taylor and the Zuñi Plateau: 6th Ann. Rep. Director U. S. Geol. Survey. Washington, 1885, p. 192 (field work, 1884).

‡ Am. Jour. Sci., 3d ser., vol. XX, p. 221; vol. XXVI, p. 437; vol. XXVIII, p. 431; vol. XXXII, p. 154; vol. XXXV, p. 399; vol. XXXVII, p. 374; vol. XXXVIII, p. 29; and Bull. U. S. Geol. Survey, No. 30, 1886, p. 15.



Cambrian (Tonto beds). He also observed unconformities by erosion between, *first*, the upper Cambrian and Devonian; *second*, Devonian and lower Carboniferous; *third*, upper Carboniferous and lower Permian; *fourth*, lower Permian and upper Permian. A similar unconformity between Algonkian and upper Cambrian was observed by him in Llano county, Texas.

With regard to the Mesozoic, Dr. C. A. White\* first made the following suggestion, based on the finding of fresh-water Jurassic fossils in Colorado and Wyoming:

"In conclusion, I think it may be safely assumed that the great inland portion of our continent was not so permanently the seat of oceanic waters during the Mesozoic times as has been generally supposed."

I have already in a previous publication stated my belief that the Archæan areas in Colorado occupy the sites of mountain elevations that were uplifted above the ocean in post-Archæan time, and which in a more or less modified form have constituted land areas ever since—that is, that in the times of the greatest general depression of the region they were never so completely submerged as to admit of continuous sedimentation over them, but some mountainous islands always existed, from the abrasion of which the sediments in the adjoining seas were formed. This view is opposed to that held by the late Dr. F. V. Hayden, and also to that expressed by Major J. W. Powell in his geology of the eastern Uinta mountains,† both of which involve a former complete arching over of the present crests of the mountains by the strata now upturned along their flanks. It had, however, already been advocated by Mr. Clarence King‡ in his Systematic Geology, and by Dr. A. C. Peale§ of the Hayden survey.

The necessity of this view was impressed upon me by the structural conditions of the beds resting on the eastern flanks of the Colorado range long before I had made any special studies of Colorado geology, and my subsequent field work there has only served to confirm its general correctness by the persistent evidence it has afforded of the littoral character of the sediments along the assumed shore-lines, which changes rapidly as they are left; and by the character of much of the organic life whose remains, found in these sediments, indicate the vicinity of land areas, and add to the impossibility of explaining in any other way the peculiar stratigraphical relations observed.

In tracing the effects of orographic movements upon the earth's crust, a marked contrast is noted between the regions of violent disturbance, generally mountainous areas, and those in which the strata show little change from the horizontal position in which they were originally deposited, which

\* Bull. U. S. Geol. Survey, No. 29, 1886, p. 14.

† Geology of the Eastern Portion of the Uinta Mountains. Washington, 1876, p. 26 et seq.

‡ Fortieth Parallel Reports, vol. I, 1878, pp. 128, 533, 729.

§ Am. Jour. Sci., 3d. ser., vol. XIII, 1877, p. 181.



are characteristically represented by the great plain areas of the present day. In the former, the strata show the effects of powerful and repeated tangential compression, not only in their steeply inclined positions and sharp folds and faults, but in the frequent and marked angular unconformities between beds deposited before and after an orographic movement. In the latter, on the other hand, the inclinations of the strata diverge but little from a horizontal position, the folds are but gentle undulations or monoclines broken by faults of moderate displacement, and no angular discordances between successive strata are to be observed, whatever orographic disturbance may have intervened between the times of the respective depositions.

Nowhere is this change of condition more marked and sudden than in the Rocky Mountains of Colorado. In leaving a mountain area one may pass in a mile or two from steeply upturned and even reversed strata, showing evidences of violent movements accompanied by long periods of erosion before succeeding beds were deposited, to an adjoining plain where the same beds rest in horizontal position and in perfect stratigraphical accordance one over the other, and where the only evidence of erosion on the beds below the horizon of the movement may be a variation in their aggregate thickness. Not only is this true of the outer flanks of the mountain ranges, but it can also be observed to hold good for many of the interior depressions which would seem to have been either valleys or arms of the sea throughout the various phases of the geological evolution of the region.

It is evident, therefore, that except in highly disturbed regions actual evidence of unconformity must be extremely rare, the parallel succession of beds after an orographic movement, or parallel transgression as it is designated by European geologists, being far more common than actual discordance of stratification; but even in highly disturbed districts, I have found that a very marked discordance of stratification is not always shown by an actual angular unconformity along the line of dip, but that its evidence is readily found only in variations in the strike between beds deposited before and after an orographic movement, or, what amounts to the same thing, by the observation that the later beds rest at different points upon different horizons of the earlier series of beds. The explanation of an extreme case of conformity in angle of dip, combined with the greatest variations in strike, which has come under my observation, is very readily apparent and, with local modifications, is doubtless applicable to all similar structural phenomena. In the given case, the beds already deposited were by an orographic movement thrown into a series of folds whose axes had a general east and west direction. After the crests of these folds had been planed off by erosion, a second series of beds was deposited upon them, producing a complete succession of beds with no discrepancy of angle, along an east and west line in the troughs of the synclinal folds, but with gaps of varying width in the succes-

sion of beds on the crests of the anticlinals. In the following movement both series were thrown into a series of folds the prevailing direction of whose axes was north and south, or at right angles to the preceding folds; and after these folds had been eroded, in the beds left standing with a steep western dip, the evidence of the earlier folds is found only in their irregularly-waving line of strike as compared to the comparatively straight one of the later beds, while the angle of dip in the two series is in many cases perfectly conformable, and what variations may exist in other cases is generally undistinguishable, either from its slight amount or from the unfavorable position of the exposures.

In weighing the evidence for or against an orographic movement in a given region it would seem, therefore, that the positive proof afforded by one or two instances of unconformity should overbalance the negative testimony of many instances of apparent conformity.

In endeavoring to trace out the orographical history of the Rocky Mountain region I have followed the method of reconstructing in my mind the probable outlines of its various land-masses when a period of sedimentation began after the close of an orographic movement, and the changes produced in those outlines by each succeeding movement.

*Rocky Mountain Region.*—The mountain area which is referred to in this paper as the Rocky Mountain region, is a north and south belt about 150 miles in width, extending from northern New Mexico through the state of Colorado into southern Wyoming, a distance in round numbers of about 400 miles. As the land areas at the close of the successive movements especially referred to correspond more or less closely to the areas of the principal mountain ranges, areas whose general lines of uplift it may be assumed were determined very early in its history, perhaps at the close of the Archæan, they will be referred to as islands under the names that are now applied to the ranges. Their general disposition is as follows: The mountain uplift fronting the Great Plains, which as a whole has a meridional trend, is divided by depressions having a general northwest trend into three more or less distinct ranges, whose northern continuations, leaving the line of uplift which fronts the Plains, trend to the northwest and thus produce a structure *en échelon* for the whole system. The northern and most extensive of these, the Colorado range, extends from Pike's peak northward to the Colorado state line and then splits into two distinct uplifts on either side of the broad elevated valley known as the Laramie plains. The eastern of these uplifts, the Laramie hills, was a submerged reef in Palæozoic times and has a somewhat broken connection by small projections of Archæan exposures with the Black Hills of Dakota. The western uplift, known as the Medicine Bow range, trends northwestward between the Laramie plains and the North park, at one time having been connected with the northern end of the Park

range or Grand Encampment mountains. It disappears beneath the present east and west depression of central Wyoming; but a submerged line of uplift, proving a possible connection with that of the Wind River mountains, is found in the Archæan exposures of Rawlins peak and the Sweetwater mountains.

Immediately west of the Colorado mountain mass are the broad valley depressions of North, Middle, and South parks.

Southwest of Pike's peak and separating the Colorado range from the Wet mountains is a bay-like depression extending northwestward from Cañon City toward the southern end of the South park.

The Wet mountains form the mountain front from Cañon City south to Huerfano park, and have a small depression or park to the westward, known as the Wet Mountain valley, which is of less orographical significance than those already mentioned, having once probably been part of an elevated region, brought down to its present position by faulting and erosion in more recent times. The northwestern continuation of the Wet mountains has also lost its former topographical importance, but is recognized geologically in the Archæan area along the Arkansas river, west of the Royal gorge.

Huerfano park is a second bay-like depression, which, if extended to the northwest, would merge into the Wet Mountain valley. It separates the Wet mountains from the Sangre de Cristo range, which, rising gradually from the plains of New Mexico, forms the east front of the Rocky Mountains as far north as Huerfano park, and then trends northwestward, forming the western boundary of that park and of the Wet Mountain valley in the same general line of uplift as the Sawatch range.

The original Sawatch uplift, now divided by the upper Arkansas valley into the Sawatch and Mosquito ranges, formed the earlier western boundary of the South park depression, as the Mosquito range does to-day.

The western boundary of the Middle and North parks is formed by the Park range, a line of uplift also having a northwesterly trend parallel to that of the Sawatch and set off *en échelon* a little to the northeast of it. Its northwestern end is known as the Grand Encampment mountains, and the southern continuation, which at times has been separated from it, is called the Gore mountains.

To the southwest and west of the Sangre de Cristo is the great valley depression of the San Luis park, on the same general meridian with the other parks, but geologically distinct in that it is probably of more recent formation, since there is no evidence that Mesozoic sediments were ever deposited in it. To the northwest, and separating it from the head of the Gunnison and lower Grand rivers, is a broad area of moderate elevation now buried beneath extensive bodies of igneous rocks. But little can now be learned by actual observation of the structure of the underlying rocks of

these two areas, owing to their almost unbroken covering of alluvial and eruptive material; but, as will be seen later, it may be inferred from the structural conditions of the adjoining regions on the north and east that another elevated island once occupied some portion of it, possibly connected with the southern end of the Sawatch island, which has disappeared under the influence of erosion or local subsidence.

A western meridional line of elevation beyond those above mentioned is formed by the San Juan mountains west of the San Luis park, the Elk mountains west of the Sawatch range, and the White River plateau. The two latter are closely connected together, but are separated from the greater uplift of the San Juan mountains by the broad east and west depression of the Gunnison valley. This line of elevation, as compared with that to the east, is characterized by having been the scene of intense eruptive activity in late Mesozoic and Tertiary times; and the same evidence of eruptive activity is seen on the same north and south line in the Elkhead mountains on the western flanks of the Park range.

It is only of the beds deposited during and subsequent to Cambrian times that the outcrops are exposed in sufficient continuity to justify an attempt at differentiating the land areas around which they were deposited.

#### PRE-CAMBRIAN LAND.

Of the extensive series of clastic sediments which the investigations of Irving and his colleagues in the Lake Superior region have shown must have been deposited upon the Archæan basement of distinctly crystalline rocks previous to the earliest Cambrian, for which the general term Algonkian is now proposed, only a few isolated exposures have yet been discovered in the Rocky Mountain region, and these have not been sufficiently studied to attempt any correlation between them. With regard to the earlier land areas, therefore, only a few general conjectures can be formed.

*Algonkian Exposures.*—Between the western Archæan continent (of which, as King has shown, the present Wasatch uplift must represent the eastern shore-line) and the Archæan islands of the Rocky Mountain region, it may be assumed that a general depression existed in Algonkian time commensurate with that which has obtained in later periods. The Grand Cañon and Chuar series, which Walcott has assumed to be of Algonkian age, and on the upturned and eroded edges of which rest upper Cambrian beds, are on the general north and south line of the Wasatch uplift. The only other known pre-Cambrian exposure in this depression is that of the Red Creek quartzites of the eastern Uinta mountains, which were classed as Huronian by the Fortieth Parallel geologists, and probably belong to one of the Algonkian series. They serve to show that the Uinta uplift, which is of post-

Cretaceous age, probably owes its position to a pre-Cambrian ridge which acted as a buttress or *point d'appui* to the forces of compression which produced this most remarkable and exceptional anticlinal fold of 30,000 feet of practically conformable beds. The series of schists, slates, and quartzites of the Black Hills, which have hitherto been classed as Archæan, are probably of Algonkian age also.

In the Rocky Mountain region Mr. Arnold Hague found a considerable thickness of quartzites resting on the Archæan in the Medicine Bow range at its northern extremity, and an isolated patch of quartzite and conglomerate is known to exist on the east flanks of the Colorado range near Boulder. In the hills east of the Arkansas river at Salida and south of the South park, Mr. Whitman Cross discovered a thickness of about 10,000 feet of slates and schists entirely distinct from the Archæan and probably unconformable with it. On the north slope of the San Juan mountains near Ouray, I have found over 10,000 feet of closely folded quartzites, conglomerates, and slates of pre-Cambrian age, and believe that the Quartzite peaks in the southern portion of this region are probably composed of the same series of rocks.\* Quartzites have also been noticed connected with the Archæan of the southern end of the Sangre de Cristo range which may on general grounds be assumed to be the remnants of some Algonkian beds.

While these various exposures are too isolated and have been too little studied as yet to justify an attempt at correlation between them, they are easily distinguished from the Archæan or basement rocks even when not found directly associated with them. The latter, so far as the great areas exposed have been studied, are distinctly crystalline, consisting mainly of granites, gneisses, mica and hornblende schists, with none of the limestone or apparently fragmentary beds which confuse the student of Archæan developments in the east; while in the former, secondary alteration is either very slight throughout the series or limited to certain beds, so that there can be no doubt of their clastic or mechanical origin.

The character of the material of which they are composed and their great thickness show that they result from a long-continued abrasion of high Archæan land-masses in their near vicinity. It is to be noted, moreover, that all the Algonkian exposures, with the exception of that near Salida, are on the outer flanks of the area which has been designated the Rocky Mountain region. Their beds are steeply upturned or sharply folded, and all Cambrian or later sediments rest unconformably upon them, as upon the Archæan; hence there must have been at least two and possibly more orographic movements between Archæan and Cambrian times.

*Cambrian Exposures.*—At the base of the Palæozoic section in the Wasatch mountains, as exposed in Big Cottonwood cañon, are 12,000 feet of quartzites

\* This opinion is confirmed by Mr. Van Hise, who has visited this region during the past summer.

and slates, resting unconformably on the granite body of Little Cottonwood cañon and upon a series of schists which form the western flank of this body. These were classed by the Fortieth Parallel geologists as Cambrian, while the schists were assumed on lithological grounds to correspond with the Red Creek quartzites of the Uinta mountains. In my study of the Uinta range in 1871 I found only upper Carboniferous beds, as determined by their fauna and their lithological correspondence with already defined horizons in the adjoining Wasatch range, and considered that the great thickness of quartzites, conglomerates and shales underlying them in apparent conformity and forming the core of the range belonged to the silicious or middle member of the Carboniferous. Powell, however, having found, in the cañon of the Green river at the eastern end of the mountains, an unconformity by erosion between the upper and lower portion of these sandstones, I assumed that the lower portion, the Uinta sandstones, must correspond to the Cambrian quartzites of Big Cottonwood cañon.\* In his later examination of the Big Cottonwood section, Mr. Walcott found lower and middle Cambrian faunas in the upper 2,000 feet of the Big Cottonwood quartzites, and classed the lower 10,000 feet as Algonkian. According to this classification the Uinta sandstones would probably be of Algonkian age, but of a later period than the Red Creek quartzites.

In the Grand Cañon region, throughout the Rocky Mountain region, in the Black Hills of Dakota and, so far as known, in Texas, New Mexico, and Arizona, only upper Cambrian beds were deposited. It must therefore be assumed that during early and middle Cambrian times, while the Big Cottonwood beds were being deposited, these regions were elevated above the ocean; but that a progressive subsidence was going on which initiated a cycle of deposition in the Rocky Mountain region extending from upper Cambrian to middle Carboniferous time.

The beds deposited during this interval are of extremely limited thickness as compared with that of corresponding horizons in Utah and Nevada, no exposures thus far examined showing as much as one-tenth of the thickness represented in the Wasatch section. Their fauna also has thus far proved to be extremely meager. A fairly uniform succession in character of sediment is observed throughout the region, the Cambrian commencing with a fine basal conglomerate indicative of an advancing shore-line, followed by varying thicknesses of sandstones, which pass upward through calcareous sandstones and shales into silicious limestones in the Silurian and pure dolomites or limestones in the lower Carboniferous, with a somewhat abrupt passage into clays and sandstones above, showing evidence of shallow-water deposition.

Such palæontological evidence as has been obtained proves the existence

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\* Fortieth Parallel reports, Vol. II, p. 199.



of faunas characteristic, in other regions, of upper Cambrian, of some horizons of the Silurian, of lower Carboniferous, and of the Coal Measures. From time to time individual forms, apparently indicative of a Devonian age, have been found; but in every case a more exhaustive examination of the locality has shown their association to be overwhelmingly Carboniferous or Silurian. The Devonian, therefore, seems to be wanting in the Rocky Mountain region, as it has thus far been found to be in New Mexico, Texas, Arkansas, and the Black Hills. To account for its absence in the latter region, Mr. W. O. Crosby \* has advanced the ingenious theory that, in the cycle of deposition succeeding the Cambrian, the ocean had in Devonian time reached the abyssal depth at which, according to Murray, sedimentation is no longer possible. While I must admit that evidence of shallow-water deposition is less conclusive in this interval than in those which succeeded, and that portions of the Colorado islands were then submerged which were not subjected to sedimentation during the succeeding intervals, I am unable to accept this explanation for the Rocky Mountain region, and am more inclined to attribute the absence of Devonian to a partial recession of the ocean. The direct evidence of such recession is, it must be confessed, as yet very slight, being limited to an unconformity by erosion between Silurian and Carboniferous, observed in a single locality only,† and to the existence of a thin and not always persistent sandstone between Silurian and Carboniferous limestones.

This supposition corresponds better with the course of events on the eastern continent as recently traced out by Prof. J. D. Dana.‡ The break which he shows to exist at the close of the Lower Silurian does not correspond exactly in geological succession with the gap which appears to exist in the Rocky Mountain region; but the exact position of this gap in the geological column is not yet determined. It is quite possible, moreover, that the elevation of land may not have been strictly contemporaneous in both continents, and that the succeeding subsidence which allowed the reoccupation of the region by ocean waters may have proceeded more rapidly in the one than in the other.

#### EARLY PALÆOZOIC LAND.

The land areas that existed during this time, or rather the degrees to which the present elevated regions were submerged so as to admit of sedimentation, were somewhat as follows:

*Colorado Island.*—At the north the Laramie hills extension of the Colorado range was submerged beyond the state line, and the shore-line extended

\* Proc. Bos. Soc. Nat. Hist., vol. XXIII, March, 1888.

† Monographs U. S. Geol. Survey, No. XII, 1886, p. 56.

‡ Bull. Geol. Soc. Am., vol. I, 1889, p. 36.



continuously along the flanks of the Medicine Bow range and across its extremity to the Park range, but the ocean waters did not penetrate the North and Middle parks which, up to post-Cretaceous time, formed a single connected valley. On the east the shore-line probably reached higher and further westward than the present hogbacks. Pike's peak stood out as a promontory, or possibly as an island, the shore-line extending across the ridge to the north of it into the bay now occupied by Manitou park, while to the southwest the waters of the Cañon City bay covered Webster park and portions of the ridge through which the Royal gorge of the Arkansas is now cut, and northwestward may have penetrated the South park depression. The main connection of South park with the ocean was, however, from the northwest around the northern point of the Sawatch uplift and across what is now the northern portion of the Mosquito range.

Further north the western shore of the Colorado island was formed by the Park range, so that its general outline was triangular with apex toward the south and its width about 100 miles at the broadest part.

*Sawatch Island.*—To the west of the South Park bay was the Sawatch island, which included the west flanks of the present Mosquito range and the upper valley of the Arkansas. The area of its present Archæan exposures within the fringing reef of Cambrian quartzites is about 100 by 30 miles. It was undoubtedly smaller at the time when these were deposited, but their outline probably preserves the general shape of the original island, as they resist erosion even better than the Archæan rocks.

*Southern Areas.*—With regard to the southern portion of the region, it is difficult to reconstruct the probable distribution of land and sea at this time, partly on account of the uncertainty with regard to the outlines given on the Hayden map, and partly because observers have not hitherto discriminated between upper and lower Carboniferous horizons.

South of the latitude of Cañon City and of the southern end of the Sawatch island, the only region where the lower Palæozoic rocks can with certainty be said to have been deposited is in the western portion of the San Juan mountains. Along the Sangre de Cristo range the conglomerate series of the upper Carboniferous is known to rest upon the Archæan in many places, and at the southern end of this uplift Stevenson found lower beds which may belong to the earlier series; but in the present state of our knowledge of the Carboniferous fauna of the Rocky Mountain region the palæontological evidence is not decisive. By analogy it would seem probable that the two exposures of Carboniferous on the east flanks of the Wet mountains belong to the lower series. On the other hand, in the outlying regions of the Uncompahgre plateau, in western Colorado south of the Grand river, and at the Zuñi and Nacimiento mountains in northern New Mexico, upper Carboniferous beds rest directly upon the Archæan, which is in so far an evidence of

land areas there during Palæozoic time. As will be seen later, the elevation which accompanied an orographic movement did not affect the whole area uniformly, but some regions were raised more than others, and indeed there is some evidence to prove that some portions of the area were actually depressed while others were being raised. In a general way, therefore, it may be said of the southern area that the distribution of land areas was probably somewhat more widely spaced than in later times, and that interior depressions existed that were afterwards raised above ocean level, and even became parts of prominent mountain masses as the outlying land-masses were depressed.

#### THE LATE PALÆOZOIC MOVEMENT.

The existence of land areas toward the close of Palæozoic time has been frequently suspected by western geologists from the evidence of shallow water and shore-line conditions in the beds which have been considered upon somewhat meager and often conflicting palæontological evidence to belong in different localities to the upper Carboniferous, Permian, or Trias; but, so far as I know, no actual unconformity has hitherto been observed. In the summer of 1882 I first noticed what seemed conclusive evidence of the existence of such an unconformity in the Elk mountains, but it was not until two years later that actual field work with my assistants, Messrs. Cross and Eldridge, enabled me to fix its horizon as in the middle or upper part of the Carboniferous.\* Since that time I have found such corroborative evidence of its existence in various parts of the Rocky Mountains as justifies the conclusion that a general orographic movement took place throughout this region, whose effects may probably be found to have been felt beyond it. It is a movement that is in many ways difficult to define. Firstly, on account of the wide range of most of the abundant molluscan species which are found in Carboniferous beds, owing to which palæontological evidence by itself is thus far of but little value in determining the relative position of any beds except those at the two extremities of the series. Further, because the dynamic disturbances that accompanied the movement were very unequally distributed, and their effects are to be observed, as a rule, only in regions which were again violently disturbed during the succeeding movement, where they were consequently much obscured. Its determination as occurring in middle or late Carboniferous time has, therefore, necessarily been founded mainly on the stratigraphical relations and lithological character of the beds.

That it was not earlier than middle Carboniferous is proved by the finding

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\* A notice of this, and of the Jurassic unconformity observed in the same region, was published in the Sixth Annual Report of the Director of the U. S. Geol. Survey, 1885, p. 64.

of Coal Measure fossils in the limestone pebbles that in some regions form a characteristic feature of the conglomerates deposited immediately after the movement. On the other hand, the thickness of beds deposited after the movement, presumably of Carboniferous age, is far greater than that of those beds deposited before it; but as these are of extremely coarse material, evidently deposited during the rapid abrasion of high land-masses in comparatively close proximity, it is evident that the mere thickness of the deposit is not a very reliable time-gauge.

During this movement some areas were uplifted and eroded in such a way that the later sediments overlapped the upturned edges of the earlier beds. In others, for instance around the shore-line of the Sawatch, the elevation was of such a nature that the succeeding sediments were deposited in perfect conformity, and no evidence of erosion has been detected between the two series of beds, though land plants and limited developments of coal or of bituminous shales are found at certain horizons.

Perhaps the most remarkable feature of the sedimentation which followed the movement was the great thickness of very coarse conglomerate along the present Elk mountain and Sangre de Cristo ranges, reaching a thickness of 3,000 to 6,000 feet, which are not found at all on the east front of the Colorado and Wet mountain ranges. In the Elk mountains the pebbles are mostly of limestone, which are entirely wanting at corresponding horizons along the adjoining Sawatch range. In the Sangre de Cristo range they are mostly of gneiss and granite, with some limestone pebbles; the fragments of Archæan rocks in the beds opposite the Wet Mountain valley are often as much as 25 or even 50 feet in diameter, and must either have dropped from adjoining steep cliffs or have been carried out into the sea by ice. To account for the formation and present stratigraphical relations of the Elk mountain conglomerates it is necessary to assume that during the movement a land area was uplifted to the south of that region, from which the earlier Palæozoic beds were mostly denuded, and whose original outlines or area can no longer be determined.

The sediments that were deposited between this and the succeeding movement near the close of the Jura were largely conglomerates, with a few mud shales and occasional thin beds of limestone. The Triassic "Red Beds" near the top contain finer grained sandstones and some clays. Gypsum is found locally developed at various horizons.

In most of the beds deposited during this interval it has hitherto been impossible, in the absence of decisive palæontological evidence, to determine how much of the entire series is represented. Only the Carboniferous beds have been found to contain molluscan remains, and these are wanting in the coarser grits and conglomerates. The evidence afforded by plant life has thus far proved to be somewhat meager and uncertain. In outlining geolog-

ical divisions on maps, therefore, too much reliance has necessarily been placed on distinctions derived from the character of the sediments. While that of the upper part of the Trias seems to be persistent over this and the adjoining regions, the earlier sediments only show a general prevalence of conditions of rapid abrasion and shallow-water conditions. Whether the Permian beds, recognized in the Wasatch and Grand Cañon regions on the one side and along the borders of the eastern continent and in Texas on the other, are represented here seems still uncertain. Plants of Permian facies have been found, but they are often associated with a Carboniferous fauna. It is possible that the general elevation, which the shallow-water conditions imply, may have shut out the ocean waters during part of this period; this is rendered probable by the evidence of a movement at the close of the Permian said to exist in other regions. The erosion which took place at the close of the next succeeding movement is known to have been locally very great in the Rocky Mountains. Whether the marine Jura, as developed to the west and north, was deposited in this region and has in great measure been eroded away, or whether its elevation was such that the early Jurassic seas did not penetrate it, remains yet to be determined by future investigation. The only fact bearing upon this point is the observation by Mr. G. H. Eldridge of an unconformity by erosion between the Trias and fresh-water Jura along the foothills of the Colorado range near Denver.

#### LATE PALÆOZOIC LAND.

The outlines of the various land areas during the subsidence that followed this movement were, as far as can now be determined, somewhat as follows:

*Colorado Island.*—Along the eastern and northern shores of the Colorado island, no upper Carboniferous beds corresponding to the conglomerates of the Elk and Sangre de Cristo mountains have yet been recognized. The Triassic "Red Beds" now rest directly on an Archæan or lower Palæozoic basement, as the case may be. Hence it may be assumed that during upper Carboniferous time these shore-lines were still above water, and that the subsidence had continued into Triassic time, so that what upper Carboniferous sediments might have been deposited were overlapped and buried from sight by those of the Trias. Triassic sediments invaded the depression of North park, but apparently did not extend far into the Middle park.

South park was connected with the western ocean across the northern end of the Mosquito range, as in early Palæozoic time, and received a complete and regular series of sediments. On the south the bays at Manitou and Cañon City were probably not so deeply invaded as in early Palæozoic time, nor is there any evidence that upper Carboniferous or Triassic sediments ever oc-

cupied Webster park or Parkdale valley; if they did they have since been very completely eroded away.

Park range was probably isolated and formed an island, which was not connected with the Colorado island. Along its present shore-lines the upper Carboniferous beds are now so completely masked by subsequent Mesozoic sediments that their original extent cannot be determined. They are disclosed, however, by the more recent uplift and erosion of the White river plateau to the west, over which area sedimentation apparently went on continuously without leaving any very marked evidence of the movement.

*Sawatch Island.*—Around the immediate shores of the Sawatch island sedimentation apparently went on in unbroken continuity up to the time of the Jurassic movement, no evidence having yet been detected in the remarkably regular series of beds that now surround it of any dynamic disturbance. The character of these sediments shows, however, that shallow-water conditions prevailed from the middle of the Carboniferous to the close of the Trias, some small deposits of coal having been locally formed, and beds of coarse conglomerates, containing pebbles that must have been derived from some neighboring land-mass of Archæan rocks, constituting a very considerable proportion of the section exposed. Alternating with these are occasional beds of limestone, which are of so frequent occurrence and have so little persistence that they cannot be assumed to necessarily imply deep-water deposition, but rather local changes in conditions of sedimentation.

On the immediate western flanks of the Sawatch range, in the Elk mountains, were deposited at this time a thickness of not less than three thousand feet of reddish conglomerates, characterized by a great abundance of limestone pebbles associated with those of Archæan rocks, of which no lithological correspondents are found in the beds encircling the Sawatch uplift. These beds have been deposited over eroded surfaces of previously folded Palæozoic beds, and Carboniferous fossils have been found in some of the pebbles. Their material must have been derived, therefore, from the abrasion of some land-mass formed by the upheaval during this movement of an area over which sedimentation had been going on during early Palæozoic time. They could not have come from the erosion of the Sawatch island, otherwise the time correspondents of these beds around that island would have contained limestone pebbles also.

A careful consideration of the present stratigraphical conditions of the region shows that this land-mass must have existed somewhere to the south of the Elk mountains in the region about the head of the Gunnison valley, and possibly extended towards the northern end of the San Luis park. This land-mass may have been connected with the southwest end of the Sawatch island.

At the southeast end of this island is a similar unusual thickness of coarse

sandstones and conglomerates of prevailing red color, exposed by the erosion of the Arkansas river after it assumes its eastward course, which occupy a corresponding stratigraphical horizon, without, however, showing any evidence of unconformity with the beds below.

*Wet Mountain Island.*—The Sangre de Cristo mountains, from the Arkansas river southeastward to the head of Huerfano park, must have formed the western shore of the Wet Mountain island at this time, their relative positions as mountain and valley having been then the reverse of those which exist now. This range opposite Silver Cliff is largely made up of an immense thickness of conglomerate whose pebbles, of all varieties of Archæan rock, cannot have suffered any very prolonged attrition, for they not only consist of relatively soft material, but are sub-angular and often in immense blocks over 25 feet in diameter which could not have been carried very far.

It seems probable that these conglomerates extend the entire length of the range, since they have been observed by Stevenson on its eastern flanks, extending beyond the state line into New Mexico, where they contain limestone pebbles associated with those of Archæan rocks. He gives them an aggregate thickness at one point of about 6,000 feet.

It is a question whether the material of which they were composed was derived from the Wet Mountain island or from some land-mass to the westward which has now disappeared. The fact that on the east flanks of the Wet Mountain island no beds at all corresponding to them in thickness or coarseness of material have been found, would favor the latter conclusion.

The section at Cañon City shows a thin limestone conglomerate or breccia, made up of slightly rounded fragments, immediately and unconformably overlying the lower Palæozoic beds, and succeeded by a few hundred feet of beds mostly of reddish arkose material with a few limestone pebbles near the base. The characteristic red sandstones of the Trias have either been eroded away or are overlapped and concealed by the unconformable Jura-Dakota beds. Two exposures of Triassic beds are indicated on the Hayden map south of this point along the eastern flanks of the Wet Mountain range. Elsewhere they have been overlapped by the unconformable Jura-Dakota series. In like manner, south of Huerfano park, along the east front of the Sangre de Cristo range, the Jura-Dakota beds abut directly against Archæan or Carboniferous rocks, and no Triassic beds have been recognized, except near its southern extremity.

*San Juan Island.*—In the San Juan region, elevation and erosion is shown to have taken place by the fact that on its northern flanks a slight angular unconformity is observed between the lower Palæozoic series and the coarse grits, sandstones and shales that were deposited during the later Carboniferous. This discrepancy of angle was not observed on the southern slopes of the mountains along the Animas cañon, but of the areas represented there



on the Hayden map as Devonian and Carboniferous the lower part is known to be Silurian and the upper part Triassic. If the upper Carboniferous is not exposed it must have been overlapped, as on the eastern shores of the Colorado island, by the succeeding Triassic sediments.

In the wide area of the Uncompahgre plateau, to the west and northwest, Triassic beds are well developed, and the Carboniferous exposures represented as resting directly on the Archæan are considered by Dr. Peale to belong to the upper portion of this series. It would seem probable that these and the similarly outlying regions of the Zuñi plateau and the Nacimiento mountains were island elevations in the early Palæozoic seas over which no sediments were deposited, and that after the late Palæozoic movement they were depressed below the sea level, since recorded observations seem to show that continuous sedimentation went on over them from Carboniferous into Mesozoic time.

*Conclusions and Correlations.*—Without a special examination of the region with this object in view, it is difficult to make any satisfactory conjectures as to whether the Carboniferous beds at a given locality belong to those deposited before or after this movement, or whether both are represented. From the present evidence it would appear that in the middle portion only of this region was the movement accompanied by any marked dynamic disturbances, and that elsewhere it was in the nature of a parallel transgression.

Again, while in the interior the aggregate thickness of the Palæozoic beds reaches from five to seven thousand feet, along the east flanks of the Colorado range, in the Laramie hills of Wyoming and the Black Hills of Dakota their exposures rarely show more than seven or eight hundred feet of beds. While it is certain that in the latter regions the lower Palæozoic beds are represented, no evidence has yet been presented to show that upper Carboniferous horizons are exposed there; but the Triassic "Red Beds" are in most cases characteristically developed. Palæontologically, Coal Measure forms, which are abundant throughout the Carboniferous beds, cannot be considered characteristic of either series, and it is only those having a Permian facies that afford definite evidence of the existence of the upper Carboniferous beds. On the other hand, in the Rocky Mountain region the lithological characteristics, that further west serve to distinguish the beds carrying a Permian fauna from the Carboniferous on the one hand and from the Trias on the other, are wanting; and there are very considerable thicknesses of beds about which it can only be said that they were deposited somewhere in the interval of time between the Carboniferous and Jurassic movements. Whatever may be predicated in regard to the orographical history of this interval is necessarily based upon data which are liable to be modified in the future, and hence are very conjectural. It is, that the elevation accompanying the movement was followed by an irregular subsidence, which was more pro-



nounced in the interior region, but in the outlying region was followed by further subsidence in Triassic time, as a result of which the earlier beds were overlapped to such an extent by the Triassic sandstones that they have rarely been exposed by later movements or erosion.

In the Wasatch and Uinta regions, the upper Carboniferous and Permian are undoubtedly represented. If I am right in considering that only the upper members of the Carboniferous are represented in the Uinta range, it would become probable that the erosion observed by Powell in the cañon of Green river on the beds underlying the Carboniferous was produced during the elevation that accompanied this movement.

With regard to the broader and more continental elevations, the fact that over the Palæozoic continent of Utah and Nevada, as well as over the great Appalachian continent, not only Mesozoic but also Permian beds are wanting, would indicate an alternate movement between those regions and the Rocky Mountains—that is, that during the Carboniferous elevation of the latter these still remained below the level of sedimentation, though shallow-water conditions prevailed to a certain extent, but that, while in the Rocky Mountain region subsidence continued into the Trias, the continents on either side reached a permanent elevation at the close of the Carboniferous time which was so far maintained that the waters of the ocean never again invaded them.

A similar condition, according to present evidence, would seem to have obtained in northern Mexico; for Dr. White\* considers that south of the 34th parallel no Trias or Jura exists, but that the marine lower Cretaceous (which also includes possible representatives of the *Atlantosaurus* beds) rests directly upon the Carboniferous.

#### THE JURASSIC MOVEMENT.

The succeeding orographic movement of the region, which was even more widespread and more marked in its effects, has been designated the Jurassic movement, because the first beds deposited after it were those containing the vertebrate fauna determined by Professor Marsh to be of late Jurassic age, and called by him "*Atlantosaurus* beds." A somewhat meagre fresh-water molluscan fauna, considered by Dr. White as also of late Jurassic age, has been found by him in the *Atlantosaurus* beds of the eastern flanks of the mountains, and by Mr. Eldridge in beds corresponding stratigraphically and lithologically with these on the west flanks in the Elk mountain region, where the dynamical effects of the movement are most marked and have been most carefully studied. The beds which in the Rocky Mountain region are characterized by this fresh-water Jurassic fauna are generally very thin, contain as a rule but scanty remains of organic life, and want the persistence and

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\* Am. Journal Sci., 3d ser., Vol. XXXVIII, 1889, p. 440.

peculiar lithological composition of the overlying Dakota Cretaceous which renders that formation one of the most readily recognizable of all the Mesozoic series. As actual observation has shown that in some cases the earlier geologists included these beds in their Dakota formation, the term Jura-Dakota has been used in this paper to designate the beds first deposited after the movement, in order to distinguish them from the marine Jurassic beds of other regions, which were deposited before them; without, however, implying thereby, in localities that have not been personally observed, more than the probability of the existence of the fresh-water beds.

The evidence of this movement thus far obtained is of two kinds: First, that derived from personal observation in regions of violent disturbance, where, during the elevation produced by the movement, considerable areas had been uplifted by folding, often combined with faulting, and great thicknesses of rocks, sometimes thousands of feet, had been eroded away; and where, during the subsequent depression, Jura-Dakota beds had been deposited upon these eroded surfaces. The most marked evidences of such movements are found in the Elk mountain region, where, along a single line of strike, the Jura-Dakota beds upturned during the post-Cretaceous movement are seen to rest alternately and in repeated successions upon beds of all the horizons from Archæan up to Trias, and to rest upon the latter in the middle of the region in perfect conformity. Other violently disturbed regions observed are the northern Mosquito range, the eastern flanks of the mountains near Cañon City, and the northern portion of the San Juan mountains.

The second class of evidence is the fact indicated by geological maps that the Dakota Cretaceous, presumably Jura-Dakota, rests directly upon Archæan or Carboniferous at very many points throughout the region. In the other portions of the region, where the Jura-Dakota is represented as resting on the Trias, unconformity by erosion has in a few cases been detected.

The most persistent and readily recognizable horizon of Mesozoic age in the Rocky Mountains is the Dakota Cretaceous. It is prevailing a sandstone with a characteristic basal conglomerate, the sandstone becoming readily quartzitic, even when adjoining sandstones are not altered, so that its upturned strata, owing to their resisting nature, always stand out prominently. The fresh-water Jura below it, so far as it has been studied, generally has a sandstone at or near its base which is softer and frequently cross-bedded to a remarkable degree. Between these two sandstones is a series of shales and clays, carrying a certain amount of limestone, which in some places forms a continuous bed, and at others occurs in lenticular bodies in the shales. The shales are frequently variegated in color, and beds of gypsum are sometimes found.

The Cretaceous beds above the Dakota consist, in the Fort Benton group, largely of dark shales, with a slight development of limestone, often bitumi-

nous; in the Niobrara, light-colored limestones predominate over the shaly members, becoming chalks in the deeper portions of the seas. The Fort Pierre is a great thickness of gray shales mostly argillaceous, while in the Fox Hills the shales become more arenaceous and pass into sandstones at the top of the formation. The Laramie is mainly sandstone in the enclosed sea-basins near large land-masses, with an increasing admixture of shales as the distance from these land-masses increases.

An abundant and characteristic vertebrate fauna has been discovered in the Jurassic beds at Como lake, in Wyoming, and at Cañon City and Morrison, in Colorado; a somewhat meager fresh-water molluscan fauna is associated with this in the two former localities, and some of the same forms occur at a corresponding horizon in the Elk mountains of Colorado. They are also reported from the Black Hills of Dakota and somewhat doubtfully from the Green River basin of Wyoming.

The Dakota formation carries an abundant flora which includes many deciduous plants, but in the Rocky Mountain region no marine forms have yet been found in it. The faunæ of the other horizons of the Cretaceous up to the Fox Hills are all marine, and in the Rocky Mountain region the change from the marine forms in this horizon to brackish-water forms in the Laramie is most marked and distinct.

#### JURASSIC LAND.

The more detailed and local effects of the Jurassic movement upon the various land areas under discussion were, so far as present facts afford any indication, somewhat as follows:

*Colorado Island.*—The general outline of Colorado island as determined in early Palæozoic time had thus far not been essentially changed. A general encroachment of the ocean upon its shores had been in progress, whose effects were more marked in the shallow bay-like depressions at its northern and southern extremities than along its steeper east and west shore-lines. The present areas of the North and Middle parks then formed a single depression, the present dividing line between them having been formed in post-Cretaceous times. North park had already been invaded by ocean sediments, and after the Jurassic movement further subsidence took place, so that the sea extended through the Middle park connecting with the waters occupying South park, and also across the Gore mountains westward to the Colorado plateau waters.

The relative distribution of the marine and fresh-water Jura is as yet but imperfectly known. To the west of the Laramie plains, throughout the Uinta and Wasatch regions and in eastern Idaho, the marine Jura is well developed, but as yet no fresh-water beds have been recognized; while at the Como lake anticlinal both marine and fresh-water Jura are found.

On the eastern shores of the Colorado island no evidence of the existence of marine Jura has been found south of the latitude of the Laramie plains. The fresh-water beds rest directly upon the Triassic without any apparent discrepancy of angle. The thickness of "Red Beds" assigned to the latter age varies very greatly from point to point. This would naturally be explained by the unequal erosion of these beds during their elevation; but where the evidence of sub-aerial erosion seems insufficient it might be partly accounted for in the case of beds, which like these bear internal evidence of having been deposited in strong along-shore currents, by the existence of broad, ridge-like corrugations in the sea bottom extending out at an angle to the shore-line, on the crests of which the accumulation of sediment would be much less than in the adjoining depressions. There is some evidence of the formation of such corrugations during the movement of elevation at various points along the eastern front of the mountains, though it cannot always be definitely assigned to this period.

In the Cañon city region there is evidence of considerable elevation and erosion during the movement, followed by a subsidence which admitted the Jura-Dakota waters to Webster park and to the valley of Parkdale at the west end of the Royal gorge. How far these waters extended to the northwest towards the South park depression has not yet been determined. Near Cañon City the discordance of strike between the now sharply upturned Jura-Dakota and the underlying beds is most marked, and points to a very considerable disturbance and erosion of the latter before the former were deposited. As the immediately underlying beds are here very soft and easily eroded, the actual contact and any discrepancy of dip-angle that may exist with these intermediate beds, whether Carboniferous or Triassic in age, has not been observed. The Jura-Dakota beds rest at different points, however, on these, on the early Palæozoic beds, or on the Archæan; and their discrepancy of angle with the two latter is very marked.

The western shore-line of the Colorado island is more difficult to define than the eastern, since it has been more extensively faulted and eroded in post-Mesozoic times.

It is noticeable that the northwest structural line along which the greatest disturbance has taken place passes through the Cañon City region just described. The most notable effect of the orographic movement along this line was the cutting off of the previously existing connection between the South park bay and the western ocean of the Plateau region, an effect which has a more than local significance. It was produced by an uplift of the northern portion of the Mosquito range and of the Gore mountains on the east side of the Mosquito fault, which has been traced northward along the western crest of the Mosquito range and thence northwestward along the west flanks of the Gore mountains to within fifteen or twenty miles of the Grand

river. The character of this uplift was not the simple uptilting of a block of the earth's crust into a monocline, as has been shown to be the prevailing character of movement in the Plateau region by the geologists who have worked there, nor the vertical upthrust of a block bounded by two lines of faults, which one of them has propounded as the type of the uplift of the Park province or Rocky Mountain region. It was the result of compressive folding, producing a fracturing or faulting along the steeper side of a one-sided or S-fold, which is the prevailing structural type in this region. From the northern end of the Mosquito range and the Gore mountains, thus raised above the ocean level, the sedimentary beds from Cambrian up to Triassic, which had been deposited upon them around the northern end of the Sawatch uplift, were almost entirely eroded away, a few patches only remaining on the crest and steeper western side of the uplift to prove the character of the fold. Around the eastern and northern flanks of this uplift, from the waters which during the succeeding depression entered the Middle park, whether from the north through North park or from the west across the Park range north of the Gore mountains, the Jura-Dakota beds were deposited directly upon the denuded Archæan; west of the Park range they stretched continuously across the fault line and rested in apparent conformity upon the Triassic beds, north of Eagle river and west of the fault line, which had escaped erosion.

This view of the structure of the region, which involves important modifications in the structural history of the Mosquito range given in my monograph upon the Leadville region, has naturally been adopted with extreme reluctance and under the influence of gradually accumulating evidence in its favor, combined with an inability to explain the known geological occurrences in any other way. In that monograph\* I assumed, in the absence of any direct evidence of dynamic movements previous to the close of the Cretaceous, that the folding and faulting of the Mosquito range was probably post-Cretaceous, although I foresaw the possibility and even probability that further investigation might lead to a modification of this view. The age of the porphyries, which were folded and faulted with the enclosing sedimentary beds and hence were necessarily older than the dynamic movement, I assumed to be late Cretaceous, since similar rocks are found in other parts of the Rocky Mountains cutting through the latest Cretaceous formations.

According to my present view a part at least of the uplift of the Mosquito range must have occurred in Jurassic time, though I still think that the mountains were further disturbed and uplifted during the great post-Cretaceous movement. The greater part, if not all, of the porphyries must, however, have been intruded before the Jurassic movement, and the original

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\* 1886, pp. 23 and 31.

ore-deposition of the region must also be assigned to a period anterior to that movement.\*

North of the Gore mountains, the Park range opposite Middle park was submerged, for a distance not yet determined, during the Jura-Dakota subsidence; but the northern part of the range remained above water, and the Grand Encampment mountains may, as already suggested, have formed part of the same island with the Medicine Bow range. Tertiary and Recent deposits now mask the flanks of these mountain masses to such an extent that all that can be said with certainty is that the Cretaceous deposits wrapped around them without apparently extending up the present valley of the North Platte as far as the North park.

*Wet Mountain and Sangre de Cristo Islands.*—During or possibly even before the Jurassic elevation, these two islands were consolidated into a single land-mass, which may now be called the Sangre de Cristo island. If any Triassic sediments had been deposited between them upon the upper Carboniferous they had been entirely eroded away. The eastern shore-line of this land-mass had the same general outline as the mountain front of to-day, with a reëntering bay at Huerfano park extending somewhat further into Wet Mountain valley than it does at present, and probably some submerged ridges making out at an angle from this shore-line. Either from unequal deposition over these ridges, as explained above, or on account of an unequal erosion of the Triassic beds, the latter are only found at widely separated intervals along the flanks of the Wet mountain range, and are apparently altogether wanting along the Sangre de Cristo range, except possibly at its southern end, in New Mexico. The Jura-Dakota beds consequently rest for the most part upon upper Carboniferous or Archæan rocks at different points along the shore line.

The western limits of the Sangre de Cristo island may never be accurately determined, for the reason that on this side the basement rocks are now completely concealed beneath the recent alluvial deposits of the San Luis valley and the immense flows of igneous rocks to the north and west of this depression. From observed conditions in the present known exposures of Mesozoic beds in this region, however, it seems probable that it formed a continuous land-mass with the San Juan uplift, and that the Jura-Dakota shore-line bent around the southern end of the present Sangre de Cristo

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\*I regret to say that a locality of critical importance with reference to this movement has not, so far as I can learn, ever been visited by any geologist now living. This is the northwest corner of the Gore mountains where the Mosquito fault, according to the indications of the Hayden Map, after separating the Triassic on the west from the Archæan on the east, is cut off at right angles by Jura-Dakota beds stretching across its path and resting on either formation. The geological outlines there given, however, were laid down by the hand of Mr. A. R. Marvin, who surveyed the region, but whose untimely death occurred before he had written up his field-notes for publication. Experience has given me such confidence in the accuracy of Mr. Marvin's work that I have no hesitation in accepting the essential correctness of these outlines, which are partially confirmed by the observations of Mr. Holmes, who crossed the fault a few miles south of this point, and by those of myself and my assistants, who have traced minutely the Mosquito fault northward to within twenty miles of this point.



range not far north of Santa Fé, and thence ran northwestward across the Rio Grande valley, westward around the head of the present basin of the San Juan river, and again northward across the west flanks of the San Juan mountains at the head of the Dolores and San Miguel rivers, turning eastward again across the heads of the Uncompahgre and other tributaries of the Gunnison.

It is possible that the northwestern extension of the Jurassic land-mass connected with the southern end of the Sawatch island, for all Mesozoic sediments are now wanting between the Arkansas and Gunnison rivers.

The San Juan area was, during the period of elevation, uplifted and eroded in such a manner that along the northwestern flanks the Jura-Dakota beds, which were deposited during the succeeding subsidence, not only rested in distinct angular unconformity upon the edges of the Triassic and upper Carboniferous beds, but overlapped in places onto the underlying lower Palæozoic series. On the southern flanks, however, the angular unconformity is not readily apparent, but the Triassic beds apparently thin out and finally disappear to the eastward of the Animas cañon, having probably been eroded away.

*Sawatch Island.*—The area of the Sawatch island was very largely increased during this movement, not only by the recession of the surrounding seas, but by the actual addition of adjoining areas by dynamic movements. That on its northern extremity has already been mentioned. The uplift of the northern portion of the Mosquito range and of the Gore mountains extended its area to the borders of the Middle park. A thickness of not less than 6,000 feet of beds has been eroded from the crest of the Mosquito range, and, although it cannot be assumed that this was entirely accomplished during the period of elevation, it is evident that enough time must have elapsed to allow of the complete denudation of the northeastern flanks of the Mosquito range where Jura-Dakota beds now rest directly upon the Archæan.

On the west side of the Sawatch there is more definite evidence of the amount of erosion that must have taken place after the upheaval that accompanied this movement. It is in the Elk mountains that this record is now found—a region that was so intensely disturbed in the post-Cretaceous movement that it is now impossible to correctly outline the land area that was added to the Sawatch island, or even to say with certainty that the portions of this region that must have been above water were actually connected with it. It is probable, however, that a ridge extended eastward from the region at the head of the valley of Roaring fork to Treasury mountain, and that another extended southward toward the ancient land-mass at the head of the Gunnison valley, from each of which the Triassic beds, and in some cases a large portion of the upper Carboniferous, were eroded. The best localities for studying the effects of this erosion and the unconformity of



the Jura-Dakota beds with those on which they rest are along the western flanks of the mountains in the present valleys of Slate and East rivers, which flow southeast, and of Rock creek, which flows northwest. Along these valleys the beds are now upturned at a sharp angle and often inverted, and it is by discrepancy in strike alone that the unconformity is shown. Proceeding northwestward from the Gunnison river up the former valleys, the Jura-Dakota beds are first found resting directly upon the Archæan; then on the east side of the valley, neglecting minor irregularities due to local folds and faults, they rest successively on upper Cambrian, Silurian, lower Carboniferous, upper Carboniferous, and, finally, at Copper creek, opposite the town of Gothic, near the head of East river, they rest in apparent angular conformity upon the Triassic "Red Beds." Following the strike further northwestward, the Jura-Dakota contact descends again in horizon, resting upon upper Carboniferous beds and, around the remarkable Archæan protrusion of Treasury mountain, upon lower Palæozoic limestones, now changed to most beautifully variegated marbles. Still further north along the valley of Rock creek, the upper Carboniferous and Trias come successively up to the base of the Jura-Dakota.

In the region along the Grand river and the White river plateau beyond it, which has not been visited by the writer, no unconformity between the Jura-Dakota and Trias is noted by the members of the Hayden survey, though the outlines on their maps are such as to suggest that evidence could be found both of this and of the earlier movement if they were studied to this end.

*Western Region.*—In the broad area south of the Gunnison and Grand rivers, which was a region of comparatively little disturbance in pre-Cretaceous time, no evidence of unconformity was noted by the members of the Hayden survey who visited it. The beds which they classed as lower Dakota in the coloring of their map are, however, the lithological correspondents of the *Atlantosaurus* beds as developed in the Elk mountain region; and Mr. Holmes has recently stated to me that he now considers them to belong below the Dakota and to be probably of Jurassic age.

On the eastern shore-line, at the base of the San Juan mountains, there is a heavy littoral conglomerate and an evident unconformity at the base of the Jura-Dakota, which has been noted also by Mr. R. C. Hills.\* Whether the limestone, which he places below this unconformity and above the red sandstones containing vertebrate and plant remains of Triassic age, should be considered to represent the marine Jura of the Wasatch and Uinta mountains is somewhat uncertain, as no organic remains have yet been discovered in it.

*Northern New Mexico.*—Newberry and Holmes both failed to find any

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\* Am. Jour. Sci., 3d ser., Vol. XIX, June, 1880, p. 490.

Jurassic beds represented in northern New Mexico, although Marcou in his earlier explorations, coming to the region from the east and along a line not visited by either of the others, found beds corresponding to what he had considered as Jurassic in northern Texas. Newberry found Triassic plants in reddish sandstones immediately beneath sandstones which he regarded as Cretaceous, but it does not appear from his published accounts that their relative position was such as to preclude the possibility of a slight unconformity between them.

Further south, in the Zuñi mountains, Dutton found a considerable thickness of sandstones above the "Red Beds" which he regarded as probable representatives of the Jurassic of the Plateau region, although he obtained no fossils from them.

To the eastward, in the region around the southern end of the Sangre de Cristo range, Stevenson found the Dakota Cretaceous to have suddenly thickened to 1,700 feet from the normal development of about 300 feet which obtains with remarkable regularity from a few miles northward along the whole front of the Colorado range, and this thickening seems to have taken place below the sandstone generally recognized as characteristic of the Dakota throughout the Rocky Mountain region. He, also, failed to recognize the Jurassic of Marcou. Newberry, however, thinks to have recognized representatives of the fresh-water Jurassic in northern New Mexico\*.

*Texas and Arkansas.*—Recent geological observations in Texas and western Arkansas show, according to Mr. R. T. Hill,† that the marine Cretaceous beds of that region have been deposited along the southern base of an uplift, as yet imperfectly known, of the Palæozoic rocks, extending from Arkansas westward through Indian Territory and northern Texas, and southwestward into New Mexico. It is not yet definitely known whether early Mesozoic beds are involved in this uplift, so that its formation could be correlated with the Jurassic movement in the Rocky Mountain region, though certain facts render this probable.

The Cretaceous beds are divided by Mr. Hill into an upper and lower series, divided by a land epoch marking a physical as well as a palæontological break. The upper beds deposited since this break show a similar cycle in the character of their sediments with the Cretaceous beds of the Rocky Mountains, with which they are correlated by Mr. Hill, the Lower Cross-Timber (Dakota) being a littoral formation, with basal conglomerate and abundant plant remains. The succeeding beds indicate gradually deepening waters culminating in the Rocky Comfort chalk (Niobrara), and showing evidence of a shallowing sea in the upper series, which corresponds to the

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\*Personal communication.

†Am. Jour. Sci., 3d ser., Vol. XXXVIII, 1889, p. 282.

Fox Hills—representatives of the Laramie not yet having been definitely recognized, possibly through having been eroded away.

Unconformably below these beds come a series of marine beds of lower Cretaceous age, known as the Comanche series, which have been traced through Texas southward into Mexico, the base of which is formed by the Trinity beds, or *Dinosaur* sands, which resemble the *Atlantosaurus* beds of the Rocky Mountain region. These rest unconformably upon the underlying beds, which in most cases thus far observed are found to be of Carboniferous age.

No representatives of the Comanche beds have yet been found in the Rocky Mountain region nor in the Plateau province; but from near the international boundary, in about longitude 115°, the Canadian geologists have traced a series of marine Cretaceous beds stretching northward into British Columbia, known as the Kootanie beds, which are lower than the Dakota Cretaceous. From the plant and molluscan remains found in these beds Mr. George M. Dawson\* regards them as equivalents of the Comanche series (though perhaps not reaching quite as far back in geological time), and of those developed on the Pacific coast in Queen Charlotte's island, and considers that they were once connected with the latter north of the 54th parallel.

*The Great Plains.*—As early as 1877, Dr. White† called attention to the probability of a post-Jurassic subsidence which carried the eastern shore-line of the interior Mesozoic ocean eastward across the Great Plains and permitted the deposition of Dakota beds in central Iowa, which subsidence continued through Fort Benton and Niobrara times, causing a still further eastward extension of the shore-line and a corresponding change in the character of the sediments from shallow to deep water.

Since that time evidence has been found at various points throughout the area of elevation, folding and erosion of the underlying beds previous to this subsidence.

In the Raton mountains, some sixty miles east of Trinidad, Cretaceous beds rest unconformably on steeply upturned Triassic sandstones. North of this, at Fort Lyons, on the Arkansas river, an artesian boring disclosed a slight thickness of Jurassic beds interposed between the Trias and Cretaceous. Further east and north, through Kansas and Nebraska, the Dakota Cretaceous rests in places on Trias, at others on Permian or Carboniferous beds. The chalk beds, which in Texas correspond to the limestones of the Niobrara along the foot-hills of the mountains, have also been found in eastern Kansas, and recently in Nebraska as far west as the 103rd meridian.

*General Conclusions.*—The present distribution of Mesozoic sediments in

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\* Am. Jour. Sci., 3rd ser., Vol. XXXVIII, 1899, p. 120.

† Hayden's Report for 1877, p. 280.

the interior region of our continent shows that there were two principal meridional lines of depression in the earth's surface at that time, the one in the region of the Great Plains to the east of the Rocky Mountain front and the other to the east of the Wasatch uplift, each of which probably extended north beyond the Canadian boundary. The western continent beyond the Wasatch mountains had its greatest east and west extension between the 40th and 45th parallels of north latitude, the Mesozoic ocean extending further westward both to the north and south of this continent and possibly connecting beyond our boundaries with that on the Pacific slope. It is probable, therefore, that in these middle latitudes the general level of the country, as represented by its plains and valleys, was higher than in the more northern and southern regions, the bottoms of the principal depressions having a general slope northward and southward toward the present oceans.

The general elevation that accompanied the Jurassic movement therefore raised the whole interior region above the ocean, while the dynamic movements produced the effects already noticed within the Rocky Mountain region, and also raised a barrier which kept out the waters of the southern ocean, or Gulf of Mexico, from the eastern and partially, or possibly entirely, from the western meridional depression.

During the elevation a fresh-water lake, whose extent is as yet imperfectly defined, accumulated behind this barrier. It filled the valleys of the Rocky Mountain region and extended north as far as the Black Hills. It must have filled a portion at least of the Great Plains depression, but its western shore-line is now buried beneath Cretaceous deposits and may never be accurately defined. The extent of fresh-water Jurassic beds on the south and west of the Rocky Mountain region will, however, probably be determined in future examination of the region. At present it can only be said that fossils apparently belonging to this horizon are said to have been found in northern New Mexico by Newberry on the south, and on the banks of the Green river in Wyoming by Steward, of Powell's party, on the west.

During the gradual subsidence which followed this elevation the barrier was being eroded, and an outlet may have been formed through which the Jurassic lake was drained, so that no further deposition went on in its bed until it was again invaded by the ocean; though, as far as present evidence goes, the subsidence was not sufficient to admit the waters of the ocean within the Rocky Mountain region until Dakota times. Marine waters, however, must have entered the western depression from the north in British Columbia to admit the deposition of the Kootanie series of beds, and it seems not improbable that marine Cretaceous beds below the Dakota may yet be found in the western depression to the south, in the Plateau province.

That a certain amount of erosion of the fresh-water Jurassic beds after the drainage of the lake may have taken place in the Rocky Mountain

region seems probable from their apparent absence in certain sections and from actual proof of local movement and erosion discovered by Mr. Eldridge at Golden, Colorado; but it cannot yet be said that there was a general dynamic movement preceding Dakota time corresponding to that which Mr. Hill assumes to have affected the northern portion of Texas before the deposition of the upper Cretaceous there.

The character of the sediments and of the contained organic remains of the Dakota Cretaceous throughout the whole interior region, however, shows that they were deposited in a slowly advancing ocean during a progressive subsidence of the whole region. This subsidence continued to the middle of the later Cretaceous time, and was followed by an equally gradual elevation, which culminated in the shallow water conditions of Laramie time, when the oceanic waters finally retreated from the interior region even more slowly than they had advanced, never to penetrate it again.

The same general succession or cycle in the character of sediments deposited during later Cretaceous time may be observed throughout the interior region, though a variation is found in the thickness and in the prevalence of coarser or finer materials of the series as a whole, according as they were deposited near elevated land-masses and in narrow bays, or in broader seas at a distance from any considerable land-masses. While the sedimentation during this cycle was essentially conformable and undisturbed in character, a few unconformities by erosion have been observed, which indicate at least local movements about the middle of the period whose extent will probably be increased by future investigations. These are, an unconformity by erosion at the close of the Niobrara Cretaceous observed by G. Eldridge\* at Golden, Colorado; one noted by F. B. Meek† at the same horizon on the Missouri; and a third at Austin, Texas, described by R. T. Hill‡.

The occurrence of lacustrine life in the Belly River and Dunvegan beds in Manitoba may likewise be found to be some way connected with these movements.

*Correlations.*—On the Atlantic border there is direct evidence of an orographic movement which seems to correspond pretty closely in geological time with that just described. The Triassic series of the eastern slopes, which include in places beds that are considered by some to be of Jurassic age, were uplifted, folded, and extensively eroded before the deposition of the succeeding Cretaceous beds. The earliest of the latter series, the Potomac formation, is essentially a shore-line deposit, and though its age is not fully agreed upon, some regarding it as late Jurassic and others as early Cretaceous, it may probably be considered to be the stratigraphical equivalent of the beds first deposited after the Jurassic movement in the Rocky Mountain region.

\* Bull. Philosophical Soc. of Washington, Vol. XI, 1889 (in press).

† U. S. Geol. Surv. of the Territories, Vol. IX: Invertebrate Palæontology. Washington, 1876, p. XXXIII.

‡ Amer. Jour. Sci., 3d ser., Vol. XXXIV, 1887, p. 297.

On the Pacific border of the western or Nevada continent, both stratigraphical and palæontological conditions are much less easily defined. Whitney and King regarded the Jurassic beds of western Nevada, which apparently overlies conformably the Star Peak or Alpine Trias, as of the same age as the auriferous slates which are upturned against the western flanks of the Sierra Nevada, and considered the uplift of the Sierra Nevada as post-Jurassic and contemporaneous with that which folded the Nevada beds. As the Jurassic fauna of the latter corresponds with that of the marine Jura of the interior region, the movement would closely correspond with the Jurassic movement we are now considering.

Later observations by Mr. G. F. Becker\* and Dr. C. A. White† differ in some respects from the conclusions drawn by Whitney and King. They consider the auriferous slates (Mariposa beds) to be palæontologically distinct from the Nevada Jurassic and to be more closely allied to the Knoxville beds of the Shasta group. Dr. White is not fully decided as to their age, but is inclined to place them in early Cretaceous (Neocomian) or late Jurassic. The Chico-Téjon beds, which rest unconformably upon the Shasta group, he considers as in part very latest Cretaceous (in this confirming Mr. King's earlier view) and in part early Eocene. While Mr. Becker does not commit himself definitely to a statement of the change in previous orographical views which this would involve, doubtless because he was on the eve of obtaining further and more decisive data from his proposed detailed study of the auriferous slates of California, he evidently foresees the necessity of some such view as the following, if future investigation confirms the conclusions then reached by Dr. White and himself. This is, that an uplift of the Sierra Nevada region occurred at the close of the Nevada Jurassic which permanently excluded the ocean from western Nevada and established the shoreline of the Mariposa beds and their contemporaries west of the crest of the Sierra Nevada, and that the movement which upturned these beds and produced the main uplift of the Sierra Nevada occurred in Cretaceous times previous to the deposition of the Chico-Téjon series and hence may prove to have been closely related to the great post-Laramie movement of the Rocky Mountain region.

It is an interesting coincidence that in Europe, also, there occurred an orographic movement in Jurassic time, in consequence of which, according to the generalizations of Suess‡ and Neumayr,§ the sea retreated entirely from the middle regions of Europe, where toward the close of this period only fresh-water sediments were deposited, and not until Cretaceous time did marine forms again appear.

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\* Bull. No. 19 U. S. Geol. Survey, Washington, 1885.

† Bull. No. 15 U. S. Geol. Survey, Washington, 1885.

‡ *Antlitz der Erde*. II Bd., Wien, 1888, p. 350.

§ *Erdgeschichte*. II Bd., Leipzig, 1887, p. 387.



## THE POST-CRETACEOUS MOVEMENT.

The post-Cretaceous movement, as has been almost universally recognized, was that which produced the main plication and faulting and played the most important part in determining the present orographic features of the Rocky Mountain region. But, as it is evident that these features had been in a great extent already outlined in the movements that went before, it is also more than probable that the post-Cretaceous folds and faults have been further emphasized along the principal lines of disturbance in the less violent movements that have affected the region since, even into very recent times. It is therefore manifestly impossible to determine with absolute accuracy how much of the present displacement of Cretaceous beds in folds and faults was produced in the first post-Cretaceous movement and how much in those that have supervened in Tertiary and Recent times. That during this movement the tangential thrust or force of compression was very intense is proved by the fact that in very disturbed regions the upper beds of a series, upturned against the flanks of an ancient island, often stand at steeper angle than the lower beds of the same series, producing thus something similar to the fan structure observed in the Swiss Alps.

The character of the sediments deposited during the periods immediately preceding this movement, which show gradually shallowing waters during the Fox Hills period, culminating during the Laramie in an entire change of its fauna through brackish-water into fresh-water forms, indicates a gradual elevation of the land until barriers similar to and perhaps more or less corresponding with those formed during the Jurassic movement cut off the whole interior region from the ocean. It might naturally be expected that during such elevation the shore-lines of succeeding stages would recede somewhat, and such Dr. White\* states to have probably been the case with the eastern shore-line of the Cretaceous ocean in the Great Plains depression, which, he considers, after reaching its greatest extension during the Niobrara was carried westward during late Cretaceous times. In the Rocky Mountain region, where erosion and denudation have naturally been greater than in the plain regions, it is more difficult to determine the original extent of the beds last deposited previous to the orographic movement, since these were necessarily the first to suffer abrasion and denudation, which would have carried their outcrops further back from the original shore-line of the continental islands than those of the subjacent beds. Still, some idea of the probable extent of the Laramie deposits can be formed by considering to what extent they still occupy the great valley depressions formerly covered by the Cretaceous seas, since there denudation would have been less uniform and thorough than on the mountain slopes and ridges.

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\* Hayden's Eleventh Report (for 1877), p. 260.



*Laramie Land.*—At the present time, within the mountain area roughly defined by the east flanks of the Colorado range on the east, by the Laramie plains, the Park range, White river plateau, and Elk and San Juan mountains on the west, and by the southern flanks of the San Juan and Sangre de Cristo ranges on the south, no beds of the Laramie or coal-bearing formation proper are known with certainty to exist, except in the South park. The beds which form the dividing ridge between the North and Middle parks, and which were colored on the Hayden maps by Marvine as of Laramie age, were so determined solely on the evidence of fossil plants, in spite of their unconformity with Cretaceous rocks below and their want of lithological correspondence with the Laramie beds developed elsewhere in Colorado. In North park Mr. Marvine discovered, in beds which he referred also to the Laramie group, though without expressing any opinion as to their stratigraphical equivalence with the Middle park beds, a few molluscs, of which Dr. White, after an examination of all the evidence both in field and office, says: "Of themselves they are not sufficient to determine the age of the strata containing them or their equivalency or otherwise with those of the Laramie group."\* A recent examination of these Middle park beds made under my direction by one of my assistants has satisfied me that they were deposited after the post-Cretaceous movement, and that if Laramie beds proper were ever deposited in the Middle park they have since been removed by erosion. As in the adjoining South park Laramie beds still remain under very similar physical conditions, there seems to be some reason for assuming that the Laramie shore-line did not reach as far south in the Middle and North park depression as did that of the earlier Cretaceous seas in which case the bay in which the South park Laramie was deposited must have had its connection with the open sea by way of Cañon City.

In Huerfano park, which forms the southern end of the Wet Mountain valley depression, Laramie beds still underlie unconformably the Eocene Tertiary deposits which Mr. R. C. Hills has recently discovered there, but it is not probable that they ever extended much further north in this depression than the present divide.

No Cretaceous deposits whatever have been found in the depression of the San Luis valley, and if this depression, as I assume on confessedly rather indefinite grounds, was formed, like the valley of the upper Arkansas, by post-Cretaceous displacements and recent erosion, the Cretaceous seas did not cover it at all, except possibly the extreme southwestern border now buried beneath recent eruptive rocks.

On the western edge of the mountains, on the other hand, the great area of the Uncompahgre plateau and the valleys of the Gunnison and lower Grand river, from which the upper Cretaceous beds are now almost entirely

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\* Op. cit., p. 203.

absent, was probably to a great extent covered by the Laramie deposits, which may also have covered a great part of the present area of the Elk mountains and of the White river plateau.

On this method of reasoning, therefore, it would appear that already in Laramie time the ocean waters had in great measure receded from the interior portion of the Rocky Mountain region which they had occupied in the earlier part of the Cretaceous period, but that this recession was accompanied by no dynamic movements. These movements were initiated only after the coal-bearing Laramie beds had been deposited, and whatever sediments were formed in the region after these movements were laid down in lacustrine waters.

*Date of the Movement.*—I have spoken of this movement as post-Cretaceous, although, as occurring at the last stage of that series, it might more strictly be called post-Laramie. Twenty years ago the former term might have been objected to as fixing too early a date for the movement; to-day there seems to be some danger of a similar objection being made to it on the ground that it implies too late a date. All geologists are more or less familiar with the controversy which existed so long as to the age of this important formation, which carries almost all the economically valuable coal deposits of the Rocky Mountain region. It arose mainly from the fact that in the earlier explorations fossils were brought in from widely separated districts whose stratigraphy under the circumstances could not be exhaustively studied; hence correlations had necessarily to be made on palæontological evidence without that accurate knowledge of the stratigraphical succession and structural relations of the beds in question which is an indispensable basis for the correct determination of horizons in a new geological field. The determinations made by various classes of specialists under these conditions presented a wide range for the same series of beds. By the vertebrate palæontologists the Laramie was considered without doubt of Cretaceous age. From a study of its molluscan remains opinions varied between Cretaceous and Tertiary, with a decided leaning toward the latter; while the palæobotanists assigned some of its beds to the Miocene and others to the upper Eocene, the former being in actual stratigraphical position nearest the base of the series.

The geologists of the Fortieth Parallel, who first introduced in the western mountain region systematic examinations of continuous areas based on topographic maps of these areas, after following Laramie outcrops in a belt one hundred miles wide across eight degrees of longitude, found that stratigraphically and structurally it belongs to the Cretaceous, forming the closing phase of a continuous sedimentation through that period, and being followed by the most marked physical break since that at the close of the Archæan.

Professor L. F. Ward\*, in his historical review of the opinions held in regard to the Laramie group, seems to regard the point of view assumed by Mr. King in summarizing the evidence on this subject as puerile; nevertheless I am convinced that much of the confusion that has obtained in the minds of palæontologists in regard to the proper position of these beds in the geological column would have been avoided had they possessed an accurate knowledge of the stratigraphical relations of the beds of each locality from which their fossil evidence was obtained.

No one has done more to reconcile the opposing views and clear up this confusion than Dr. C. A. White, who has combined in his work the qualities of the structural geologist with those of the palæontologist. In his recent review of the North American Mesozoic† he says:

"The formations which overlies the Laramie were, by common consent, long ago regarded as of Tertiary age; but concerning the age of some of them, differences of opinion have since arisen. Between the Laramie and any overlying formation there is often, but not always, unconformity. In Utah, and apparently in the valley of the Yellowstone also, I have found the Laramie passing gradually up into purely fresh-water deposits without any stratigraphical break. In the former case I am sure, and in the latter case I believe with Professor Newberry, that the upper strata represent the lower part of the Wasatch group."

Without knowing more about the locality referred to than is here expressed, I should not consider, from a stratigraphical standpoint, that this disproved in any degree the unconformity, and the orographic movement which that implies, between the Laramie and the Wasatch; since in the broader depressions away from the immediate vicinity of a line of disturbance the succeeding beds, even after a physical break, may be expected to be found quite conformable with those below them. As regards continuance or non-continuance of certain forms of life across such a break, I do not wish to invade the province of the biologist in offering an opinion, but would merely suggest that the probable persistence of land areas of some kind throughout the various orographic changes that have occurred in this region, which I have here insisted on, would seem to be of some importance in explaining survivals here which are unusual in other regions.

As regards the coal-bearing Laramie in the Rocky Mountain region, which I have hitherto spoken of as the Laramie proper, it has now been examined more thoroughly than any other formation on account of its economic importance, and those who have carefully studied it in one locality find no difficulty in recognizing it in others, in spite of local variations in character of sediment and thickness of beds. Its exact relation to the beds which have been deposited upon it since the movement in question are, however,

\* Synopsis of the Laramie Flora: Sixth Ann. Rep. Director U. S. Geol. Survey, Washington, 1886.

† Proc. A. A. S., Vol. XXXVIII, Aug., 1889.

often obscure in a given section, and can only be accurately determined by a careful stratigraphical study of a considerable area. This is well illustrated in the case of the Denver region, of which a most exact and detailed survey has been made recently under my supervision by Messrs. Cross and Eldridge. They have shown that, since the movement at the close of the Laramie proper, there have been deposited upon its eroded surface two succeeding series of beds, of a thickness of 800 and 1,400 feet respectively, called the Arapahoe and Denver formations, the former of which was uplifted and eroded before the deposition of the latter. The great length of time that must have elapsed subsequent to the post-Cretaceous movement is proved by the fact that the Arapahoe formation is made up of material recognizable as derived from different horizons of the 14,000 odd feet of Mesozoic beds upturned by it, including the Laramie. It is further emphasized by the composition of the beds of the Denver formation, which are largely, and in their lower portion almost exclusively, made up of débris of a very great variety of andesitic rocks, none of which could be found in the lower beds and the source of which has not yet been discovered in the adjoining regions, showing that the interval must have been of sufficient length to admit of the outpouring of a great variety of andesitic rocks and of their almost complete denudation before the close of the Denver period.

In earlier examinations of the region, on account of the peculiarly complicated structural conditions, all these beds had been assumed to belong to one conformable series, and the plants collected from the Laramie beds and from the Denver beds above are indiscriminately designated by Professor Ward, in his Synopsis, as "from the Laramie at Golden," although I had previously called his attention to our discovery of the unconformity, and pointed out the differences in the matrices of the respective specimens in his collections.

With regard to the age which would properly be assigned to these later beds from a palæontological point of view—that is, as determined by the general laws of succession of animal and plant life, which the present knowledge of the development of life in Mesozoic and Tertiary times in other parts of the world have led biologists to make,—there exists considerable uncertainty. Of the organic remains thus far discovered neither plants nor invertebrates can be considered of sufficient taxonomic value to afford decisive evidence as to their Cretaceous or Tertiary age. The vertebrate remains, on the other hand, present the nearest analogy to a recently described vertebrate fauna, assigned by its discoverer to the Laramie Cretaceous. No published evidence exists of the stratigraphical or structural relations of the beds in which these occur; only the bare statement of the author that they belong to the Laramie. Furthermore, it is known that some of the beds, whose fauna is said by palæontologists to have a Laramie facies, are dis-

tinctly fresh-water and separated from the Laramie proper, or, as they designate it, "the lower Laramie," by a physical break; and this I have reason to believe is the case in at least one locality where the vertebrate fauna, which that of the Denver beds most resembles, has been found.

*Conclusions*—In no region can the palæontologist afford to neglect the evidence of stratigraphy and geological structure, and this is especially true in a new and extremely complicated region like the Rocky Mountains, where already the succession of life has been found in certain horizons to vary quite markedly from the laws previously established by studies in Europe and the east. The stratigrapher, on the other hand, must necessarily depend on the palæontologist for such determinations of the relative age of his horizons as will enable him to establish correlations between different series of beds between which there may exist stratigraphical or geographical gaps or hiatuses.

For the accumulation of material essential for true and complete geological history of a given region it is therefore necessary, not only that each should freely furnish the other with all the facts he has determined from his particular standpoint, but also that he should draw his conclusions, not from that standpoint alone, but give due weight as well to the evidence afforded from the standpoint of his collaborator.

It is in pursuance of this idea that I have laid stress upon the importance of the movement at the close of the coal-bearing Laramie in the Rocky Mountain region; and I desire to protest against what seems to be a tendency among those who are studying the palæontology of the region to give little weight to it, or even to neglect it altogether in their determination of horizons. It is unquestionably one of the most important events in the orographical history of the entire Cordilleran system. With the exception of the great unconformity between the Archæan and all overlying sediments, which is a phenomenon *sui generis* and altogether exceptional, no movement has left such definite evidence as that which followed the deposition of the coal-bearing rocks, to which the name Laramie has by universal consent been applied. Against the positive testimony of nearly horizontal beds of Eocene or later age actually overlapping the edges of more or less steeply upturned Laramie beds, found in so many and in so widely separated portions of the region, the negative evidence of conformity of angle between these beds in other localities has absolutely no weight at all.

It is further a fact universally admitted that while the beds deposited previous to the Laramie were marine, all deposited since that period were essentially fresh-water sediments. Now, it is known that land and fresh-water molluscs are of little value as indices of the passage of geological time. It seems reasonable, moreover, to assume that, in a region where land surfaces have existed throughout the orographic movements, fewer extinctions or

changes in plant life would be produced in the progress of geological time than where such movements produced an entire submergence of adjoining land areas. Hence it is to the successive changes in vertebrate life that we must look for the most definite palæontological evidence of the lapse of geological time.

Palæontologists tell us that, between the vertebrate fauna of the lowest Eocene beds yet studied in this region and that of the Laramie, there is an important gap in the normal succession of life that remains to be filled. It is now over fifteen years since Mr. King stated from the evidence then available that no Eocene beds existed on the eastern flanks of the Rocky Mountains, and this statement has held good until within the last year, when an extensive series of beds, over 7,000 feet thick, discovered by Mr. R. C. Hills at Huerfano park, on the eastern flanks of the range, have been determined to be in part of Eocene age, though they have not yet been sufficiently studied to determine their entire vertical range in the geological column. These beds overlap the upturned edge of the Laramie beds, as do, or did before removal by erosion, the Arapahoe and Denver beds already alluded to. It is probable that, as special investigations to this end are made, other series of beds, occupying an intermediate position between the lowest Eocene now known in the region and the coal-bearing Laramie, will be discovered; and it may be hoped that in time the gaps in the succession of life may be filled. From the nature of things it will probably be a long time 'ere such a complete knowledge of the succession of fauna can be obtained. These later beds were of limited and local extent, they have been but imperfectly consolidated since their deposition, and, being the first to be affected by Tertiary erosion, they exist now only in fragmentary patches; hence it requires such minute and detailed study to determine their true stratigraphical relations as in the present stage of geological investigation in this country can seldom be accorded to them. Hence all determinations of succession of life based on palæontological evidence alone, must for a long time be provisory. It would seem, therefore, to be illogical, when there is an apparent conflict between the definitely determined physical evidence of an orographic movement and that afforded by analogy with the laws of succession established in other parts of the world, to allow the former to be neglected or even to be outweighed in making such provisory determinations.



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## Orographic Movements in the Rocky Mountains

S. F. EMMONS

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## Notes

