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CHARLES D. WALCOTT, DIRECTOR

GEOLOGY

OF THE

DENVER BASIN

IN

COLORADO

BY

SAMUEL FRANKLIN EMMONS, WHITMAN CROSS
AND GEORGE HOMANS ELDRIDGE

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LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Washington, D. C., January 22, 1896.

Sir: I have the honor to transmit herewith the manuscript of a report upon the geology of the Denver Basin of Colorado.

Although this work was undertaken at my suggestion and has been conducted under my supervision and direction, the actual field work has been carried on chiefly by Messrs. Whitman Cross and George H. Eldridge, by whom, as will be seen, the greater part of the manuscript has been written.

Various causes have combined to delay the publication of this material, among which was the desire to obtain further light on certain important paleontological points. You have wisely decided that this publication should be delayed no longer.

Very respectfully, your obedient servant,

S. F. Emmons, *Geologist.*

Hon. Charles D. Walcott,
Director United States Geological Survey.

PREFACE.

To account for what might otherwise appear as an unnecessary and unwarrantable delay in the publication of the material comprised in the accompanying volume, it is needful to give a somewhat detailed history of the work since its inception.

While the office of the Rocky Mountain division was still located at Denver, and after the completion of the field work for the monograph upon Leadville, it seemed wise to have some work in progress which could be carried on during seasons when that in the high mountains was rendered impracticable by snow, and which might serve to occupy such moments of leisure as members of the corps might have in intervals of more important economic work. With this view authority was obtained from the Director to have Mr. Whitman Cross make a study of the basaltic mesas at Golden, Colo., and of the zeolitic minerals known to occur there. This work was carried on at convenient intervals in other work from the autumn of 1881 to that of 1883, when the mineralogical results were published in the American Journal of Science.[1] Incidental to this work it was discovered that a series of beds occurring there which had hitherto been considered part of the coal-bearing Laramie formation were distinctly unconformable with the latter and separated from it by a long geological time interval. To these was given the name Denver beds. This discovery was of far-reaching importance both from a strictly scientific and from an economic point of view. Upon the correct and final determination of the age of these beds depended not only the accurate fixing of the age of the Rocky Mountain uplift and of the line between Cretaceous and Tertiary formations in general, but also the means of recognizing the coal-bearing

[1] Am. Jour. Sci., 3d series, Vol. XXIII, 1882, p. 452; ibid., Vol. XXIV, 1882, p. 129.

horizons throughout the whole Rocky Mountain region wherever they had not yet been developed by actual mine workings.

It was therefore judged wise to extend the scope of the work to an accurate and detailed study of the geology and economic resources of the Denver Basin area, which would thus serve as a type of many similar basins along the eastern front of the Rocky Mountains. For such work an adequate topographical map was a necessary preliminary. It was at first supposed that the enlarged Hayden map, corrected by data from Land Office and railroad surveys, would be sufficiently accurate for the purpose, but as the work progressed and the complexity of the geological structure became more and more apparent frequent revisions had to be made, first by topographers as they could be spared from other field work, and finally by the geologist himself. Mr. Eldridge commenced his study of the Mesozoic rocks of the region in November, 1885, and remained in the field almost continuously, except when driven in by stress of weather, until March, 1887. In 1888 papers were published in scientific journals by Messrs. Cross and Eldridge discussing the principal orographic movements deduced from the stratigraphic study of the field, and their bearing upon the age of the Denver beds, for the purpose of calling the attention of paleontologists and of geologists working in other fields to the conclusions which it seemed legitimate to draw from these studies, that they might be led to contribute facts which would confirm or oppose these conclusions.

Mr. Eldridge's extremely detailed field work necessitated a correspondingly extended study in the office and laboratory, and owing to the interim nature of the work he was interrupted before its completion to compile coal and artesian maps for the Director and to undertake an economic survey of Florida, which could be done only in winter, in the months usually devoted to office work. The delays in the publication of the work which have been thus occasioned have not, however, been entirely disadvantageous, for they have resulted in the discovery of formations similar to the Denver in other regions, notably the Livingston beds of Montana, and in the revision of the old and the addition of much new faunal and floral evidence on the basis of the corrected stratigraphy. Although upon the question of the absolute age of the Denver beds paleontologists are not yet entirely in harmony with stratigraphers, the delay has enabled us to put our evidence on such a basis of undisputed facts that a final agreement can be only a question of time. While the economic data have lost somewhat in freshness from the protracted delays in publication, due first to one cause and then to another, it is believed that this is more than offset by the increased definiteness which has accrued to conclusions upon various disputed points, and that the work will serve, as it was intended, to illustrate the structural and economic conditions which govern not only the limited area mapped, but also, to a greater or less extent, that of the entire plain belt at the east foot of the Rocky Mountains. It presents the fruits of the labors of several individuals not mentioned on the title-page, and acknowledgments are due to Mr. F. H. Knowlton for a chapter on the flora of the Denver beds, to Prof. O. C. Marsh for one on the vertebrate fauna of the field, to Mr. George L. Cannon, jr., for investigations of the Pleistocene formations, and to the latter and Prof. Arthur Lakes for collections of vertebrate and plant remains from the Denver beds; also to Messrs. C. S. Slack and P. H. van Diest for collecting data with regard to the location, depth, etc., of artesian wells, which have been freely used in this report. To the many mine superintendents, foremen, and others, too numerous to mention by name, who have given in the most generous manner facilities and information in furtherance of the objects of this work, thanks are also tendered.

S. F. Emmons.

GEOLOGY OF THE DENVER BASIN IN COLORADO.

By S. F. Emmons, Whitman Cross, and George H. Eldridge.

CHAPTER I.

By S. F. Emmons.

GENERAL GEOLOGY.

PHYSIOGRAPHY.

The area specially treated in this report is the portion of the foothill belt of the Great Plains lying between the meridians of 104° 37′ and 105° 20′ west longitude and the parallels of 39° 30′ and 40° 27′ north latitude. The extent of the area is about 1,000 square miles. The South Platte River, which debouches from the mountains just beyond the southern boundary of the area, crosses it diagonally to its northeastern corner, receiving in its course two tributaries from the mountains on the west and a few from the mesa region to the southeast.

Not only does the present surface constitute a topographical basin, but, as will be seen later, a still better defined basin exists in the rocks which form its substructure. The city of Denver, situated on the banks of the Platte, occupies a central position in this area, and it has therefore been named the Denver Basin.

In its broader geological and topographical features this area may be taken as a type of that portion of the Great Plains which immediately adjoins the eastern front of the Rocky Mountains within the State of Colorado, and which may be denominated the foothill belt. A description may therefore appropriately treat first of the general characteristics of the whole belt, and then of the details peculiar to the special area under consideration.

The whole region is remarkable for the intimate dependence of topographical form upon geological structure. To such an extent is every detail of topography founded on some underlying geological cause that the field geologist saves much unnecessary labor by drawing his general deductions from the larger and more characteristic features, and by looking for variations from the general rules of geological structure thus determined only where some peculiar variation from the characteristic type is found in the topographical form.

The region described comprises three distinct types of topographical structure: (1) mountain slopes; (2) foothills proper; (3) plains.

MOUNTAIN TOPOGRAPHY.

The mountain topography is necessarily much older than that of the foothills or the plains, since not only the sediments of which the latter are composed, but also the waters which have carved them into their present form, have been derived from the mountain region. It is therefore necessary to consider briefly the topographical structure of the entire mountain area in so far as it has had any influence upon that of the foothills or the plains.

The eastern front of the Colorado Range has a general north-and-south trend; that is, this is the general direction of its prominent mountain faces. What might be called its shore-line, however, or the line which marks the junction of the sedimentary beds deposited along its flanks with the complex of crystalline rocks that constitute the mountain mass, is far from straight in detail. The striking feature of its divergence is the tendency to form loops or bays opening out to the southeast. The most prominent of these loops or bays are that to the south of Pikes Peak in which Canyon City is situated and that called Huerfano Park, still farther south, between the Greenhorn or Wet Mountains and the Sangre de Cristo Range. One less prominent in the present topography is that at Manitou, north of Pikes Peak. The shore-line in the Denver Basin area forms part of a shallower loop, and has a trend N. 20° W. as far north as Boulder Canyon, beyond which it assumes a general direction N. 15° E. to the next projecting headland between the Thompson and Cache le Poudre rivers.

In Paleozoic and Mesozoic times these indentations or bays formed a much more prominent feature in Rocky Mountain topography than at present, when they have become partially effaced by the sedimentation and subsequent erosion which accompanied the successive subsidences and elevations. Their orographic significance is hence much greater than would appear at first glance. They show that the broader features of the present mountain structure were blocked out in very early geological time, and though these features have been modified locally by successive orographic movements and outflows of eruptive rocks it is upon them that the present drainage system is primarily dependent.

The present eastward-flowing drainage of the Rocky Mountains follows two great river systems, the Arkansas and the Platte. These streams all take their rise to the west of the main crest or Front Range of the Rocky Mountain system, and drain, respectively, one or more of the great interior valleys, which are a characteristic feature of its topography.

The upper valley of the Arkansas is the most westerly and also, in geological structure, the youngest of these interior valleys. The present Arkansas River is not, however, necessarily of younger formation than the two main branches of the Platte, which drain the older depressions of the South and of the North Park, respectively. After following in a southerly direction the entire length of the Upper Arkansas Valley, which was blocked out in late Mesozoic time, the present stream bends abruptly eastward, cutting deep canyons of comparatively recent formation through preexisting ridges, the most remarkable of which is the Royal Gorge, 3,000 feet deep, and receives through Grape Creek the drainage of Wet Mountain Valley, which formerly went out in a southeasterly direction through Huerfano Park. The location of this easterly course of the present stream must have been originally determined at some time during the Tertiary era, but a very large portion of the gorge cutting, especially in the lower part of its course, must have been accomplished since the Glacial epoch.

At various periods during Paleozoic and Mesozoic time the South Park depression was connected directly with the ocean, probably through the Canyon City Bay. This connection was broken during the period of orographic movement and volcanic activity that followed the deposition of the Laramie coal measures at the close of the Cretaceous. Subsequent to this period, but at how late a date in the Tertiary it is not yet possible to determine, a new drainage channel for this interior valley was started across the mountains in a general northeasterly direction, which has since developed into the canyon gorges of the South Platte River. Here, as in the Arkansas Valley, a considerable portion of the gorge cutting, especially in the lower part of the valley, is demonstrably more recent than the Glacial epoch, or the period of greatest extent of ice covering over the high mountains.

The Middle Park now drains westward through the Grand River to the Pacific, but was during Mesozoic time a nearly continuous depression with the adjoining valleys of South and North parks. The latter is drained by the north fork of the Platte River, which circles round the northern end of the Colorado mountain-system. Hence, neither forms any essential part of the region under consideration. Of the date of this stream it can only be said that its gorge cutting is distinctly later than beds which have been assumed to be of Pliocene age.

The mountain slopes immediately facing the plains appear, to an observer regarding them from a distance, to rise abruptly out of the sea, as it were, in one continuous but rugged slope. A closer examination shows that while the spurs immediately adjoining the shore-line are abrupt, and the intervening gorges deep and narrow, these spurs, after reaching a certain height, slope back more gradually toward the main crest, which lies unexpectedly far back; that the mountain forms are generally smooth and rounded, and that the valleys become wider and more open with increasing elevation. Pl. VI, a photographic view looking westward from Coal Creek Peak across the valley of Upper Coal Creek, shows the region intermediate between the foothill slopes and the crest of the range, with its characteristic rounded slopes and open valleys. The topographical form of the interior region above a given elevation suggests that it has been exposed to secular

VIEW WESTWARD FROM COAL CREEK PEAK ACROSS THE VALLEY OF UPPER COAL CREEK

disintegration and abrasion much longer than that immediately adjoining the foothills, and that its drainage systems are necessarily of more ancient date. The mountain forms in general show the rounded features characteristic of massive and easily disintegrated rocks, in contrast to the more rugged forms produced by the weathering of steeply upturned sedimentary beds of varying degree of hardness.

The contrast between these forms and those of the foothill region is everywhere so sharp and distinct that the line dividing the older from the more recent geological formations of which they are respectively composed could be quite accurately determined at a distance or drawn on a correctly constructed topographical map with extremely small probable error.

FOOTHILL TOPOGRAPHY.

The foothill region is a belt of sedimentary beds upturned at steep angles against the mountain slopes. The most characteristic feature of its topography is formed by the hogback ridges of harder upturned beds, which stand like a fringing reef at a little distance from the shore-line or base of the mountain slope. Within these ridges are narrow longitudinal valleys eroded out of the softer beds beneath the more resisting sandstones or limestones which form the hogback ridges. Where the harder beds rest directly upon the crystalline rocks of the mountain slopes, or the upturned edges of the Mesozoic beds are still covered by overlapping horizontal beds of Tertiary age, or where, again, through faulting or any other cause, the Mesozoic beds themselves still lie in a nearly horizontal position in contact with the underlying complex of crystalline rocks, the hogback ridges may be wanting. Still, the breaks in their continuity are in general of so limited extent that the foothill belt can nowhere be followed for any great distance without meeting them, if not in typical development, at least in some modified form of fringing reef.

In the Denver Basin area the hogback is found to extend in most perfect form from the southern boundary of the area nearly to Table Mountain, a continuous knife-edge ridge of Dakota sandstone or quartzite, broken only by the narrow gorges of the mountain streams; with a valley behind, separating it from the mountain slopes, as regular and continuous as any coast lagoon or sound within a sand bar or fringing reef. At Golden the hogback is wanting for a few miles, by reason of structural causes to be explained later. It is resumed again opposite North Table Mountain and continues with a few unimportant breaks, due in every instance to some readily explainable geological cause, nearly to Boulder, where is again a gap due to structural causes similar to those operative at Golden.

In all this area the hogback ridge, when typically developed, is formed by hard sandstones or quartzites of the Dakota formation upturned at an angle of 45° or more, which are underlain by clays and easily eroded argillaceous sandstones. The variations from this type and the causes therefor may be explained in detail as follows:

The disappearance of the hogback at Golden results from the nondeposition of the more resisting sandstones and of the easily eroded sediments beneath, caused by an arching or bowing up of the sea bottom at this point during the time of sedimentation. A similar cause, combined with the subsequent leveling off of the surface by Pleistocene detritus washed down from the mountains, accounts for the disappearance of the hogback in the immediate vicinity of Boulder, near the northern edge of the area mapped. At Coal Creek, on the other hand, the hard Dakota sandstone is present, but it rests directly on a projecting boss of granite, with no intervening softer beds by whose erosion the hogback valley might be carved out and thus separate it from the underlying Archean. Immediately north of this point the hogback valley reappears with the recurrence of the softer clays below the Dakota.

The prominence of the Boulder peaks, which is a striking feature in the foothill topography, is due to a series of north-and-south thrust faults, combined with a tendency to the échelon structure before alluded to, or the formation of minor folds oblique to the direction of the range and pitching southeastward under the plains. A more evident instance of the échelon fold and its influence on foothill topography is found immediately north of Ralston Creek, which has resulted in the offset to the eastward of a portion of the hogback ridge.

Pl. VII is the reproduction of a photographic view, looking southeastward from Ralston Peak, on a line with the axis of this échelon fold, which

VIEW SOUTHEASTWARD FROM

PEAK, ALONG BASE OF FOOTHILLS.

VIEW SOUTHEASTWARD FROM R[illegible]TON PEAK, ALONG BASE OF FOOTHILLS.

well shows the typical features of foothill topography. In the immediate foreground are outcrops of Wyoming red sandstones resting upon the Archean, and just beyond them, over the tops of the trees, can be seen a rounded hill formed by the échelon fold in the Dakota sandstones. To the left of this is a long, narrow ridge of basalt, known as the Ralston dike. Ralston Creek, issuing from the Archean area in the lower right-hand corner of the view, flows first southeast, then bends sharply east, cutting through the Wyoming sandstone ridge, and, curving round the hill of Dakota sandstone, takes a northeasterly course to the plains around the north end of the Ralston dike. In the middle distance are the Table Mountains, with Green Mountain beyond, seen over their western point. Between them and the foothills of the range can be distinguished the long line of the main Dakota hogback, whose continuity is broken at Golden, in the valley of Clear Creek, and which in the foreground of the view is offset to the eastward by the échelon fold.

Instances of horizontal Tertiary beds overlapping the upturned edges of the Mesozoic strata do not occur within the Denver Basin area, although topographically the Table Mountains and Green Mountain somewhat approach this type of structure. They are, however, no longer in actual contact with the mountain slopes, but are separated from them by a valley of erosion.

PLAINS TOPOGRAPHY.

The topography of the plains area is that characteristic of a series of recent and easily degraded horizontal beds long exposed to subaerial erosion in a semiarid climate.

It is a region of broad, shallow valleys with gently sloping sides, the higher ridges being plateaus or mesas whose surface is formed by some harder or more resisting stratum. The lower ridges within the basin areas have also the mesa structure wherever they are capped by a harder stratum, but when composed of homogeneous and comparatively yielding material they have softly rounded outlines. The stream bottoms between are wide and shallow, and sometimes are bordered by indistinct terraces.

The whole area in Colorado is divided by the erosion of the Arkansas and Platte rivers and their tributaries into two shallow basins, each nearly

150 miles wide on a north-and-south line. The divides between these basins and those on the north and south, respectively, are flat-topped ridges, sloping gently eastward from the foothill region and having average elevations 2,000 to 3,000 feet above the lowest points of the basins.

The more enduring beds which form the divide south of the Arkansas Basin are the basal sandstones of the Laramie, capped to a considerable extent by still harder sheets of basalt. The Arkansas Basin itself is largely eroded out of the clays of the Middle Cretaceous. The Arkansas-Platte divide is formed of the conglomerates and coarse sandstones of the Monument Creek series, in part capped by beds of rhyolitic tuff. The South Platte Basin is largely eroded out of the clays of the Upper Laramie and later formations, and the divide to the north, between it and the North Platte, consists of Miocene limestones and conglomerates of Pliocene age.

Within these basins the details of the topography are dependent on more recent geological phenomena. Thus, in the Denver Basin area, which occupies the southern half of the South Platte Basin, while the broader outlines of its topography were roughed out in Tertiary time, these have been more or less effaced by Pleistocene deposits of river drift and loess, upon the subsequent erosion of which the present details of its topographical form are mostly dependent.

Relics of the older topography of this region may be distinguished in the mesa-topped spurs of the Arkansas-Platte divide, only the extreme points of which appear within the area of the map, but which are characteristically developed in the vicinity of Castle Rock, just south of that area. Green Mountain and the twin mesas known as the Table Mountains, near Golden, are other features which have not been essentially changed since the Tertiary erosion.

In the more modern features are to be recognized remains of a series of terraces, some of which are undoubtedly ancient river terraces of a period of earlier Pleistocene erosion, others being apparently lake terraces, formed in a sheet of water of lake-like dimensions, which occupied the area subsequent to this period.

The most prominent river terrace is that along the east side of the Platte River. Its surface is uniformly horizontal or with a slight slope toward and down the river. The present stream has carved its channel within this terrace, its flood-plains being about 30 or 40 feet below the ancient terrace. The ancient terrace is with difficulty distinguishable along the west bank of the Platte. Similar but less prominent ancient river terraces are found along Clear and Bear creeks, but are wanting along the streams entering the Platte from the east, where the topographical forms are those of simple modern erosion.

The lake terraces are more prominent in the northwestern portion of the area mapped, owing probably to its having been less deeply cut away by modern erosion. They are particularly well marked in the area between Ralston and South Boulder creeks, where there is a blending of lake and river terraces. Here five distinct terraces are traceable, the lake terraces extending from 100 yards to 3 miles eastward from the foothills, while those more distinctly of stream origin are but from 200 to 700 feet in width.

In the southern half of the area, the conditions for their preservation being less favorable, the remains of the lake terraces are less continuous, being found here and there on the flanks of the hogback and on the granite slopes within the hogback valleys. Above the 6,000-foot contour there is a frequent recurrence of terrace remains along the foothills and on the flanks of Green Mountain, but they are not found against the Tertiary bluff along and beyond the southern border of the area mapped.

The influence of faulting upon the topography of the plains is less evident than might have been expected. No doubt much of its effect has been obscured by more recent formations, deposited since the faulting took place. Nevertheless, it is readily observable that in the northern part of the area the trend of the leading topographical features has a northeasterly direction, which is also that of the greater faults that have been detected in the coal areas round Marshall and Erie. Many of the faults that have been traced in this region, however, have had no perceptible influence upon the present surface configuration, and were detected only as a result of artificial excavations, such as ditches or mine workings.

In the region east of the Platte and north of Sand Creek within the area mapped, and on the same side of the Platte beyond this area, sand dunes constitute another topographical feature, distinct from any hitherto mentioned. These are formed, as in other parts of the Rocky Mountain region, on the west side of depressions broad enough to admit of a considerable accumulation of wind-borne sand on the leeward side of the basin, and on the slopes of divides too high for the wind to carry them over. Those within the area of the map, being not over 40 feet in height, come within the interval of its contours, and are not outlined by them.

The generally regular and gentle slope of the entire area is particularly favorable to its most important and permanent industry, namely, agriculture under irrigation. Wherever there is sufficient supply of water, it admits of its distribution from irrigation ditches over the areas below their level with great uniformity and with a minimum expenditure of manual labor. In consequence, the upland prairie country, which twenty years ago was looked upon as practically valueless except as a grazing country, is now covered with rich fields of grain and alfalfa, abounds in gardens, and constitutes one of the most valuable farming areas in the West.

HISTORICAL GEOLOGY.

PRE-CAMBRIAN FORMATIONS.

The present report has to do mainly with a comparatively recent phase in the geological history of the Rocky Mountains. That considerable portions of these mountains represent original land masses that have never been completely submerged, and that the sedimentary beds now resting on their flanks and in part covering the crests of certain mountains have been formed from the abrasion of these original land masses, has long ago been demonstrated by the writer.[1] These original land masses, which constituted an archipelago of large islands in the Paleozoic seas, consist, so far as determined by such examinations as have been made of the portions now exposed, almost entirely of crystalline rocks, among which granites, gneisses, and micaceous or hornblendic schists are the prevailing types.

A distinct unconformity and a pronounced change in lithological constitution almost invariably mark the contact between this older crystalline complex and the succeeding sedimentary beds of Paleozoic or later age,

[1] Second Ann. Rept. U. S. Geol. Survey, 1882, p. 211; Mon. U. S. Geol. Survey, Vol. XII, 1886, p. 20; Bull. Geol. Soc. America, Vol. 1, 1890, p. 252.

while the latter contain among their constituents a considerable proportion of material which can be distinctly recognized as derived from the basement of crystalline rocks, and the amount and relative coarseness of such material vary with its distance from the ancient shore-line.

According to the classification in vogue at the time the earlier geological maps of the Rocky Mountain region were made, the whole of this older series of prevailingly crystalline rocks was mapped as Archean, although, even in the earliest reconnaissances, various observers had recognized that it included two or more distinct groups, in some of which a distinctly sedimentary nature and stratified structure could be distinguished.

In later years, since the discovery in the Lake Superior region of immense thicknesses of distinctly stratified clastic or fragmentary beds older than the earliest Cambrian, yet more recent than, and as a rule unconformable with, the underlying crystalline complex, the practice has been adopted by the Survey of confining the term Archean to the oldest crystalline rocks, and of grouping all fragmentary or clastic rocks which are older than the lowest fossiliferous Cambrian in a new system called Algonkian.

Although no systematic study has yet been made of the great areas of more or less crystalline pre-Cambrian rocks in the Rocky Mountain region with the view of differentiating the Algonkian from the true Archean rocks that may occur in them, several small areas of Algonkian rock series have been recognized which possess such distinctly sedimentary characteristics, and are so situated with regard to Cambrian beds on the one hand and to large bodies of rock hitherto classed as Archean on the other, that there can be little doubt of the correctness of their assignment to this age. Such are those of the Quartzite peaks, south of Silverton, and of the Uncompahgre Canyon, south of Ouray, in the San Juan Mountains.

In the Colorado or Front Range occurrences of distinctly fragmental or clastic rocks, more or less completely inclosed in the granite-gneiss complex, have been noted at various points, but their relations with adjoining rocks have not yet been worked out over any large or connected areas.

In the Pikes Peak region Mr. Cross[1] has described several bodies of

[1] Geologic Atlas of the United States, Pikes Peak folio, Washington, 1894, Explanatory text, Algonkian period.

quartzite that are not only older than Cambrian, but are almost entirely surrounded by granite, which also sends apophyses into them. These he regards as undoubted Algonkian, while much of the granite must be of even later age.

Along the lower canyons of South Boulder and Coal creeks, within the area of the present map, and also near Big and Little Thompson creeks to the north of it, there are certain beds of highly altered quartzite and conglomerate, associated with schists, which occupy a position between the Triassic sandstones and the more massive gneisses of the interior of the range. These were first noted by Marvine, of the Hayden Survey, in 1873,[1] who regarded the quartzites as the first phase in the successive metamorphism of great series of sedimentary rocks, of which the final expression, in his idea, is a structureless granite.

The Coal Creek occurrences have since been more particularly examined by A. Lakes for C. R. Van Hise, in 1890. In analyzing the various observations Van Hise[2] finds evidence of the existence of a general fundamental crystalline complex of pre-Cambrian rocks in the Colorado Range, and regards these quartzites and conglomerates as undoubted pre-Cambrian clastics, but is unable from the evidence at hand to say definitely whether there is a sharply defined line between the two or only an insensible gradation.

In the present work, inasmuch as but a very limited extent of pre-Cambrian rocks comes within the limits of the map and the internal structure and mutual relations of these rocks have no bearing upon the subject-matter of this investigation, it was not considered advisable to enter upon the necessarily lengthy and complicated study that would be required to determine these relations. Hence, beyond noting the occurrence of the quartzites and conglomerates in the area round Coal and South Boulder creeks and recognizing their distinctly sedimentary character as contrasted with gneisses, granite-gneisses, and massive granite, which appear successively as one approaches the center of the range, nothing has been done toward definitely delimiting the areas occupied by either

[1] Seventh Ann. Rept. U. S. G. and G. Survey, Washington, 1874, p. 137.

[2] Bull. U. S. Geol. Survey No. 86. Correlation Paper, Archean and Algonkian, Washington, 1892, pp. 312, 325.

class of rocks. The distinctly sedimentary rocks are, however, not over 1,000 feet in thickness, and hence they occupy necessarily but a very small proportion of the total pre-Cambrian area represented on the map. It has, therefore, been judged best to preserve the Archean color, in accordance with existing practice, for this area, and it will be referred to under this term throughout the text; at the same time it is freely admitted as possible that future study may show that a much larger portion of this area than at present appears probable should properly be considered as Algonkian.

As the geological history of a region must be primarily determined by a study of the sedimentary beds exposed in it and of the organic remains found in those beds, and as thus far no representatives of the Lower and Middle Cambrian strata, so abundantly developed in Utah, Nevada, and British Columbia, have been found in the Rocky Mountain region, it is only for the period commencing with Upper Cambrian time that any attempt can be made at present to trace out the details of its geological development. Within this period the histories of earliest and latest phases are necessarily the most obscure—in the one case because the sediments deposited in the earliest times have been more generally covered up and buried beneath the accumulations of later ages; in the other because the latest sediments have had less time to consolidate into hard rock and have been the first to be removed by the destructive agencies that have acted on the surface during the long modern period in which the region has been exposed to subaerial erosion.

CAMBRIAN LAND.

The principal land areas of the Rocky Mountain region which projected above the waters in which Upper Cambrian sediments were deposited were the Colorado and Sawatch islands. The latter included the present Sawatch Range, and was possibly connected with other land masses to the south, but was entirely distinct from the Colorado Island and was separated from it by a bay or strait, in which considerable extents of Upper Cambrian sediments were deposited. To the east of the Colorado Island, covering the present area of the Great Plains, was the great mediterranean sea, a shallow ocean which stretched with few known interruptions to the present summits of the Appalachian Mountains.

The Colorado Island corresponded in a general way with the present form of the Colorado and Wet Mountain ranges. Its northwestern extension was, however, greater, probably taking in the present area of the North and Middle parks and reaching to the Park Range beyond them. On the southeast, on the other hand, it was divided up into a series of peninsulas or islands, by bays or straits extending into it in a northwesterly direction from the ocean. The most important of these bays was that between Canyon City and Pikes Peak, forming part of the South Park depression, which may have entirely cut off the connections between the Wet Mountains and the main island. A second important bay was that which stretched up the present depression of the Ute Pass and Manitou Park; and if, as is quite possible, the waters of the latter connected with the South Park depression, the present Pikes Peak massive would also have formed an island. There is some probability also that the present promontory known as the Rampart Range, lying between Manitou Park and the plains, was more or less submerged beneath the Cambro-Silurian seas and received sediments perhaps as late as the early Carboniferous, having been arched up into its present form during the later orographic movements to which the region has been subjected. Another prominent bay was that now occupied by Huerfano Park, at the southern end of the Wet Mountains, which it now separates from the Sangre de Cristo Range. Conditions have been so modified by later movements that in our present state of knowledge it is impossible to determine definitely whether the Wet Mountain Island was connected at that time with the Sangre de Cristo and Sawatch islands or not.

A similar uncertainty exists with regard to the northern portion of the eastern shores of the Colorado Island, but judging from the present form of the Mesozoic deposits it is probable that there were smaller bays, extending to no great distance inland, which served to give an indented form to the shore-line.

As shown by the character of the sediments deposited there, on the western shores of the island conditions differed somewhat from those on the eastern shore. The depression of South Park had certainly a connection with the ocean westward between the northern end of the Sawatch and the Gore mountains, which may then have formed part of the Park Range, and consequently of the western shore of the Colorado Island. It is probable, though less certain, that a water connection also existed through Canyon City Bay with the eastern sea; but if deposits were formed in this strait they have since been removed by erosion and can no longer be traced continuously. Only Mesozoic or later beds are now found in contact with the elder crystalline rocks on the west flanks of the present Colorado mountain range, which conceal the older deposits, so that the position of the ancient shore-line can be only approximately determined. This is also true of a considerable portion of the eastern shore-line.

EARLY PALEOZOIC SEDIMENTS.

The deposits formed in the early Cambrian seas around these islands were continued through Silurian into early Carboniferous time in a sort of cycle of deposition; that is, the successive beds formed during these periods show in their present outcrops no decided discrepancy of angle or other evidence of any pronounced orographic movement during the period which would have sensibly changed the form of the land masses around which they were deposited. That the region as a whole was subjected to changes of level with reference to that of the surrounding water, and that probably there were some local movements of elevation and subsidence producing differential changes of level on different portions of the shore-line, is evidenced by certain observed unconformities by erosion, generally of small amount, and by the thinning or even complete absence of some of the series of beds at certain parts of the observed outcrops. The thickness of beds deposited during this cycle of deposition was very slight, especially along the eastern shore, where in no case, as far as observed, does it exceed an aggregate of 350 to 400 feet. They consist mainly of sandstones, more or less calcareous, and of siliceous limestones with some shales, generally in subordinate development. The series increases in thickness to the westward, being 500 to 750 feet around the Sawatch uplift, about 2,000 feet in the Grand Canyon region, and reaching an aggregate of 15,000 to 20,000 feet in the longitude of the Wasatch Mountains.

In these outlying regions there is, as in the Rocky Mountain region, no evidence of any pronounced orographic disturbance during the deposition of the successive beds, but, as more detailed studies of the respective exposures have been made, it has been found that certain members of the series thin out locally or are entirely wanting. Thus, in the Wasatch Mountains, where the ocean waters were apparently deeper than in the more eastern regions and the series is most complete, the Upper Cambrian deposits are apparently wanting. In the Grand Canyon region, on the other hand, the Devonian is represented by less that 100 feet of beds, while the Silurian is wanting. Evidences of erosion are there very distinct, but it is still uncertain whether the Silurian was never deposited or whether it has been entirely removed by erosion. Finally, in the Rocky Mountain region, no Devonian has yet been discovered, but wherever the Lower Paleozoic section has been studied in detail the Cambrian, Silurian, and Lower Carboniferous beds have been found closely associated and quite conformable. Evidences of erosion are most frequent, however, between the Silurian and Lower Carboniferous, which would favor the hypothesis that during Devonian time ocean waters had retreated from this region and portions of it at least had been exposed to erosion. The studies that have been made of this series of rocks on the eastern flanks of the Colorado Island, in the Canyon City and Manitou bays, respectively, show besides a notable decrease in thickness a decided change in the character of the sediments from those observed on the west side of the island on the flanks of the Mosquito Range, as well as a considerable variation in either respect between those in the respective bays. The Cambrian is here very thin, and at some points does not appear, but the close association of its sediments and fauna with those of the succeeding Silurian renders it probable that there was no actual discontinuity in the deposition of the two series, the local absence being due to overlapping by the Silurian. The Silurian beds are relatively well developed and contain an abundant and characteristic fauna, which has rendered it possible to distinguish three distinct subdivisions or formations in this group. The local thinning out or absence of the uppermost of these formations proves that a considerable period of erosion must have intervened before the deposition of the succeeding Lower Carboniferous beds, and in so far confirms the opinion, hitherto only tentatively put forth, that the absence of Devonian beds in the Rocky Mountain region is due to a depression of the ocean-level or an elevation of this region after Silurian time.

Within the area mapped no outcrops of Lower Paleozoic beds are found, but there is good reason to assume that they underlie all the later sediments and do not reach the surface simply because they are concealed along the Archean contact by the overlapping of Mesozoic and later deposits. A short distance south of this area, however, in Perry or Pleasant Park, at the base of the Archean foothills, is a small exposure of Paleozoic beds whose exact horizon has not been determined, but which, from descriptions and analogy with other exposures, are assumed to belong to the Lower Paleozoic series. The overlap of the Mesozoic over the edges of the older beds is there visibly demonstrated.

CARBONIFEROUS MOVEMENT.

At some time during the Carboniferous period not yet definitely determined, but probably during the latter half, an important orographic movement took place in the Rocky Mountain region which in certain localities was accompanied by some dynamic disturbance. Its most general effect was an elevation of the land, raising above water-level portions of the regions that were previously submerged and exposing them to subaerial erosion. In some cases it would appear that entirely new land masses were formed which in later movements were again submerged, and that in other cases land masses were depressed so as to be subject to sedimentation which had received no sediments during the early Paleozoic cycle. The movement was therefore of a differential and somewhat local character in this region, though it appears to have been nearly contemporaneous with important movements in far distant regions, notably that which preceded the coal-forming era in the Appalachians, and its effects were probably felt over a very large portion of the North American Continent.

The most visible results of this movement in the Colorado Island are seen in the extensive erosion of Lower Paleozoic beds in Canyon City Bay, from whose present position it would seem probable that the water connection with South Park was interrupted and a land connection between the main Colorado Island and its Wet Mountain extension was reestablished.

To what extent this elevation and erosion affected the eastern shore-line of the Colorado Island, immediately facing the mediterranean ocean, it is difficult to determine, on account of the uncertainty that exists with regard to the next succeeding deposits along that line.

Following the Carboniferous elevation and erosion, there was a general subsidence throughout the Rocky Mountain region, which continued in some parts through Upper Carboniferous into Triassic time. On the western slopes immense thicknesses of conglomerates accumulated during the Upper Carboniferous period, which passed upward into red sandstones, gradually growing lighter in color and finer in grain, the final development being the Red Beds, which have been generally considered Triassic, mainly on stratigraphical grounds.

Along the eastern front no great conglomerate series comparable to the Upper Carboniferous of the western slope has yet been observed, and the beds occurring below the Jurassic have, on account of their red color, hitherto been assigned to the Trias, but the red color is not an infallible criterion, for red sandstones are known to occur in beds carrying Upper Carboniferous fossils.

WYOMING FORMATION.

In the case of isolated and incomplete exposures of a series of beds deposited between two nonconformities, the lithological constitution of the beds is, in the absence of all paleontological evidence, the only, though necessarily very uncertain, means of determining their geological horizon, for the earlier formation of the series may be concealed by overlap if there was a continuous subsidence during the period, and the later formations may have been removed by erosion during a later elevation.

The assignment of the lowest series of beds in the present field to the Trias is based mainly on lithological correspondence with the upper part of the Red Bed series as developed on the west flanks of the Rocky Mountain uplift. There is, however, a further reason for this assignment in the fact that the variation in thickness of the formation, which is very considerable, is at the bottom rather than at the top of the series, and hence is mainly due to overlap rather than to erosion. Whether any considerable amount of beds not represented in the actual outcrops exists under the

Denver Basin at some distance from the foothills can be only a matter of conjecture in the present state of knowledge. It is possible that the lower portions of the series, where the observed thickness is greatest, may correspond to what is elsewhere considered Upper Carboniferous on similar grounds of stratigraphical and lithological correspondence, and which, on the Pikes Peak sheet of the Geologic Atlas, has been designated by Mr. Whitman Cross the Fountain formation. That the upper part of the typical Red Beds are of Triassic age is rendered more than probable by the discovery in them at various points in the Cordilleran region of characteristic vertebrate and invertebrate remains, together with typical plants. It has seemed necessary, therefore, to recognize them as a distinct formation, and the name Wyoming has been assigned to them because of their widespread development in that State.

In the present field Mr. Eldridge has judged best to divide the formation into an upper and a lower series on grounds of lithological composition and structure.

LOWER WYOMING FORMATION.

This formation varies in thickness in this field from about 500 to 2,500 feet. It consists essentially of coarse sandstones and conglomerates with subordinate red shales, and a few thin beds of limestone, generally compact, with conchoidal fracture, and of light-drab or white color. The base of the formation always consists of waterworn fragments of granite, gneiss, and schist, or their constituents, feldspar and quartz, the prevailing red color being largely due to the abundance of red feldspar. In the upper part is a series of white sandstones, made up almost entirely of quartz grains, called from their prevailing color the "creamy" sandstones.

The variation in thickness of this formation is due mainly to the unevenness of the floor or sea-bottom upon which it was deposited. Besides the regular slope away from the mountains, or eastward, it also deepened southward. Moreover, in the neighborhood of Golden a ridge or low promontory extended for some distance from the foothills, upon which in the earlier part of the period there was no sedimentation. It is assumed, however, that the ocean-bottom was continually sinking during this period and the sediments consequently advancing shoreward on the gentler slopes and overlapping those previously deposited. Hence, at the present day, this formation is found to be thickest along the southern portion of the foothills and to reach its greatest attenuation at Golden.

The neighborhood of Golden has been the scene of a peculiar series of deformations in this and succeeding periods which merit especial mention. From the minute study made by Mr. Eldridge of the existing beds and the character and position of their outcrops, it appears that already at the close of the Carboniferous movement there must have been a ridge or arch of Archean rocks about 4 miles wide extending out eastward at right angles to the general shore-line, which was above water during the early part of the Wyoming period and became subject to sedimentation by sinking below the ocean-level only toward the close of the period. It is not possible now to say what was the cause of the arching up of the sea-bottom at this point, whether it was due entirely to a movement within the rocks or in part to an unequal planing down of their surface by erosion. That there was a deformation of the crust, however, is rendered probable by the fact that in later movements there must have been a repetition of the arching which raised this portion of the surface successively above the general level of the sea-bottom and thus prevented sedimentation for a time at this locality. It is the proof of the repetition of this movement which forms the most convincing argument against the hypothesis of an overthrust fault at this point, which would be suggested by a first glance at the present disposition of the outcrops of the successive strata as represented on the geological map.

The strain which produced this local arching may be assumed to be a compressive force acting in directions parallel with the shore-line, as contrasted with that which produced the final general upturning of the beds, which must have acted at right angles to this direction.

UPPER WYOMING FORMATION.

The beds assigned to this division by Mr. Eldridge consist of about 185 feet of red sandstones and shales, with some thin limestone bands, followed by 300 to 400 feet of shales, variegated in color and gypsiferous in the upper part and ending in a persistent band of pink and brown sandstone.

A portion of the beds included in this division have hitherto been classed in the succeeding Morrison group, or Jurassic, but as they contain, so far as observed, no fossil remains, the Hallopus fauna which occurs near Canyon City not having been detected in this region, the line of division has been drawn on grounds of lithological composition and structure. In lithological composition the variegated shales resemble similar beds belonging to the Jurassic on the western slopes of the mountains, but the structural evidence was what finally determined Mr. Eldridge to draw the line where he did. This point will be discussed later.

JURASSIC MOVEMENT.

A widespread orographic movement, resulting in elevation and erosion, and in some parts accompanied by folding and faulting, took place in the Rocky Mountain region previous to the deposition of the series of beds which, from their containing vertebrate remains, have been considered as of late Jurassic age. This has been designated the Jurassic movement, since its effects were most apparent during that period, though it may have been inaugurated toward the close of the Trias, when shallow water and in some places lacustrine conditions prevailed. As a result of this elevation, the marine deposits of Jurassic age, the Baptanodon beds of Marsh, which were formed in the regions to the north and west, were shut out from the Rocky Mountain region of Colorado, and during the depression which followed only fresh-water beds were laid down in this region; the character of the fossil remains found here indicates that oceanic waters did not enter the region until Dakota time, or at the commencement of the Upper Cretaceous cycle of deposition.

A notable feature in the Jurassic movement, deduced from the evidence which present conditions afford, is that the folds produced by it were in general at right angles to those formed by succeeding and more pronounced movements; therefore, after the crests of folds have been planed off by erosion and a later series of beds deposited over their upturned edges, when the whole complex is again folded at right angles to the earlier folds and again eroded, the unconformity between successive series is shown in the resulting outcrops by discrepancies in strike rather than in dip of beds. This effect is more pronounced on the western than on the eastern slopes of the region. On the eastern shore of the Colorado Range the movement and the succeeding erosion were so uniform that it is difficult to detect any discrepancy of angle either in strike or dip between Triassic and Jurassic beds. In the area mapped, however, the effect of the movement is shown in the Golden arch, whose axis runs just north of Clear Creek, between it and Gold Run. The crest of this arch and the Triassic beds already deposited over it were raised about 420 feet by this movement, and by the subsequent planing of the crest a great portion of the upper Wyoming formation, down to the limestone near its base, was removed. That the absence of these beds from where the arch once existed is due to erosion rather than to nondeposition is proved by the fact that as one follows the strike of the present upturned beds toward Golden from either direction, the beds of the upper Wyoming formation disappear successively from the top downward, and the discrepancy in strike is between them and those of the next succeeding higher horizon. The movement is also assumed to have produced a similar though less pronounced arch in the vicinity of Boulder, from the crest of which the upper Wyoming formation was eroded off and over which the succeeding Morrison beds were not deposited. The same general phenomena obtain in these beds in their present outcrops as near the Golden arch. It was for this reason that the upper beds of this formation, which from their lithological constitution were formerly considered Jurassic, have been classed by Mr. Eldridge as Triassic.

MORRISON FORMATION.

The beds of this formation, which were deposited during the general depression that followed the Jurassic movement, consist mainly of marls with varying proportions of sandstones and thin limestones, the whole having an average thickness of 200 feet. Lenticular bodies of drab limestone occur in the clays of the lower two-thirds of the formation, which also carry the remains of gigantic saurians characteristic of the formation, and from which the name "Atlantosaurus beds" has been given to it. The upper third of the formation is more arenaceous, sandstones sometimes predominating over the clays and passing into a conglomerate at the base.

Its thickness in the Denver field is somewhat variable from point to point, the variation being assumed to be mainly the result of erosion.

The Morrison formation is chiefly remarkable for the abundant remains of gigantic saurians and other reptiles found in its beds, together with fishes, birds, and a few diminutive mammals. The abundance of the land animals and the discovery of fossil plants in the beds is further proof, if any were needed, that they were formed along the shores of a large land mass. Molluscan remains, of fresh-water habit, indicating that the sediments were deposited in an inclosed lake, are also found in these beds.

As both molluscan and plant remains found at this horizon have too wide a range to be of value in the determination of the age of the inclosing beds, this determination has been based exclusively upon the vertebrates. Although the latter have some affinities with the European Wealden or Lower Cretaceous, to which Professor Marsh was at first inclined to assign the horizon, he found the evidence in favor of late Jurassic age to be so much stronger that he assigned to this period not only these but other beds with a similar fauna, notably the Potomac beds of the East, which on other grounds had been considered early Cretaceous and which present many structural analogies with the Morrison beds.

From the point of view of the stratigrapher, the assignment of the Morrison beds to the Lower Cretaceous rather than to the Upper Jurassic is much more desirable, not only because it accords better with the sequence of sedimentation thus far disclosed in the adjoining regions of Kansas and Texas, but because it places the physical break whose effects are recognized over the whole continent between these two great time divisions rather than in the midst of one of them.

EARLY CRETACEOUS MOVEMENT.

It has been hitherto assumed by the writer and others that a movement must have occurred in the Rocky Mountain region between the time of deposition of the Morrison or Atlantosaurus beds and those of the succeeding Dakota formation, now considered as the base of the Upper Cretaceous. In this interval a considerable thickness of earlier Cretaceous beds has been deposited in other regions, notably the Comanche series of Texas and Mexico and the Kootanie series of British Columbia, whose representatives have for a long time been supposed to be wanting in the Rocky Mountain region. The area of this assumed nondeposition has been somewhat circumscribed of late years by the discovery of Kootanie beds in Montana, and more recently in the Black Hills region, and of Comanche beds in New Mexico on the east front of the Rocky Mountains, not far south of the Colorado boundary. The intermediate region, however, comprising the higher portion of the Rocky Mountain region of Colorado and a considerable portion of the Great Plains opposite or to the east of this region, appears, as in Jurassic time, to have been cut off from the access of ocean waters, since no representative either of the marine Jura or of the earlier Cretaceous or Neocomian beds has yet been found in it.

From their fauna the Morrison beds are assumed to have been deposited in fresh or lacustrine water, whereas the Dakota beds are distinctly marine, and the character of the conglomerate at their base indicates that they were deposited in an ocean that was slowly advancing over an area that had for a long time been exposed to subaerial disintegration.

The physical data from which the character of the movement may be inferred are as yet somewhat meager. It was assumed that the lake in which the Morrison beds were deposited was separated from the ocean by a barrier raised during the previous (Jurassic) movement along a line extending eastward in the latitude of the Raton Hills and probably connected with the old Paleozoic elevations of northern Texas, the Indian Territory, and western Arkansas. A similar barrier may have extended eastward in about the latitude of the northern boundary of Colorado. It was assumed, further, that during the early Cretaceous movement these barriers were broken and the region possibly slightly elevated, so that the Morrison Lake was drained and its bottom remained above the ocean during early Cretaceous time, exposed to subaerial disintegration and to some slight erosion. At the close of the movement a general depression is supposed to have set in, which continued to the middle of the Upper Cretaceous cycle and during which the ocean waters filled the area formerly occupied by the Morrison Lake. The evidence of the movement in this area is found in the varying thickness of the Morrison formation from point to point. This variation, as Mr. Eldridge shows, is in part from the bottom upward, hence caused by nondeposition on more elevated portions of the sea-bottom, but mainly from the top downward, hence to be ascribed to erosion previous to the deposition of the succeeding Dakota beds.

The Golden arch is assumed to have been further elevated by this movement about 1,000 feet, for the reason that this thickness of the Cretaceous sediments (including the Dakota and the lower part of the Benton Cretaceous) apparently did not cross it. A further effect of the movement is seen in the apparent overlapping of Dakota sediments across the underlying Morrison beds onto the Archean floor at Coal Creek.

DAKOTA FORMATION.

The first beds deposited in this epoch were characteristic conglomerates, consisting mainly of small, very well rounded grains of chert, jasper, quartzite, and often of other of the more resisting rock varieties, together with some limestone pebbles. The whole formation, which averages 250 to 350 feet in thickness in this field, is essentially a sandstone, which changes to the quartzitic condition with remarkable facility, and, thus offering greater resistance to erosion than the other rocks, generally constitutes the hogback ridge wherever the Cretaceous strata are upturned against the flanks of the mountains. From an economic point of view, this formation is important for the remarkably pure beds of fire clay which occur in bodies of varying thickness within the sandstones.

In organic remains it is remarkable for the variety and great number of fossil plants found within its beds. Dicotyledonous plants make their first appearance in the Colorado mountain region at the Dakota horizon. Marine mollusks, though not yet found in the Denver Basin, occur plentifully at this horizon in the plains region of Kansas and Texas.

Vertebrate remains are not known to the writer to have been found in these beds in the vicinity of the Denver Basin.

Significant from a structural point of view is the fact that among the pebbles of the basal conglomerate of the Dakota formation in the Denver Basin Mr. Eldridge has detected some Silurian fossils and ill-shaped coralline forms. It is not conceivable under existing conditions that these should have been derived from the degradation of Paleozoic limestones resting on the flanks of the range immediately above the Dakota beach, for these had already been overlapped and buried beneath the Triassic sediments. They must be assumed, therefore, to have been brought into this position by strong long-shore currents from some Paleozoic exposures to the southward, either at Perry Park or still farther south; possibly from remnants left upon the flanks of the Rampart Range.

COLORADO FORMATION.

The cycle of deposition inaugurated in Dakota time was continued in a progressively deepening sea through the Colorado Cretaceous. During the Benton division of Colorado time there were deposited up to 600 feet of beds, mainly argillaceous shales, characterized by their dark, almost black, leaden hue, and containing thin fossiliferous and often bituminous limestone beds of widely varying thicknesses and frequent concretionary clay-ironstones. The shales carry considerable disseminated pyrites, together with gypsum and sulphur. The succeeding Niobrara division of the Colorado is characterized by a persistent limestone at the base, reaching 50 feet in thickness, of light color, and here somewhat dolomitic in composition, though at other points of remarkable purity, succeeded by about 100 feet of gray and up to 250 feet of buff shales, with some thin limestone bands and iron concretions. All these clays contain considerable amounts of alkaline salts.

Remains of a remarkable series of vertebrate animals have been found in chalky beds that apparently correspond to the Niobrara limestone of this horizon, along the Solomon, Saline, Smoky Hill, and other rivers in Kansas. These animals include marine swimming reptiles, birds with teeth, and pterodactyls, and from the latter they have been called by Marsh the "Pteranodon beds."

MID-CRETACEOUS MOVEMENT.

Until within a comparatively few years it has been assumed that the cycle of deposition of the Cretaceous deposits of the Rocky Mountains was entirely uninterrupted. The character of the sediments of the middle part of the series, which is prevailingly shales with unimportant and unpersistent harder calcareous and arenaceous layers, is such that, in the absence of any discrepancy of angle, unconformity by erosion would not be readily distinguishable. Since the discovery in this field of unmistakable evidences of considerable erosion following the deposition of the Niobrara Cretaceous, attention has been called to facts indicating that, throughout the area of the Great Plains at least, there was a general elevation producing a temporary recession of the ocean waters, which was followed in places by considerable erosion before the area was again depressed below ocean-level.

In the Denver Basin area the principal evidence of this movement is found in the Golden arch, which, according to Mr. Eldridge's observations and inductions, must have been elevated by it some 9,500 feet, so that its cross-section widened to 21 miles from north to south and the involved strata up to the top of the Niobrara were crumpled into minor folds. In the erosion which followed, the whole thickness of the Niobrara, Fort Benton, Dakota, and whatever may have been left from previous denudations of the earlier Morrison and Wyoming formations, was entirely removed from the crest of the arch. The thickness of material thus removed from the crest of the arch Mr. Eldridge estimates at something over 1,000 feet.

Over the Boulder arch the present disposition of the strata indicates the probability of an earlier movement at the close of the Dakota, this formation apparently having been eroded, to a certain extent, before the deposition of the Benton clays. The evidence of this movement is of less conclusive character than that of the post-Niobrara movement, and its effects were at best very local in their character, so that it may be passed over without further consideration.

General depression followed the erosion of the post-Niobrara elevation. It has been suggested that this erosion may have been submarine and due to the action of strong long-shore currents in not yet consolidated material recently deposited on the ocean bottom. This depression lasted during a large part of Montana time and was probably followed by a gradual elevation and shallowing of the waters during Fox Hills and Laramie time.

MONTANA FORMATION.

The lower subdivision of the Montana formation, the Pierre, consists mainly of plastic clays, generally gray in color, with lenticular bodies of limestone, and an arenaceous zone from 100 to 300 feet thick about one-third way up in the formation. Its aggregate thickness is taken at about 7,700 feet, no part of which is supposed to have crossed the Golden arch. The clays contain a few clay-ironstone concretions, and are impregnated with gypsum and alkaline salts. The formation has a characteristic molluscan fauna, whose remains are usually found in the lenticular bodies of impure limestone.

The upper subdivision of the Montana, the Fox Hills, has an average thickness in this field of 800 to 1,000 feet, only the upper 500 feet of which is assumed to have been deposited over the crest of the Golden arch. The formation is characteristically more arenaceous than the Pierre, and is generally of a yellowish or buff color. The arenaceous shales in the lower part carry some ferruginous concretions and gypsum, and lenticular limestones are also found in subordinate quantity, which contain a characteristic molluscan fauna and some plant remains. The most characteristic and persistent stratum in the formation is a sandstone at the very summit, which in this field is about 50 feet thick, of greenish-yellow color, and carries an abundant and typical marine fauna. It consists of quartz grains, with a little muscovite and biotite mica and disseminated iron.

LARAMIE FORMATION.

Lithologically in close connection with the Fox Hills is the Laramie formation, which consists of a series of basal sandstones up to 200 feet in thickness, above which are in this field 400 to 1,000 feet of clays, with small lenticular bodies of sandstone.

The basal sandstones of the Laramie and the sandstone at the top of the Fox Hills often form a single sandstone bluff. The fossil horizon forms a sharp division between these horizons, and the Laramie sandstone is usually white in color, consisting mainly of quartz, with minute grains of black chert and but few other impurities. The Laramie sandstones are generally divisible into three benches by clay bands or coal seams, and it is within these sandstones that the best workable coals are found. Coal seams have also been found in the upper clayey division, but the coals are lignites with higher percentages of water and of inferior economic value. One band of sandstone above the two lower benches is of importance as being more generally fossiliferous, and hence a valuable indicator in searching for coal. It contains a considerable percentage of lime. The fossils found are mollusks of brackish- and fresh-water habit, together with remains of plants. No vertebrates have yet been found in beds that could with certainty be assigned to the Laramie horizon, as defined in this report.

POST-LARAMIE MOVEMENT.

At the close of the Laramie period the general shallowing of the ocean waters, which had been going on slowly during the latter part of Cretaceous time and which was probably accompanied by some elevation of the sea-bottom, culminated in a widespread orographic movement whose effects have been traced from one end of the continent to the other, but are most marked in the Cordilleran region. It is to this movement that the roughing out and outlining of the mountain forms of the present Rocky Mountain system has been generally ascribed, and while it is not possible to decipher with certainty in a given region the amount of deformation which was due to each of the orographic movements to which it has been subjected, it is evident that the post-Laramie movement must have played relatively the most important part in these deformations, since its results were to shut out the ocean waters from the plain as well as from the mountain areas of the entire Western region.

In this post-Laramie movement not only was there a general continental elevation of the whole region, but the mountain areas suffered a differential uplift in relation to the surrounding plains or lowlands, so that the edges of the strata resting against these flanks were in many places upturned at considerable angles. With the dynamic movements which caused the differential elevation of the mountain masses and which produced folding and dislocation of the strata was associated considerable eruptive activity, which inaugurated a succession of outbreaks of eruptive rocks that continued from time to time during the Tertiary era, and which formed an important and characteristic feature of that era.

The dynamic effects of this movement, as seen in the Denver Basin region, show that it was more intense than previous movements and was produced by forces acting at right angles to the foothill region and to the general strike of the strata, instead of nearly parallel, as were those which produced the various uplifts of the Golden and Boulder arches. It was apparently in the nature of a powerful compression along the base of the foothills, or the contact of the later sedimentary beds with the basement complex of crystalline rocks, accompanied here and there by a certain amount of thrust-faulting, which tended to push the higher horizons forward toward the mountains and over the lower ones. A most important and somewhat singular effect of this movement, which Mr. Eldridge's explanation of the Golden and Boulder arches renders necessary, was the flattening out of these arches, so that the present line of contact of the lowest exposed sedimentaries with the Archean, which, since the Laramie movement, is a line of strike, is a comparatively straight line; whereas the line of strike of the higher beds, which were deposited over the arch, have now a decided curve inward toward the mountains, and must, before being upturned, have been compressed into something like a synclinal trough, as explained graphically in a later chapter.

It seems possible to the writer that some of the curve in the strike line of the upper (Laramie and Fox Hill) beds, or, in other words, of the irregular overlapping of the strata by the Montana and Laramie formations, may have been produced by overthrust faulting along a line making but a slight angle with the bedding, which would naturally have taken place in the great clay horizons of the Middle Cretaceous, where little traces of the shearing would be left.

The general upturning of the Mesozoic strata along the foothills, which has produced the characteristic phenomena of the hogback ridges, must have been inaugurated by this movement, but it was not completed, as the succeeding Arapahoe and Denver formations have also been upturned at steep angles in the foothill region, and there is some reason to assume that the forces which produced this upturning have been acting in comparatively recent times.

That the Mesozoic strata were uplifted along the foothills above the general level of the beds, and their upturned edges exposed to erosion, is proved by the fact that rolled fragments of the rocks of the different formations are found in the succeeding Arapahoe and Denver formations. The period of erosion that succeeded the movement of elevation must have been of long duration, since as much as half the total thickness of the Laramie was removed from portions of the field before the succeeding Arapahoe beds were laid down.

ARAPAHOE FORMATION.

After an erosion of the Laramie beds which removed from portions of the Denver Basin 600 feet or more of the previously deposited sediments, a considerable fresh-water lake was formed and sedimentation again set in. What the exact area of this lake was it is not possible now to determine; its extent was undoubtedly considerably larger than that covered by its beds at the present day, especially to the northward. To the southward vertebrate fossils characteristic of the post-Laramie formations have been observed by Professor Marsh in Monument Park, and remnants of beds resembling the Arapahoe and Denver series have been observed near Canyon City which may have been contemporaneously deposited, but whether the lake was continuous along the mountain front or there were several small isolated basins it is as yet impossible to determine. For the present discussion it will be assumed that the Arapahoe Lake was confined to the Denver Basin.

In it were deposited more than 600 to 800 feet of sediments, the excess above these figures being the unknown amount that was eroded off before the Denver beds were deposited. Of these sediments the lower 50 to 200 feet were conglomerates, the upper 400 to 600 feet arenaceous clays. In the persistent band 40 feet in thickness at the base of the formation have been found among the pebbles coal, silicified wood, and white sandstone from the Laramie; limestone from the Niobrara; the characteristic cherty conglomerate from the Dakota; limestone and red sandstone from the Jura and Trias; and silicified limestone with casts of Beaumontia. The last named, which are most abundant in the southern portion of the field, must have come from Carboniferous limestones in Perry Park or beyond, and are an indication that strong long-shore currents setting northward prevailed in the Arapahoe Lake, as they did in the Dakota Ocean.

The material distinctly traceable to sedimentary beds is throughout of subordinate amount in the beds, the bulk of the sediments being derived from the abrasion of the crystalline rocks here classed as Archean. It is noticeable, however, that none of the andesitic débris, which form so important a part of the succeeding series, are found in these beds.

Vertebrate remains are found in both the conglomerates and the clays, more abundant and better preserved, however, in the latter. They are classed among the Ceratops fauna, which is also characteristic of the Denver beds. The forms found are, however, in general more fragmentary and less well preserved than those obtained from the latter.

POST-ARAPAHOE MOVEMENT.

Between the deposition of the Arapahoe and Denver beds a considerable time-interval occurred, during which, as the record of the rocks shows, the Arapahoe Lake was drained and the sediments deposited in its bottom were considerably eroded. The movement which caused the drainage of the lake was, as far as present indications go, rather local in its effects, and produced no important deformation of the lake beds already deposited. In the mountain region, however, it was accompanied by outbreaks of andesitic lava, which must have completely covered the crystalline rocks in the drainage area tributary to the lake basin. This movement was succeeded after a considerable lapse of time by a depression sufficient to allow of the formation of a second lake in the Denver Basin, and probably of others in the Middle Park region to the west of the mountains and in other parts of the Rocky Mountains.

The nature of the depression which produced such lakes without admitting marine waters to any extent within the areas affected is not readily conceivable, yet its effects are shown to have been widespread by the considerable thicknesses of fresh-water beds, consisting largely of eruptive débris, which are found overlying the Laramie in various portions of the Rocky Mountains, and which are manifestly more recent than the Laramie, yet older than any Eocene deposits hitherto recognized. From evidence already obtained it appears that such lakes existed along the east front of the Rocky Mountains at Canyon City and in Huerfano Park; on their southern slope in the valley of the Animas; on the west along the flanks of the Elk Mountains; and in the principal interior valleys, the North, South, and Middle parks.

To the northward, along the east front of the mountains, the continuity of the post-Laramie exposures is broken in northern Colorado and southern Wyoming by a covering of Miocene and Pliocene beds, but they reappear in the basin of the Cheyenne River, and are abundantly exposed in the valleys of the tributaries to the upper Missouri.

DENVER FORMATION.

The beds deposited in the Denver Lake reached a thickness of over 1,400 feet along the flanks of the mountains, but were probably somewhat thinner toward the middle of the basin. The total thickness of the beds as originally deposited can no longer be determined, owing to the extensive erosion to which they have since been subjected.

The most striking characteristic of these beds is the extent to which débris of great varieties of andesitic lavas enter into their composition. The lower 400 feet of the series are composed entirely of eruptive débris; above this point Archean and sedimentary débris are found in small but increasing proportion, and above 900 feet the material derived from the abrasion of Archean rocks is largely predominant, eruptive débris being still present in small amount, however, to the highest remaining part of the beds. The distribution of these varying constituents shows that the eruptive material must have come from the mountains to the west of the lake. The Archean material contains large bowlders, and the sand grains are angular. With the first appearance of Archean débris are found a limited amount of pebbles, traceable to the Dakota conglomerate and Laramie sandstones.

That the Denver beds were deposited in shallow waters is shown by the frequent cross bedding observable both in sandstone and conglomerate, and by the plant remains and standing tree stumps that abound at certain horizons.

About midway in the period, or after 500 to 600 feet of beds had been deposited, several successive flows of basaltic lava were poured out upon the sea-bottom and rapidly covered by deposits of sand and tuff. This eruptive action had no traceable connection with that which produced the andesites, but proceeded from fissures in the strata of the plains. Although most of the flows were poured out upon the surface of the sea-bottom, some small sheets were evidently intruded between the strata already deposited. The conclusion drawn by Mr. Cross from his most complete and thorough study is that in the long period during which the lower portion of these beds was being deposited the Archean and sedimentary rocks in the area from which they were derived were entirely covered by flows of andesitic lavas, but that toward the end of the period these lavas had been almost entirely worn away. Beds composed largely of coarse andesitic material, resting unconformably upon upturned Cretaceous rocks, are found in the Middle Park, on the western side of the Colorado Range, which, as well from their contained plant remains as from this similarity of constitution, are evidently of the same period with the Denver beds. Somewhat similar beds of andesitic débris are reported from the northeastern portion of the South Park. It seems probable, therefore, that the andesitic flows must have covered the mountains lying between these two depressions, but singularly enough no remnants of these flows have yet been observed on them. It must be added, however, that as no systematic survey has yet been made of this interior region it is by no means certain that some may not yet be found.

The vertebrate remains found in both the Arapahoe and Denver beds are considered by the paleontologists to whom they have been referred to have Cretaceous rather than Tertiary affinities, and so high an authority as Prof. O. C. Marsh is decidedly of the opinion that, in spite of the evidence of the two physical breaks and the long time-interval that must have intervened, both Arapahoe and Denver formations are properly to be considered a part of the Laramie. It is to be remarked, however, that in the Denver Basin these vertebrate remains are not found in the coal-bearing rocks here classed as Laramie; neither is there as yet any certain evidence that this fauna existed prior to the Arapahoe and Denver periods.

Abundant plant remains are found in the Laramie and Denver formations, which have hitherto been classed together as belonging to one continuous and uninterrupted series of beds. A careful revision of all the fossil plants collected from these and corresponding horizons has shown, however, that the floras of the Laramie and Denver periods were quite distinct. Of those collected in the Denver Basin (240 species in all) only 10 per cent are common to the two horizons. In the post-Laramie formations of Middle Park and Montana over 75 per cent of the plant remains are common with those of the Denver beds.

These facts, taken together with the stratigraphical evidence in this and in other fields of a great time-interval and physical break intervening between the original Laramie and these later formations, while as yet there is no evidence of any important physical break or erosion period in the time intervening between the deposition of the Denver and of the succeeding Eocene formations, seem to render it in the highest degree inadvisable to include these two later formations under the general head of Laramie, as has hitherto been done and as some paleontologists would still do. The post-Laramie formations, as they have been provisorily called, constitute a very important part of the geological column, which, up to the time these investigations were undertaken, had either been entirely overlooked by geologists or else confounded with underlying or overlying formations, as the case might be. Consisting, as they generally do, of soft, slightly compacted material, they have been readily eroded, and as their remnants are generally found in regions where the strata occupy a nearly horizontal position—that is, where the unconformities to be observed are those of erosion and not of angle of dip—they are not likely to be recognized as distinct from preceding or succeeding formations in ordinary reconnaissance work. Beds that occupy a corresponding position with these formations have been recognized stratigraphically by the present observers at so many points on the periphery, as well as in the interior of the Rocky Mountain uplift in Colorado, as to indicate a general prevalence of similar conditions of sedimentation throughout the region in post-Laramie time. The fossil fauna of most of these exposures is, however, not yet known. On the other hand, at the several exposures from which representatives of the Ceratops fauna have been described, the true position of the particular beds in which their remains occur has in no case, outside of the present field, been so definitely determined stratigraphically as to permit of their exact correlation with other known horizons. From information furnished by Professor Marsh and others it appears that representatives of the Ceratops fauna have been recognized at other localities along the east front of the Rocky Mountain uplift from New Mexico to Canada, and in the great bay that once extended across the uplift westward to the base of the Wasatch Mountains. Wherever these remains have been systematically studied by the vertebrate paleontologist, his attention has been principally directed to the biological problems involved, it having been assumed that the horizon occupied by them was sufficiently defined as Laramie, since it was higher than the Fox Hills Cretaceous, and the affinities of the fauna itself were regarded as Cretaceous rather than Tertiary.

After a careful weighing of all the available evidence furnished by invertebrate and plant remains, as well as by vertebrates found in these localities, and of the somewhat meager data as to their relative stratigraphic position, Mr. Cross concludes that the Ceratops fauna has not as yet been described from any locality belonging beyond dispute to the true Laramie, as defined by King in the Fortieth Parallel Reports, while several of the known occurrences may be correlated more or less definitely with the Arapahoe or Denver formations.

POST-DENVER MOVEMENT.

After the deposition of the Denver beds the region was subjected to another orographic movement, whose dynamic effects are particularly noticeable in the steeper upturning of the Mesozoic strata along the foothills. At this time the Denver Lake was drained and the Denver beds were thereafter exposed to erosion. In the absence of any recognized representatives of the beds that in other parts of the Rocky Mountain region, notably along its western flanks in the Colorado and Green River basins, were most abundantly deposited during the latter half of the Eocene period, it is impossible to fix with any definiteness the time of this movement. It may have occurred at the close of the Eocene, and hence been contemporaneous with that recognized in the above regions as the post-Bridger movement,[1] since the only beds definitely determined to be of Eocene age which have been found on the east flanks of the mountains, viz, those at Huerfano Park, were upturned by this movement; or it may, on the other hand, have been more nearly contemporaneous with those recognized in the Green River Basin, prior to or following the deposition of the Green River Eocene.[2] It is evident that some dynamic movement took place during the Denver period in connection with the outflows of basalt which formed the Table Mountains, for the faulting of the Laramie and Fox Hills strata near Ralston Creek, opposite the main vent or fissure through which the basalt is supposed to have been extravasated, is evidently referable to the same movement which produced this fissure.

The faults which fracture the coal measures, and in one case the overlying Arapahoe beds, in the northern part of the Denver Basin area, may also have been determined by the shattering which accompanied this volcanic eruption, especially if, as it is reasonable to assume, the eruption of the Valmont dike in this region was contemporaneous with that of the Table Mountain sheets.

Whatever may have been the time in which the effects now recognized as caused by the post-Denver movement were produced, whether it was a single movement, or a succession of periodic movements, or an extremely slow and long-continued movement, its character was peculiar and typical of the foothill region in general, and will be specially considered under the head of "Structural geology."

The erosion which followed the Denver movement was most extensive, but here again it is difficult to differentiate that which properly belongs to the period intervening between the deposition of the Denver and of the next succeeding Monument Creek beds. In the center of the Denver Basin something over 1,000 feet of the Denver strata have been removed up to the present day. Under the edges of the Monument Creek beds, on the southeastern edge of the area mapped, about 600 to 700 feet of Denver beds probably remain, which, on the assumption that their original thick-

[1] R. C. Hills, Orographic and structural features of Rocky Mountain geology: Proc. Colorado Sci. Soc., Vol. III, p. 408.

[2] Fortieth Parallel Reports, Vol. II, Descriptive Geology, pp. 203–204.

ness was 1,200 feet, would indicate a removal of about 500 feet in the intervening period. This amount is relatively small if the period is bounded by the Cretaceous on the one hand and the Miocene on the other, and thus affords a further, though confessedly not very strong, argument against assigning a Cretaceous age to the Denver and Arapahoe beds.

MONUMENT CREEK FORMATION.

This series of beds, of which only projecting tongues from the large area forming the divide between the Platte and Arkansas waters extend into the region mapped, consists in general of much coarser material than the Denver beds, but is most readily distinguished by the absence of the andesitic débris which characterizes the latter. It has been less carefully studied, and no fossil remains have been found in the portions examined. It consists in general of conglomerates, sandstones, and arenaceous clays of variegated colors, made up mostly of Archean débris. Two divisions have been distinguished, marked by an apparent unconformity and period of erosion. The lower division is capped by flows of rhyolitic tuff, which forms the present protecting cap of many mesas, as do the basalts of the Denver beds of Table Mountain. The upper division contains, in addition to the Archean detritus, fragments of rhyolitic tuff and of other eruptive rocks.

The assignment of a Miocene age to the beds of this series is based on the discovery, by earlier explorers, of vertebrate remains of this period at points which, while not so definitely located by them as to make it possible to trace the actual connection of the beds, appear to have been sufficiently near the area under consideration to leave little doubt that they must have come from the Monument Creek beds, and probably from the lower series.

On the other hand, there are grounds of probability for assigning the upper division to the Pliocene period, though they were not considered sufficiently definite to justify the distinguishing of the upper series by a distinct color or name. These grounds are, first, the discovery by O. C. Marsh in 1871 of a Pliohippus fauna in the beds capping the Arkansas-Platte divide, south of the Smoky Hill River near the eastern boundary of the State; second, the fact that fossils which probably belong to the same horizon have been discovered at various points within the area of the Denver Basin, and, though not actually in place, in such positions as to indicate that they must have come from the disintegration of beds in the near vicinity. In addition to this, there is the analogy of the beds forming the divide between the North and South Platte rivers, along the Colorado-Wyoming boundary, where the Miocene[1] (Brontotherium) beds are overlain by Pliocene (Pliohippus). Although these beds differ somewhat from the Monument Creek beds in lithological composition, containing more argillaceous and calcareous material, this difference is readily explainable by the different character of the rocks composing the mountain masses to the westward, from the abrasion of which the sediments composing the respective series were formed. In Wyoming, Paleozoic and Mesozoic formations once arched entirely over the Archean nucleus of the mountains and protected it from erosion, whereas in Colorado this Archean nucleus was never entirely submerged, but has always been exposed to erosion.

It is probable that when the plains region to the east of the Denver Basin shall have been systematically surveyed remnants of these beds will be discovered that will be sufficient to prove that both Miocene and Pliocene lakes were continuous across the Denver Basin northward, as was probably the case with those in which the Arapahoe and Denver beds were deposited. With regard to their southern extension, there is more uncertainty, as erosion in the Arkansas Basin seems to have been deeper and more extensive than in that of the South Platte. Professor Marsh is of opinion that the Miocene deposits show signs of thinning out to the southward. This idea is negatively confirmed by the fact that no Miocene beds have been found in Huerfano Park, where Eocene beds are directly overlain by what are supposed to be Pliocene strata.

LATER MOVEMENTS.

Of later orographic movements in this field, the record is too incomplete and fragmentary to afford anything more than a general indication or suggestion.

[1] The assignment of a Miocene age to the Brontotherium beds is on the authority of Prof. O. C. Marsh. Prof. W. B. Scott and some other paleontologists class them as Oligocene.

That there has been a general differential uplift of the mountain or subsidence of the plains area—a continued action of the same forces which produced the upturning of the Mesozoic (including the Arapahoe and Denver) beds—is indicated by the observed upturning, at angles of from 15° to 20°, of the Monument Creek beds near the flanks of the mountains. Elsewhere, so far as observed, they do not depart from a practically horizontal position, and apparently have not been subjected to deformation resulting from a general orographic movement. Movements of elevation and subsidence, rather of an epeirogenic or continental nature, are indicated by both Tertiary and Pleistocene deposits that have a lacustrine origin, since the present inclination of the plains region, which shows an average descent in round numbers of 10 feet to the mile from the foothill region to the valleys of the Missouri and Mississippi, would not admit of the holding of lake waters on its surface.

It has already been suggested by earlier writers that the present conditions of the Tertiary deposits of the plains region indicate a differential tilting of this region which has produced a relative change of level of 5,000 feet or more between its eastern and western borders. The area of the present investigation has been too circumscribed to furnish much additional data on this subject. It can only be said that movements of this general nature have in all probability been several times repeated during Tertiary and Pleistocene times, but until the extent and character of these deposits shall have been carefully studied over the whole plains region and their relations to the underlying beds determined it will be impossible to trace with any approach to accuracy the nature and history of these movements.

PLEISTOCENE FORMATIONS.

In the absence of any phenomena in the region that can definitely be assigned to Pliocene time, whatever has occurred since the deposition and elevation of the Monument Creek beds is provisorily assumed to be post-Pliocene or Pleistocene. In this period the present drainage areas of the plains took definite form. The Monument Creek beds were removed from a part, and possibly from nearly the whole, of the area mapped, and the present outlines of the Platte Basin were generally established. How much of this erosion may have been already accomplished prior to the Glacial period it is impossible to determine, but it is probable that the greater part of the erosion was due to the melting of the ice. The floods of that period carved out river channels more or less coincident with those of the present stream beds of the Platte, Clear Creek, etc , which were subsequently filled as the reduced slope of the streams diminished their corrading power, and when, in a later period of erosion, these streams cut their present beds, which are of relatively diminutive size as compared with those of the ancient streams, they varied somewhat in detail, and their courses, though generally conforming to ancient drainage lines, cut into the old river gravels to a depth of 30 to 50 feet. Between these two periods of erosion there was deposited over the whole area of the Denver Basin, below a level of 5,800 to 6,000 feet, a fine silt or loess, which apparently extended out over the plains of Kansas and Nebraska, and which gives to this region its remarkable fertility wherever it is susceptible of irrigation. In its physical structure and composition this loess is very similar to that of the Mississippi and Missouri valleys, the principal difference being its greater coarseness of grain. With the exception of the alluvium of the river valleys and of modern sand dunes, it is the most recent deposit of the region, and hence, being unconsolidated and readily disintegrable, it has been so very largely removed by modern erosion that its original extent is not easily determined. Its thickness in certain portions reaches 200 to 300 feet, but in the valleys is generally under 50 feet.

The origin of this peculiar and economically important deposit in different parts of the world is one of the problems in geology that has been found most difficult of satisfactory determination. The great loess deposits of China, the most important in the geologically known world, are now conceded by all geologists who have examined them to be of subaerial origin. On the other hand, the geologists who have made the most recent and detailed studies of the loess of the Mississippi and Missouri valleys consider it to have been formed by the fine silt produced by the grinding of the great northern ice-sheet. The great difficulty involved in the latter theory is to account for the existence of a body of comparatively tranquil water in which such finely divided material could have been deposited.

In the loess of the Denver Basin the evidence shows that the lower part at least must have been of subaqueous origin. It seems necessary to suppose that, after the rapid erosion which carved out the ancient river beds, by some tilting of the plains region its general slope was so reduced that the abundant water, resulting from the melting of the ice in the mountains, gradually backed up in a temporary lake which existed long enough for the settling to its bottom of this fine silt, which was readily carried a long distance from its shore-line, and that subsequent tilting in a reversed sense produced the present slope of the plains and the conditions of modern drainage. It is quite possible that after the waters had entirely drained away there would have been, under favoring climatic and meteorologic conditions, a certain rearrangement of and adding to this material, which would thus have been of subaerial origin, similar to that forming at the present day in China.

Before this subject can be satisfactorily treated, however, it is necessary to learn more than is at present known of the extent of this loessial material.

STRUCTURAL GEOLOGY.

The tectonic or structural geology of an area like the present, though at first glance apparently very simple, involves some of the radical problems of geotectonics or mountain building, and it is therefore important to note all the details of its structure and endeavor to draw some conclusions as to the manner in which the present structure was produced. It is not proposed, however, to enter into any discussion of first causes—that is, whether the forces which produced the observed deformations are the result of the contraction of a cooling crust on a molten globe, of overloading of areas near old shore-lines, or of any of the various hypothetical causes which geologists and physicists have proposed to account for the observed facts of the geological structure of our globe. Geologists are as yet far from being in accord on these theoretical points, but those who have had the most extensive field experience are agreed that the observed effects are most readily accounted for by the action of intense forces of compression of the outer crust of the globe acting generally in certain determined directions, whether these forces are the result of contraction or of any other cause.

In the Denver Basin the beds underlying the plains area, except for some slight fracturing in the developed coal beds of the northwestern portion of the area, are practically in the position in which they were originally deposited. They have been lifted above sea-level and exposed to erosion at various times, and there is possibly a slight upward curve of the Mesozoic beds on the eastern edge of the basin sufficient to produce a basin structure, but of deformation or pronounced flexing of the beds there is, so far as observed, a notable absence.

In the foothill region, on the other hand, there is pronounced deformation, manifested in both folding and faulting, but it has a character of its own, distinct from the intense plication found in highly disturbed mountain regions, though partaking of some of its characteristics. It occupies structurally, as it does geographically, an intermediate position between the relatively undisturbed areas of the plains and the intensely disturbed and plicated rocks of the mountain region.

The Archean areas of the present region, as has already been stated, have not been specially studied; hence nothing need be said of their structure except that they were already so intensely deformed prior to the deposition of the Mesozoic beds that it is highly improbable that any study of their present structure would enable one to trace the effects of the later movements which have affected the more recent beds, though these movements undoubtedly must have been felt within the crystalline complex.

PLAINS AREA.

The departure from a horizontal position of the strata on the plains is usually so slight as not to be susceptible of instrumental measurement, so that it must be measured by the relative position of outcrops of the successive beds as platted on an accurate profile. Such profiles, given on the structure sheet (Pl. IV, in pocket), which are limited in extent to the width of the map, also show no very perceptible rise of the strata to the eastward, and from these one would judge that the basin in which the Arapahoe and Denver beds was deposited was a basin of erosion. In crossing the plains still farther east, though the surface rises slightly, one crosses successively lower outcrops of the Laramie strata as one goes eastward; hence there is apparently a slight rise or arching up of the strata toward the present surface, which, combined with the effects of the erosion of the Platte and its predecessors, has produced the eastern rim of the Denver Basin. The amount of arching is not readily determinable, since it does not come under direct observation. It would be greater or less according to whether, on the one hand, at this distance from the original shore-line there is already a considerable thinning of the strata or, on the other hand, the arching is within the limits of what students of orographical geology have called the syncline of deposition,[1] which, as they assume, is produced by the extra weight brought upon the sea-bottom by the greater thickness of beds deposited along the shore-platform of a continent or continental island.

In the present case, if there had been a syncline of deposition whose eastern limb had a perceptible inclination to the west the subsequent movements of compression would have produced an anticlinal fold of visible amount of arching along the limb, which is evidently not the case.

On the other hand, it is to be remarked that, though the present surface rises slightly from the Platte Valley eastward, if one takes into consideration a longer distance eastward—say from the point nearest the foothills where the strata assume a horizontal position to the eastern boundary of Colorado—there is a general slope of the surface eastward, which may be sufficient to account for the appearance of successively lower beds of the horizontal formations, without having recourse to any supposed arching of the strata or of the sea-bottom to produce a syncline of deposition. The actual proof of the one fact or the other could under these conditions be obtained only by the accurate determination of the relative position of the bottom line of some formation or of an easily recognizable bed within a formation at a number of different points. Such a determination can hardly be hoped for under existing conditions. It may be assumed, then, as most probable that the existence of the Denver Basin is due rather to erosion than to curving of the strata into a low arch within a hundred miles from the mountains. It is probable that the long-shore currents with a general northern direction, which, as has already been shown, are proved to have existed in the Dakota Ocean as well as in the Arapahoe and Denver lakes, may have produced a series of

[1] Conditions of Appalachian faulting, B. Willis and C. W. Hayes: Am. Jour. Sci. (3), Vol. XLVI, Oct., 1893, p. 257.

low ridges or sand bars on the ocean or lake bottoms, more or less parallel to and at some little distance from the shore-line. The waters pouring out from the mountains at various periods of erosion would have come in greatest volume from the present general upper drainage system of the Platte River; these ridges would have tended to give an initial northern direction to their course, which, once determined, would have influenced all drainage courses of subsequent erosion systems. Thus, as is shown in a general way on the profiles, the hollowing out of the bottoms of the Denver and Arapahoe lakes to form the Denver Basin would have had at first a northerly direction, and would bend more and more rapidly eastward with the general slope of the country as its distance from the ancient shore-line increased.

FOOTHILL STRUCTURE.

At first glance the geological structure of the foothill regions seems extremely simple, being merely the upturning of the ends of the sedimentary beds along the mountain flanks where they were most nearly in contact with the crystalline core of the range. The first explanation to suggest itself for such upturning is evidently a vertical upward movement of that core, which carried up with it the beds immediately resting upon it. It seems hardly necessary to mention the theory maintained by early explorers in the region, when the study of mountain structure was in its infancy, that this upturning was merely the remaining limb of a great anticline whose crest had been eroded off and planed down, and that the whole series of upturned strata once arched entirely over the mountain crest. This theory has long been disproved by a demonstration of the rarity in nature of such conditions, once held to be typical of mountain ranges, and of the impossibility of explaining by it the actual phenomena in this field.[1]

The idea that mountain elevation was produced by a vertical upthrust or force acting directly upward under the center of the range was one of the primitive theories held when the field of geological observation was very limited and theories were based more on meditation in the office than on actual exploration in the field. As field study advanced it was entirely

[1] Mon. U. S. Geol. Survey, Vol. XII, p. 20.

abandoned and was replaced by the theory of tangential compression, under which the more or less yielding interior of the mountain was, so to speak, squeezed up, thus producing in effect something analogous to a vertical upthrust, but as the result of a horizontally rather than a vertically acting force. Recourse has again been had by a few writers[1] to a vertically acting force for the explanation of mountain uplift, but they have found few followers among the actual working geologists.

In the present case the objection to the theory that the upward curve of the sedimentary strata adjoining the mountain flanks was produced by the rising of the mountains, dragging up the ends of the strata with them, is readily apparent on an examination of the existing conditions shown by the accompanying geological map and sections. In the first place, the movement of displacement on the various longitudinal or strike faults along the foothills is just the reverse of what it would be had the movement been thus produced. The beds on the side of the fault planes nearest the mountains would then have been dragged up, relatively to those on the other side, whereas in point of fact it is the beds on the opposite side of the fault plane, or farthest away from the mountain mass, that have suffered upthrow.

Again, were the upward curve of the beds produced by the upward movement of the crystalline rocks upon which they rest, those nearest these rocks would have been more steeply upturned than those farther away; or in other words, in a series of beds thus upturned whose edges were subsequently planed down, the resulting outcrops would show decreasing angles of dip as one proceeded eastward from the Archean exposure toward the plains, whereas in point of fact the reverse is the case.

This is shown diagrammatically in the following sketch (fig. 1), in which diagram *a* shows the varying dips that would be found in a series of sedimentary beds that had been upturned by a vertical upward movement of the Archean shore-line upon which they had rested. Diagram *b*, on the other hand, represents the actual conditions of dip in the beds of the foothill region, in which the angle of dip becomes steeper as distance from the shore-line increases, and which are more readily explainable as a result of tangential pressure

[1] Sixth Ann. Rept. U. S. Geol. Survey, 1886, p. 197.

The beds were probably deposited on a shelving shore; that is, the slope of the contact of sedimentary beds with the underlying complex of crystalline rocks was not vertical, but decreased in angle with the distance from the mountains. Hence a vertical upthrust of this complex could not produce the abrupt transition from the vertical to the horizontal position in the overlying beds that is shown near D in diagram *b*.

Tangential pressure, or a force of compression acting in a nearly horizontal direction, seems to afford a more reasonable explanation of the observed phenomena of deformation in the foothill region, and accounts readily for most of them, though a certain amount of differential vertical movement seems to be required for certain phases.

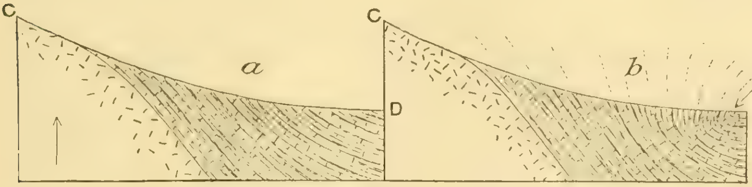


FIG. 1.—Upturning of strata along base of range.

The observed phenomena to be accounted for may be briefly enumerated as follows:

1. Eastward dip of the beds away from the mountains.—This dip increases in steepness as one ascends in geological horizon, or proceeds eastward across the strike from the foothills toward the plains, from 25° to 30°, as a rule, in the lowest or Wyoming beds to 45° in the intermediate series, increasing rapidly to a vertical or even beyond in the Laramie strata, with which the overlying Arapahoe and Denver beds, where not eroded away, are found to be involved; then changing in a few hundred yards of horizontal distance to a practically horizontal position. The dip of the upturned beds, if projected upward into the air, would produce a sort of partial fan structure. (See diagram *b*, fig. 1.) The width of outcrop, which nearly corresponds to the distance between the Archean contact and the vertical dip, varies with the thickness of the beds from 4 miles on Turkey Creek, near Morrison, to about 1 mile at Golden. At the latter point the vertical Laramie beds approach very close to the Archean

foothills, and here it is easy to conceive of a horizontal shove of the strata in a westward direction against the unyielding buttress of Archean rocks, which, a slight initial upward curve of the beds being presupposed, would bend the beds in immediate proximity to the buttress into a vertical position. The condition of things on the Turkey Creek or Morrison line, on the other hand, is less readily conceived as the result of a simple horizontal shove, for between the vertical Laramie sandstones and the Archean buttress is the great thickness of soft clays of the Middle Cretaceous, under which come the hard, unyielding Dakota sandstones at an angle of 45°, with other sandstones and clays below them at a still lower angle, and it would seem that the horizontal shove would induce a sliding upward

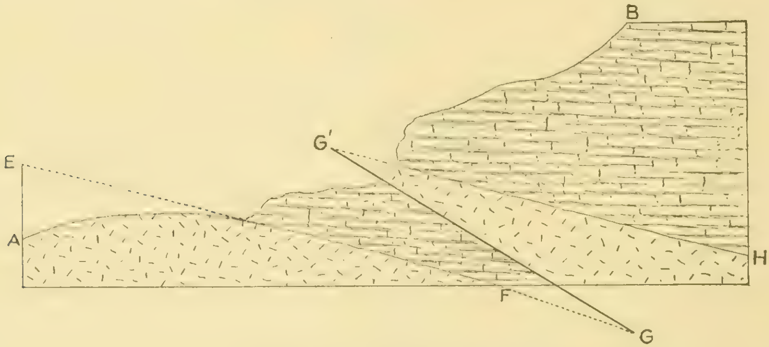


FIG. 2.—Restoration of overthrust fault near Boulder Peak.

of the upper beds over the more gently inclined lower series, instead of bending the former almost at a right angle, as they appear to have been bent, unless there were some force to hold them down.

If one examines the curve of the beds at the bend, on the sheet of cross-sections (see Pl. IV), which have been most carefully constructed from measured dips at many points and represent the most probable form of the curve of the strata underground that can be deduced from facts that actually come under observation, it will be seen that the most probable direction of a force which would make such a curve would be one acting at an angle of 45° with the horizon, or in the general direction of the arrow in diagram *b*, fig. 1. Such a force might be considered as the resultant of a horizontal force pushing westward and a vertical force directed vertically downward. The vertical force may be conceived to be the load of superincumbent strata; and if, as seems probable, there is a tendency of the plains area to sink, under the load of accumulated sediments, with relation to the adjoining unloaded mountain mass of Archean rocks, the relative effect would be the same as if the latter had been subjected to a vertical upthrust.

2. Overthrust faults.—The second series of phenomena to be considered are *the longitudinal or strike faults in the Wyoming beds*, by which fragments of the latter are left among the Archean rocks or a piece of the Archean basement is pushed up among the red sandstones. The former phenomenon is seen south of South Boulder Creek and at several points along the foothills to the north of the area mapped; the latter, at South Boulder Peak and in the hogback valley near Deer Creek.

One of the latter faults is represented in section on fig. 7, p. 116, where it is seen that the fault plane dips to the east and would, therefore, at first glance, appear to be a normal fault in which the downthrow should be to the east; but that it is in reality an overthrust fault may be seen in fig. 2, p. 48, in which the part of the section adjoining the fault is turned so as to bring the sedimentary beds to a horizontal position. In this diagram the line A B represents the present surface as carved by erosion. A F G H represents the ancient shore-line or contact of sedimentary beds with underlying Archean, broken, however, by the fault G G′, whose movement has carried the point G to G′.

In addition to the thrust movement, there has evidently been some upward movement in the beds adjoining the Archean which brought about their steeply upturned position, and this may be accounted for on the ground that as this locality was so much nearer the shore-line than the points where the sharp bend from the vertical to the horizontal position of the bed occurs there would have been a lesser load of superincumbent strata, either through nondeposition or by reason of subsequent removal by erosion; hence the element of the compressive force that tended to act vertically downward would have been smaller and the resultant force more nearly horizontal, and thus have admitted of a certain amount of pushing up along the shelving shore.

3. Transverse folds.—Next to be considered are the *arches of the sea-bottom at Golden and Boulder*, whose axes, as has already been stated, must have been more or less at right angles with the prevailing line of strike. These arches were formed previous to the main or post-Laramie movement, and must be conceived to be the result of a longitudinal compression. The writer's study of mountain uplift has shown him that in most every great mountain uplift there are evidences of two forces of compression acting more or less at right angles to each other, as here, and producing a major and a minor series of folds. In the Archean area immediately adjoining the present field, indeed, the structural lines show evidence of considerable longitudinal compression. Hence the force which produced these arches is not difficult to conceive of, but it is less easy to understand why the arch should have occurred exactly where it did and not at other points. Once initiated, it is quite comprehensible that it should ever afterward be a point of weakness, or of least resistance to the compressing forces, and thus the succeeding movements are readily conceivable. That it continued to be a line of weakness after longitudinal compression had ceased is also evidenced by the fact that it was at this locality in Denver time that the basaltic eruptions were forced up to the surface.

It might be argued that the extravasation of such a considerable mass of eruptive material from beneath the surface would account, in part at least, for the sinking of the upper part of the sedimentary series at this point (which is predicated by Mr. Eldridge's diagram, p. 99, in order to account for the present relative position of their outcrops), and that this would obviate the difficulty conceivable in the ironing out or flattening of the arch previous to the upturning of the beds along the flanks of the range. This would, however, necessitate the assumption that the greater part of this upturning occurred since the deposition of the Denver beds. If it were also assumed, as has been already suggested as possible, that the upper part of the sedimentary series above the Middle Cretaceous clays had been pushed in toward the foothills, prior to this upturning, by an overthrust movement over the arch, there would have been less of an arch to be planed down and the void left by the extravasation of the basalt might have been quite sufficient to have produced the flattening of the arch.

TYPICAL RED-BED SCENERY, GARDEN OF THE GODS

CHAPTER II.

By George H. Eldridge.

MESOZOIC GEOLOGY.

SECTION I.—THE FORMATIONS.

TRIAS.

WYOMING FORMATION.

STRATIGRAPHY.

Within the Denver Basin, lying at high angle of dip along the base of the Archean slopes and often extending to a considerable height above them, is a prominent series of brilliant-red conglomerates, sandstones, and shales, with thin limestones and gypsums in the upper part. These are the well-known Red Beds of the Rocky Mountain region. They are commonly referred to the Trias. The term "Wyoming" is here adopted as their formation name. In the Denver field they rest directly upon the ancient crystalline rocks, although in many other localities there intervene thousands of feet of Paleozoic measures, Permian (?), Carboniferous, Silurian, and Cambrian.

The thickness of the series exposed in the Denver Basin varies between 500 and 3,000 feet, but is generally somewhat under 1,500. The variation is chiefly due to the unevenness of the ancient floor upon which the formation was laid down, the Archean having been thrown into folds and having suffered extensive denudation before the deposition of the younger formations upon it.

In the southern half of the area mapped the topography of the Red Beds is that of a longitudinal valley between an Archean mountain slope on the west and a ridge of Dakota quartzite or sandstone on the east. Rising from the valley bottom are lofty, cathedral-like spires of vertical or highly inclined strata, brilliant in coloring, and producing by contrast with the green of vegetation effects most picturesque. In the northern portion of the field these effects still prevail, but the lower half of the Red Beds rises high upon the mountain slopes, forming prominent peaks along the range-front.

The formation is separable about midway into a lower division, of soft, friable conglomerates and coarse sandstones, with few shales, and an upper one of shales, with some prominent sandstone bands, narrow beds of limestone, and small local deposits of gypsum. The following section, taken at Morrison, is typical, reading from top downward:

Section at Morrison, Colo.

	Feet.
UPPER DIVISION.	
Sandstone, fine-grained, often massive, pink and brown; persistent	15 to 25
Clays, bright-colored—gray, yellow, green, pink, and lilac; gypsiferous and calcareous, especially 40 feet below their summit	125 to 175
Clays, more arenaceous than above; transitional in color, from grays, etc., above, to prevailing brick-reds below	150 to 200
Sandstone and shale, alternating; brick-red to pink; white dots; sandstones prominent	50
Sandstones and shales	60
Shales, sandy and argillaceous, brick-red, carrying narrow bands (3 to 6 feet) of white crystalline limestone	75
LOWER DIVISION.	
"Creamy" sandstone; quartzose; conglomeritic at base; two sandy limestone bands in lower part; round ferruginous concretions near top; forms prominent outcrop in valley between Archean and Dakota (average 250 feet)	200 to 400
Red Beds; conglomerates, sandstones, and shales, the last of minimum development; color, red; outcrops, lofty spires and pinnacles and towering masses of irregular shape	270 to 2,000

The lower division.—Although the contact between the Archean and the Trias occurs at a constantly varying horizon in both formations, the lower 5 to 20 feet of the Red Beds is nearly everywhere composed of coarse, subangular fragments of the adjacent granite, gneiss, or schists, with a small admixture of their derived sand, which shades in places to a red arenaceous mud. The materials are usually but loosely agglomerated, yet instances are frequent where the finer and less-worn débris is compacted to a rock so hard that, with the same mineralogical constitution, it closely resembles the underlying granite, their dividing line being very difficult to determine. Cross-bedding is developed at the base of this layer, while in its upper portion evidences of eddying shore currents exist in heavy deposits of pebbles in deep-worn depressions in the beds first laid down.

Succeeding this layer is a series of heavily bedded sandstones and grits, with small local bodies of arenaceous shale. The normal thickness of this series is about 1,200 feet. The color varies from prevailing red to gray, according as the chief constituent of the rock is red feldspar or quartz. A very fine-grained, deep-red, shaly sediment, approaching mud in consistency, contains also a considerable per cent of black and white mica. Iron oxide is generally present and assists in the coloring, particularly in the more shaly varieties.

The lower 200 feet of sediments are generally coarser and less compact than those overlying. Cross-bedding is a marked feature from base to summit.

The foregoing beds pass by a broad transitional zone of lighter-red and more quartzose sandstones to the upper member of the division, a heavy bed of cream-white sandstones from 200 to 400 feet thick. From its color this sandstone has become known as the "Creamy sandstone." It usually forms a well-marked ridge from 50 to 100 feet high along the middle of the valley of Triassic rocks. In the lower half it is somewhat more friable, and consequently more frequently eroded, than in the upper. It is also occasionally tinged a faint red, in irregular patches. Two small bands of dark-brown, quartzose limestone, from 2 to 8 feet thick, are usually present—one near the base, the other 40 feet up. The intervening sandstone is heavily cross-bedded, and in some layers conglomeritic, pebbles and matrix consisting chiefly of quartz, with occasional admixtures of other débris from the crystalline rocks, and some brown arenaceous or cherty limestone.

The upper half of the sandstone is also conglomeritic at the base, but becomes fine-grained above. It consists of quartz of great purity, and affords nearly the entire amount of silica used in the pottery and fire-brick establishments at Golden. Twenty feet from the summit are numerous small, brown or reddish nodules of cemented sand one-eighth to one inch or more in diameter, many of which first weather in relief and then roll out in balls; some of the larger, on being broken, are found hollow. The upper 6 feet of the Creamy sandstone locally becomes conglomeritic and calcareous, easily disintegrating and leaving a surface strewn with pebbles, all more or less angular. In this layer small geodes, lined with calcite crystals, also occur. The Creamy sandstone as a whole is remarkably uniform in texture and appearance. In the region of the South Boulder Peaks, however, where disturbed by faults or folds, the bed becomes a tolerably hard quartzite, fractured and slickensided, but its leading features are still maintained and its identity is easily established.

The upper division.—The lower half of this division consists of bright, brick-red, arenaceous shales and sandstones, with important intercalations of limestone. The limestones occur within 75 feet of the base, usually three or four beds from 6 to 18 inches thick in the lower 15 feet, and 50 feet higher up a bed 5 feet thick, a red, sandy shale intervening. The upper bed is overlain by a succession of thin, wafer-like layers of white limestone and red mud, in all 5 or 10 feet; these present in cross-section a wavy structure, with sharp contrast of color and texture, the surface weathering in delicate corrugations. Close examination occasionally reveals this structure in the limestone itself, the clay bands, however, being absent. Chert concretions, of purple color, which weather in concentric circles and ultimately develop circular holes in the backs of the layers, are present, as are also vugs filled with calcite crystals. Minute grains of an undetermined black mineral also occur quite generally at this horizon.

Following is an analysis of the upper limestone:

Analysis (by L. G. Eakins) of Upper Wyoming limestone from Morrison, Colo.

	Per cent.
Insoluble	5.32
CaO	48.73
MgO	2.95
MnO	.49
Al_2O_3	.53
Fe_2O_3	.38
P_2O_5	.032
H_2O	.11
CO_2	41.71
	100.252

An illustration of the variation in stratigraphic range and lithologic appearance to which the limestones are subject occurs at Willow Creek, 5 miles south of Platte Canyon. There are here four distinct bands, one lying immediately upon the Creamy sandstone, the others, respectively, 30, 60, and 70 feet above. All are white and crystalline. The lowest is 1½ feet thick, without banding, has an angular fracture, and contains abundant calcite crystals in small irregular vugs, but has none of the minute black mineral seen in the other bands. The second, 2 feet thick, is gray, faintly banded, and contains grains of a black mineral. The third, 2 to 4 feet thick, contains the black mineral and, in addition, the purple amorphous chert concretions; it also displays the banded structure. Ten feet above the third is the fourth limestone, the two being united by intervening, banded, calcareo-argillaceous beds. The upper layer is about 3 feet thick, is banded a faint purple and white, and has a considerable amount of ferruginous matter through it. Banded strata of lime and mud succeed for a few feet, when they are followed by the red clay shale which generally closes this series.

The strata above the limestone series become more and more arenaceous, though still retaining in large degree their shaly nature. About 60 feet up are a number of layers of fine-grained, compact, red sandstone, 2 to 6 inches thick, characteristically marked with sharply defined, white, circular dots, one-eighth to one-half inch in diameter, which are sections of spherical masses containing at the center minute undetermined bodies. These features are especially well seen along Bear Creek. A heavy-bedded, fine-grained sandstone occasionally appears in this series, notably in the vicinity of Turkey Creek.

At 150 or 200 feet below the top of the Trias the strata become more clayey and take on a variety of irregularly distributed bright colors—gray, yellow, green, pink, and lilac. In this zone gypsum and brown earthy limestones are common. The gypsum occurs either in small local bodies of lenticular shape or in crystals uniformly disseminated through the clay. The limestones are also lenticular, but in bodies greatly attenuated and rarely over 6 feet thick; they are especially developed about 40 feet below the capping sandstone of the formation. The larger bodies of gypsum occur in connection with the limestone. About this horizon is also found at Morrison and at Deer Creek, though not observed elsewhere, a thin band of sandstone carrying finer or coarser particles of a white and red jasper-like material.

The Trias closes with a sandstone from 15 to 25 feet thick, usually fine-grained, and composed of quartz, with a small quantity of mica and feldspar, the lower portion slightly calcareous. The sandstone is either compact and massive, when it is adapted for building purposes, or thin-bedded and friable, with a tendency to become shaly. The lower 8 feet is usually brown; the middle 10 or 15 feet, pink; the upper 4 feet, brown. The entire bed is often delicately cross-bedded and ripple-marked. Rolled particles of clay are occasionally present, which, by weathering out, leave a pitted surface. Both the under and upper surfaces of the bed are sharply divided from the shaly strata adjoining, but the upper surface is especially well defined, and at Morrison is somewhat undulating—apparently the line of an unconformity, or at least of interrupted deposition.

CORRELATION.

The Red Beds, wherever present in the West, constitute a prominent feature in the scenery, on account of their color and persistent lithological characteristics. They were regarded as Triassic by the earliest geological explorers, because they were locally found between horizons characterized by well-defined Jurassic fauna above and an Upper Carboniferous fauna below. As exploration extended, it was found that on the western flanks of the Front or Colorado Range there was a much greater development of Red Beds than on the eastern, and that their lower portion, which is more of a chocolate or maroon-red color, graded insensibly into a series of strata containing Carboniferous fossils. These facts tend to show that a part of what had been originally mapped as Trias may more properly be considered Upper Carboniferous or Permo-Carboniferous; but enough paleontological evidence has accumulated to justify the assumption that the upper part of the series, the Red Beds proper, the Wyoming formation, is probably Triassic.

This latter evidence rests, first, on the discovery by Dr. A. C. Peale in southeastern Idaho of Triassic and Jurassic fossils, which were later determined and discussed by Dr. C. A. White.[1]

Among these forms, those regarded by Dr. White as of distinctly Triassic character are *Meekoceras aplanatum*, *Meekoceras mushbachanum*, *Meekoceras gracilitatis*, *Arcestes? cirratus*, *Arcestes —— ?*, *Arcestes —— ?*, *Eumicrotis curta*, *Aviculopecten? pealei*, *A.? altus*, *A.? idahoensis*, *Terebratula semisimplex*, *T. augusta*. The Jurassic forms embraced *Pentacrinus asteriscus*, *Belemnites densus*, *Camptonectes bellistriatus* (of Meek and Hayden), and *Eumicrotis curta*, and were obtained from the same locality, but from different and much higher strata. Between these two distinct horizons are found the "Red Beds," which Dr. Peale regards as the equivalents of the Red Beds east of the Rocky Mountains, from identity of lithological characters and manner of occurrence.

Dr. White, in his remarks on the above fossils, states that "some of the types in which these forms are expressed are, as originally pointed out by Professor Hyatt, such as in Europe are regarded as characteristic of the Middle Trias—the Muschelkalk." This reference indicates that at least a portion of the Red Beds, in certain localities, may properly be regarded as Triassic, and though Drs. White and Peale employ the evidence of the fossils especially by way of distinguishing the Jura and Trias as separate formations in the Rocky Mountains the results may be equally well

[1] Jura-Trias section of southeastern Idaho, Bull. U. S. Geol. and Geog. Surv. Terr. (Hayden), Vol. V, 1871, p. 119; Fossils of the Jura-Trias of southern Idaho, ibid., p. 115; Triassic fossils of southeastern Idaho, U. S. Geol. and Geog. Surv. Terr. (Hayden), Vol. XII, 1878, p. 105; Invertebrate Paleontology, No. V, Triassic fossils of southeastern Idaho, by C. A. White.

employed in the present instance in fixing the taxonomic rank of the portion of the Red Beds under discussion, and, in addition, as evidence of the propriety of dividing the entire series into two distinct groups, thus establishing in the West the same division for the New Red sandstone as is held in Europe. Additional evidence for such division, as well as some, in the nature of plant life, opposed to it, is found in the developments by Professors Scudder and Lakes, at Fairplay, Colo.[1] In the Red Beds of this locality Professor Scudder discovered several species of cockroaches, the affinities of which led him to regard the beds with no little positiveness as Triassic. A summary of his argument is as follows: First, there exists a distinct difference between the Fairplay species of cockroaches referable to different genera of the Palæoblattariæ, or Paleozoic cockroaches, and any species heretofore known in the Paleozoic belonging to the same genera; second, there is the presence of two new genera and several new species belonging to the Palæoblattariæ, the former either notably different from any of their other genera or, with certain affinities for the associated new species belonging to one of the genera of this family already known, but which have a marked difference from the known species of that genus; third, the smaller size of the Fairplay cockroaches as compared with the Paleozoic forms, and their close agreement in this respect to European Mesozoic cockroaches—a fact that has much value; fourth, the presence of several cockroaches not belonging to the Palæoblattariæ, and closely allied to the Jurassic forms of England—so much so, indeed, that several of them, at least, would be at once recognized as such by anyone familiar with the forms already known from the formation in England; fifth, the entirely different aspect of all the latter from any and all Paleozoic forms.

Professor Scudder sums up his remarks thus: "They show a commingling of strictly Jurassic forms with a larger proportion of types which may be called Upper Carboniferous or Permian with a distinct Jurassic leaning. There is, therefore, a strong probability that the beds in which they occur belong to the intermediate formation, the Trias." Moreover, the insects found at Fairplay are two-thirds as abundant in species as the plants, which

[1] Triassic insects from the Rocky Mountains, by Samuel H. Scudder, Am. Jour. Sci. (3), Vol. XXVIII, p. 199; On some specimens of Permian fossil plants from Colorado, by Leo Lesquereux, Bull. Mus. Comp. Zool., Harvard College, Geol. Ser. I, Vol. VII, p. 243.

Professor Scudder states is "an exceptionally large ratio in beds where both occur."

In contradiction of the conclusions thus drawn by Professor Scudder from the fauna are those derived by Professor Lesquereux from the fossil plants collected from the same beds.

The plants collected, although fragmentary, permitted the recognition of several genera and species characteristic of the Permian, with even a tendency at times to a Carboniferous facies when compared with the European and Virginia forms of the Carboniferous and Permo-Carboniferous groups, respectively. Professor Lesquereux furthermore compares the Fairplay flora with Fontaine's flora of the Trias (Rhætic) of Virginia, and finds no resemblance whatever between the forms of the two localities. The same occurs on a comparison with European Trias forms also, and this entire absence of even a trace of Triassic flora Lesquereux regards as a strong argument for the Permian age of the beds considered.

Scudder, on discussing Lesquereux's evidence, meets the possible observation that this discovery of cockroaches may indicate for America an earlier advance within Paleozoic times toward later types, by remarking that such a deduction would be in direct opposition to what we know of subsequent periods in America. He cites one case in favor of this hypothesis, and one, which he considers stronger, against it, and states that from all evidence such an advance should rather be looked for in Europe than in America. Other instances of similar discrepancies are found between the Paleozoic and Secondary strata at Kaigahinsk, in eastern Russia,[1] and between the Carboniferous and Permian at Pilsen, in Bohemia.[2]

In comparing the evidence of plants and animals, that of the latter would seem to merit the greater weight, because the conditions of distribution and preservation of plant remains are in favor of their continuance, conditions which are not shared by animals, and, as Mr. Twelvetrees further suggests, it may be that the survival of the older and more persistent forms should count for less than the appearance of the new ones.[3]

[1] W. H. Twelvetrees, in Quart. Jour. Geol. Soc. London, Vol. XXXVIII, p. 495.
[2] Geikie, Text-book of Geology, pp. 748, 754.
[3] See also Geikie's remarks, Text-book of Geology, pp. 759, 763.

In the San Juan area of southwestern Colorado, Mr. R. C. Hills[1] found in the upper part of the red sandstones lying between the purple Permo-Carboniferous (?) sandstones below and Jurassic limestones above vertebrate and plant remains indicative of a Triassic age.

Newberry[2] and Cope[3] have separately referred certain plant and vertebrate remains discovered in the red sandstones of New Mexico to the Upper Trias. In the present volume Prof. O. C. Marsh also mentions the presence in the red sandstones of New Mexico and Arizona of dinosaurian and crocodilian remains of Triassic types.

Inasmuch, then, as there seems to be reasonable ground for the assumption that a portion, at least, of the Red Beds horizon of the Rocky Mountain region is Triassic in age, and since the beds treated in this report occur immediately beneath well-defined Jurassic strata and very probably represent the upper part of the great series of Red Beds, it seems proper to designate them, provisionally at least, Triassic.

The dividing line between this series of strata and the succeeding, the Jurassic, must, in the absence of paleontological evidence, be somewhat arbitrarily taken; in this case it has been determined mainly on structural grounds—an undulating line, as of unconformity or at least of interrupted deposition—though stratigraphy and a lithological character allied to the underlying Red Beds have had somewhat to do with the division.

JURA.

MORRISON FORMATION.

Throughout the Denver field and for much of the distance along the eastern base of the Rocky Mountains in Colorado the Jura is essentially a formation of fresh-water marls, of an average thickness of about 200 feet. Its upper limit is sharply defined by the Dakota sandstone, while the brown and pink sandstone closing the Trias as clearly marks its lower limit. To this formation has been assigned the name "Morrison," from the town near which it is typically developed.

[1] Note on the occurrence of fossils in the Triassic and Jurassic beds near San Miguel, in Colorado. Am. Jour. Sci. (3), Vol. XIX, p. 490, 1880; Jura-Trias of southwestern Colorado, ibid., Vol. XXIII, p. 243, 1882.

[2] Mon. U. S. Geol. Survey No. XIV, pp. 8–15, 1888.

[3] Am. Philos. Soc., Proc., Vol. XXIV, p. 227, 1887.

The marls are green, drab, or gray, and carry in the lower two-thirds numerous lenticular bodies of limestone of a characteristic drab color and a texture compact and even throughout. A small but persistent band of sandstone and limestone in thin alternating layers occurs about 20 feet above the base; in some places the arenaceous elements largely predominate, and near Mount Vernon, 3 miles north of Morrison, and in the vicinity of Van Bibber Creek, there are at about this horizon from 10 to 15 feet of dull-gray or yellowish sandstones carrying small pebbles of flint of various colors. The clays of the lower two-thirds of the Jura are remarkable for their reptilian remains, and from the predominating form have been designated "Atlantosaurus clays."

The upper third of the Jura is generally a succession of sandstones and marls, of which the former predominate; locally, however, either may prevail to almost the entire exclusion of the other. The most important sandstone occurs just above the Atlantosaurus clays, is very persistent, and from contained Saurian remains has been called the Saurian sandstone. It varies in thickness between 5 and 35 feet, and in its distance below the Dakota from 10 to 125 feet, although more generally from 50 to 80 feet. The chief constituent is quartz. The sandstone is everywhere marked with small rusty dots sharply defined and round, one-sixteenth to one-fourth inch in diameter, the result of spherical stains of brown oxide of iron; occasionally the appearance is one of irregular mottling. The sandstone is locally divided into several layers by narrow intercalations of drab clay. In the vicinity of Turkey Creek these clays reach the unusual thickness of 20 to 30 feet, the sandstones aggregating about 20 feet. The bed may be locally calcareous, especially in the northern half of the field, the lime being uniformly distributed throughout the mass. At the base is generally a conglomerate, of a maximum thickness of 8 feet, in which the pebbles so closely resemble those of the Dakota that, but for a slight admixture of red jasper and the characteristic brown dots, the two layers could with difficulty be distinguished from each other. The shales overlying this sandstone are similar to those comprising the bulk of the Jura, but carry through them a number of minor sandstones and occasionally one or two strata of limestone.

A variation in the Saurian sandstone occurs in the vicinity of Van Bibber Creek, which, on account of its determinative value in connection with the structural features about Golden is of considerable importance.

The bed is essentially a sandstone, but is divided into minor layers by bands of hard, white clay from $1\frac{1}{2}$ to 2 feet thick. Occasionally the clay also is specked with rust spots, and upon becoming coarser-grained is directly identifiable with the mottled or specked sandstone described above. It is also sometimes conglomeritic.

The cause of the variation in the thickness of the upper half of the Jurassic could not be determined from conditions existing in the Denver field, but an oft-suggested unconformity at the base of the Dakota may be the explanation.

CRETACEOUS.

Wherever along the foothills of the range the Mesozoic beds have been upturned at a comparatively high angle of inclination, the different Cretaceous formations may be recognized by their topographic features and surface relations. The Dakota sandstone, dipping east, forms a prominent line of "hogbacks"—sharp, serrated, monoclinal ridges, that extend with occasional interruptions along almost the whole front of the range. The black, slaty shales of the Benton occupy in general a shallow longitudinal depression, from 400 to 1,000 feet wide, between the Dakota terrane, and the white basal limestone of the Niobrara, which forms a second ridge, much lower than the "hogbacks," but still conspicuous. East of the Niobrara are the clays of the Pierre and Fox Hills, underlying a broad flat belt 1 to 2 miles wide, succeeded by the basal sandstones of the Laramie, which outcrop in low, somewhat irregular combs. Between the basal sandstones of the Laramie and those of the Arapahoe, next overlying, is another flat, from 600 to 1,200 feet wide, occupied by the clays of the older formation. The basal sandstones and conglomerates of the Arapahoe form local crests 10 to 20 feet above the adjoining prairie, east of which the strata gradually assume a gentle easterly dip and the surface features are chiefly those of erosion in approximately horizontal strata.

DAKOTA FORMATION.

STRATIGRAPHY.

This formation is from 225 to 350 feet thick, and usually consists of two or three nearly equal benches of massive sandstone separated by narrow bands of shale which locally become fire-clays. A characteristic conglomerate occurs at the base of the formation; at the summit, a zone of hard, white, slaty shales, 10 to 30 feet thick, transitional to the Benton; and a fossil flora is found throughout.

Sandstones.—These are composed chiefly of quartz, but contain a trace of mica and a small amount of iron which stains their normal white a brown, yellow, or red. Bitumens are locally present, which also impart a brown color. Cross-bedding and ripple-marks are common features. The sandstone is harder and more compact than any other Mesozoic or Tertiary rock of the field, and now and then verges upon quartzite, especially in the upper bench. It can hardly have been submitted to greater pressure or heat than the more loosely agglomerated Triassic sandstones, and its hardness may therefore be attributed to a more than usually large amount of silica in solution in the sea waters in which it was laid down. The conglomerate at the base of the formation is especially compact through silicification, fracturing across pebbles and matrix alike. A peculiar feature of certain layers of the sandstones is the agglomeration of the grains into forms which resemble short pieces of spaghetti from a half inch to 2 inches in length, with rounded ends, and woven in and out in the most irregular manner. To what these forms are due it is impossible to say, but they suggest the casts of worm burrows.

Conglomerates.—The conglomerate at the base of the Dakota is characteristic. It varies from a thin, almost imperceptible layer to one 30 feet in thickness, and is composed of well-rounded, smooth, in some cases almost glazed, pebbles from the size of a pea to a diameter of 1 inch. The pebbles are derived from most of the older formations down to the Archean, including some of which no trace has yet been discovered in this field. Among the latter are a few of Silurian age, identified by contained fossils, and others carrying small corals of undetermined affinities; in others silicification is so advanced that their original composition is too much obscured to permit determination of their geological source. The pebbles comprise abundant limestones (some closely resembling those of the Trias), quartzites, clays, flints, jaspers, and rocks of granitic composition, together with the separate mineral constituents of the last.

Besides the basal conglomerate, a thin sheet containing very minute pebbles is sometimes found at the base of the upper bench of sandstone, and a third near the summit of the formation.

Fire-clay.—This occurs in local development in the shales separating the heavy sandstone benches of the Dakota. There are generally two horizons of the shales, and consequently of the fire-clays, one about midway in the formation and another nearer the summit. The fire-clay may occupy the entire space between the sandstones, usually from 2 to 8 feet, or may be interrupted by intercalations of hard, white, or bluish-white, quartzose shale. The typical fire-clay is blue or blue-gray, of fine, even texture, hard and compact, jointed or concretionary, and very pure. It becomes impure through the presence of oxide of iron, by a varying amount of sand in fine grains, disseminated or in thin layers, or by carbonaceous matter. The iron weathers out in the form of minute brown spots, distinctive of the horizon.

LIFE.

Animal.—No trace of animal life has been discovered in the Dakota of the Denver Basin.

Plant.—Plant remains, chiefly leaves of deciduous trees and enormous fucoids, abound in certain localities from base to summit of the Dakota. Wood tissue in minute fragments, or the impressions of the same, or the resulting stains, are of general occurrence.

In a comparison of the Dakota of the Denver field, which may be regarded as typical for the eastern base of the Rocky Mountains, with that in the far distant and widely separated regions of Dakota, Nebraska, and Kansas, the similarity of the beds in composition, manner of occurrence, and flora is remarkable, the thickness of the formation alone being the only point of material difference.

COLORADO GROUP.

The two members of this group, the Benton and Niobrara, are broadly distinguishable from each other both in their sedimentation and in their fossils, but from the existence between the two of a zone of gradual transition in sediment, and from the common occurrence of many of their more abundant fossil forms, especially within the transitional zone itself, a definite line of demarcation can not be drawn. This relationship is in no manner a local one, but prevails in a greater or less degree wherever the two formations occur; it obtains even in the Montana and Dakota sections, where the earliest work in the Cretaceous rocks indicated a much more distinct line of demarcation than that now recognized.

BENTON.

STRATIGRAPHY.

This is essentially a formation of black argillaceous shales passing by transitional beds into the formations above and below. Its base lies within a zone of 15 or 20 feet, in which the unstratified black and white indurated shales that form the upper limits of the Dakota are succeeded by the black clays constituting the great mass of the Benton. The summit is in the vicinity of the persistent band of light-colored limestone which occurs near the base of the Niobrara and constitutes a secondary ridge east of the Dakota. The area underlain by the Benton is a narrow strip along the eastern base of the Dakota hogbacks, in width varying conjointly with the thickness of the formation and the angle of dip, but nowhere over 1,000 feet. The thickness of the Benton at Platte Canyon, its point of greatest development, is a little over 600 feet; at Deer Creek, about 590; Turkey Creek, 500; Morrison, 580; one mile north of Morrison, 400; at Ralston Creek, 430; at Bear Canyon, 3½ miles south of the town of Boulder, 348; and at Fourmile Canyon, at the northern edge of the field, about 500. At Golden, under abnormal structural conditions, it disappears entirely.

The lithological characteristics of the Benton formation are: a shaly nature; a dark leaden, almost black, hue; concretionary clay-ironstones; and thin layers of fossiliferous limestone.

Shales.—The shales are of fine clay, with a small amount of disseminated arenaceous matter. They are either jointed, concretionary, or broadly homogeneous in structure. They are compact and hard, but under atmospheric influence readily crumble to angular particles or thin scales. Iron pyrites occur disseminated throughout them in minute crystals or concentrated in thin and often finely reticulated seams. Gypsum and native sulphur are also found in limited amount, the latter usually crystallized in small cavities.

Ironstones.—The ironstones occur in a zone 40 to 50 feet thick, about two-fifths the distance from base to summit of the formation. They are in the form of concretions, from 1 to 3 feet in diameter, are very hard, break in angular fragments, and on fresh surfaces resemble in color the shales, though their exterior weathers either bright-yellow or rusty-brown. They are usually somewhat calcareous. A partial analysis of an ironstone follows:[1]

Analysis of ironstone.

	Per cent.
Silica	26.31
Iron (metallic)	22.90
Alumina	2.31
Lime	3.22
Magnesia	8.19

Limestones.—These occur in more or less noncontinuous bands, 1 to 3 feet thick, throughout the formation, but they are more numerous, thicker, and of greater continuity in the upper third. One only is persistent over the entire field, this lying about 100 feet below the summit. The limestones are of coarse texture, dark color, and generally yield a bituminous odor. The uppermost beds resemble the basal member of the Niobrara and thus constitute a zone of transition between the two formations.

LIFE.

The life of the Benton seems to have been rather poorly represented in this field as compared with other localities, for while there are evidences of organisms in profusion, both of plants and animals, the only forms especially abundant are those of the two genera of Mollusca, Ostrea and Inoceramus. To these must be added some undetermined Selachians, represented by their teeth, which occur mainly in the more strongly bituminous limestones.

NIOBRARA.

STRATIGRAPHY.

The surface area occupied by the Niobrara formation has an average width of about 600 feet, except for a distance of about 3 miles north and south of Golden, where, like the Benton, it has entirely disappeared.

The normal thickness of the Niobrara varies slightly on either side of 400 feet. In sedimentation the formation is sufficiently differentiated to

[1] Report of the Colorado State School of Mines, Golden, Colo., p. 20, 1885.

readily permit its division into three members, of which the lowest is limestone, having an average thickness of 50 feet; the middle is a succession of gray marly clays of various shades; the upper, a series of yellow or buff shales, 240 feet in thickness, containing several impure limestone bands.

Lower division.—The limestone of the lower division, from its prominent characteristics, forms an excellent datum-level in the study of the stratigraphic and structural geology of the foothills along the Colorado Range. These characteristics are, the bluish-gray, light-gray to clouded white color; the even, fine-grained texture; the superior hardness by which it effectively resists atmospheric influences and becomes persistent in outcrop; the freedom from arenaceous and clayey matter; the conchoidal fracture; the evenness of the bedding planes; and the fossil contents. The thickness of this member is about 50 feet, but the above characteristics are especially applicable to the lower 30 feet, which is also a portion of particular economic value. The upper layers are usually much thinner, and graduate through shales into the overlying group of marls constituting the middle member of the formation. Occasionally the limestone becomes shaly from base to summit, when the prominence of its outcrop is greatly diminished. The presence of bituminous matter, though recognizable, is not so marked in the limestones of the Niobrara as in those of the Benton.

Following is an analysis of a type specimen of the limestone, by Mr. L. G. Eakins, which shows it to be dolomite:

Analysis of limestone.

	Per cent.
Insoluble	12.01
CaO	27.49
MgO	18.03
MnO	.20
Al_2O_3	.54
Fe_2O_3	.11
P_2O_5	.029
H_2O	.61
CO_2	41.40
	100.419

Local variations from the above composition may easily be seen under the lens alone. These consist of differences in the amount of silica present in the form of sand; in varying proportions of iron, as instanced by the presence, in some of the lower beds, of small limonite concretions; and in a variable amount of alumina, especially noticeable in a comparison between the shaly and nonshaly varieties.

Middle division.—This consists of light-gray marls, here and there streaked with darker-gray and buff bands. It is usually a little over 100 feet thick.

Upper division.—This has an average thickness of 240 feet and is an accumulation of buff and yellow shales of a peculiar earthy and more or less calcareous composition. Several narrow layers of yellow, impure, saccharoidal limestone occur, together with beds of fine, sandy material. The whole series is fossiliferous. There is a remarkable distribution of alkaline salts throughout the series, weathering out in small white spots. Gypsum is frequently met with, and iron occurs in small concretions.

The contrast in composition and color between the yellow shales and the sediments of the overlying Pierre affords a clear line of demarcation between the two formations.

LIFE.

The fossils of the lower limestone member of the Niobrara include *Inoceramus problematicus*, *Inoceramus deformis*, Ostrea, undetermined fish remains, and sharks' teeth. The last are coated with a heavy, shiny-black, carbonaceous material, much resembling bitumen in appearance, and in the limestone containing them the odor of this substance is frequently detected.

The fossils of the yellow series embrace the forms *Ostrea congesta*, a species of Inoceramus, one of a Baculites, several long, black spines of elliptical cross-section, probably derived from the shells of some molluscan, and innumerable remnants of fish integuments, occurring as small brown or blue membranous fragments.

The vertebrate remains of animals which constitute the Pteranodon fauna of Professor Marsh occur further eastward, in Kansas, in chalky beds which are supposed to correspond in horizon with the Niobrara formation.

MONTANA GROUP.

The Montana group occupies a highly inclined position along the foothills, and, with the exception of an area in the northwest portion of the field, the width of its outcrop is but little in excess of its thickness. The latter, under more normal conditions, reaches a maximum of approximately 8,700 feet, of which the Pierre constitutes the lower 7,700 to 7,900 feet and the Fox Hills the upper 1,000 or 800 feet.

PIERRE.

STRATIGRAPHY.

This formation is, in the main, a great body of plastic clays, carrying small, lenticular bodies of impure limestone and, at a horizon about one-third the distance from base to summit, a zone of sandstone from 100 to 350 feet thick. A variable quantity of calcareous matter and alkaline salts is also generally distributed throughout the formation, while iron in the form of concretions or thin seams, fine carbonaceous matter, and gypsum are of frequent occurrence.

Clays.—The clays are usually leaden-gray, but may be blue or yellow. Contraction cracks which reticulate the surface are characteristic of areas underlain by the formation, particularly in regions of low dip. Some of these have a linear extent of 30 feet, a width of 6 inches, and a visible depth of 3 feet; usually, however, they are much smaller. The clays retain their normal characteristics over the greater part of the Denver field, but in the immediate vicinity of the Ralston dike they have been metamorphosed to hard, dark-blue or black shales. In the vicinity of the Valmont dike their metamorphism is less pronounced.

Limestones.—These occur as small, lenticular bodies whose horizontal axes are from 2 to 6 feet long, and whose vertical axes are from 6 inches to 2 feet. Their composition is between that of a clay, with little carbonate of lime, and a very pure limestone, generally inclining to the more calcareous variety. Their color is gray, their texture very fine-grained, and both color and texture are extremely even throughout the same body. Oxide of iron is occasionally present in small amount. The limestones are often reticulated with calcite seams, the ramifications extending through the entire mass. Under a hammer blow the mass flies into hundreds of small angular fragments. This also happens with rocks showing no calcite reticulations, but of homogeneous appearance, and indicates a predisposition of the rock to this structure. The limestones are irregularly distributed throughout the whole body of shales, one horizon, about two-thirds the distance from base to summit, showing a specially large number.

The limestones are the chief source of the fossils, but, except at the horizon just mentioned, no part of the group is specially marked by either abundance of forms or the development of particular species.

Sandy zone.—This is an almost continuous band of soft, friable, yellowish-gray, fine-grained sandstone, composed chiefly of quartz, with local admixtures of clay either in small seams of shale or disseminated through the mass. It rarely forms an outcrop except in deeply eroded gulches or in ditches, yet its presence is easily detected in the soil, and it constitutes an excellent datum for stratigraphical reference. Besides the beds of thin clay, two or three bands of impure limestone are locally present.

The most peculiar development of this sandstone occurs about three-fourths of a mile north of the northern boundary of the map. It is here nearly 350 feet thick, and at first sight resembles the basal sandstones of the Laramie, but on inspection is found to be calcareous in certain layers, to contain an abundance of the more common Pierre fossils, and in its coarser mineral constituents to differ materially from the purely quartzose beds of the Laramie.

Ironstones.—These are chiefly small, irregularly shaped concretions of hardened, calcareous clay, from 1 to 3 inches in diameter, containing a variable amount of iron. Their color is between an ashes-of-roses and deep rust. A larger ironstone, less frequent than the foregoing, is of much coarser texture and contains a higher percentage of iron. The third occurrence of iron is in the form of narrow, unstratified seams of impure limonite.

Carbonaceous matter.—This occurs as minute fragments of plant tissue distributed throughout the clays and their contained limestone concretions, in the latter forming one of the characteristic features.

Gypsum.—This is distributed in small scales throughout the clays.

LIFE.

The life of the Pierre is given in the tabular statement of the fossils of the Denver field.

ZONE TRANSITIONAL TO FOX HILLS.

Between the Pierre and overlying Fox Hills formation there is a change from the pure clay of the one to the arenaceous shales of the other. Limestones and small ferruginous nodules, similar to those already described, are present throughout this transitional zone, extending well into the Fox Hills. Fossils also occur, but the life of the zone is marked by the sudden increase in the members of the genus Mactra, a genus which below has only been occasionally met with, but which from this up is frequently found.

FOX HILLS FORMATION.

STRATIGRAPHY.

The Fox Hills formation has a normal thickness of between 800 and 1,000 feet, falling below this only at Golden, where its decrease to 500 feet is attributable to the nondeposition of its lower portion.

The formation consists mainly of soft, friable, arenaceous shales, with occasional interstratified bands of clay. At the summit is a persistent and characteristic sandstone, usually about 50 feet thick. The entire formation has a yellowish cast, but while the shales are generally of a grayish-yellow the sandstone itself has a pronounced tint of green. The composition of both shales and sandstones is very uniform.

Shale.—The shales carry a small amount of ferruginous matter in concretions and seams, and a minor quantity of gypsum. Limestone concretions resembling those of the Pierre are numerous, but less abundant than in the older formation; like the shales in which they occur, they usually contain more or less sand, those near the summit resembling a calcareous quartzite. All are fossiliferous. Fine carbonaceous matter is generally present. Cone-in-cone structure is frequent.

Sandstone.—The sandstone at the summit of the formation is noteworthy on account of its position as cap to the great mass of Cretaceous clays, from its wide occurrence over the West, from the fossil remains in its upper stratum, and from the marked difference displayed in its materials from those of the basal sandstones of the Laramie which overlie it. Its composition is chiefly quartz, but it carries an appreciable amount of biotite and muscovite, and iron oxide is distributed throughout its entire mass. It is fine-grained, of close texture, and usually occurs as a single bed. Occasionally it becomes concretionary. It is in close union with the basal sandstone of the Laramie; no transition bed exists; the passage from the one to the other is direct; combined they frequently enter into the formation of a single bluff 150 feet high. Notwithstanding this, the formations are easily distinguished by their lithological contrasts and by the fossil horizon marking the summit of the older.

LIFE.

While invertebrate fossil remains occur throughout the entire thickness of the Fox Hills, there is an especially conspicuous array of characteristic forms at the very summit of the formation, in the uppermost layer of the capping sandstone, none of which is ever found above, and but few of which are met with in numbers below. This is, moreover, a paleontological feature of the formation in all its western localities. Among the forms found in the Denver field those especially characteristic are—

Mytilus subarcuatus,
Nucula cancellata,
Solemya subplicata,
Veniella humilis,
Callista (Dosinopsis) owenana,
Tellina scitula,
Liopistha (Cymella) undata,
Pyrula bairdi,
Pseudobuccinum nebrascense,
Turitella sp. ?
Cylichna sp. ?
Crenella elegantula,
Cardium (Ethmocardium) speciosum,
Sphæriola cordata,
Callista deweyi,
Mactra alta,
Tancredia americana,
Fasciolaria cheyennensis,
Fusus sp. ?
Anchura americana,
Dentalium sp. ?

In plant life *Halymenites major* is generally met with in the upper portion of the formation, in both the sandstones and the limestones.

LARAMIE FORMATION.

The entire Denver field, excepting the belt along the foothills occupied by the older formations, is underlain by Laramie strata, but their surface exposures are confined to the northern and northeastern portions of the field and to a narrow strip parallel with the foothills at a distance from them of between 1 and 2 miles.

The formation is from 600 to 1,200 feet thick and is divisible into two parts, a lower of sandstones, and an upper, composed of clays. The former has a uniform thickness of about 200 feet; the latter varies. Both divisions carry workable seams of coal.

STRATIGRAPHY, LOWER DIVISION.

The two sections given in figs. 12 and 15, in the first part of Chapter VI, show the general succession of strata in this division. Sandstones largely predominate, outcropping in successive benches separated by bands of arenaceous and lignitic shale with their intercalated coal seams. The two heavy beds of sandstone at the base of the division and the bed at the top are the only ones persistent over the entire field. The intervening ones not only disappear, but vary in the horizon at which they recur. The coal beds also vary, one of the several seams being workable in one locality and another in another.

Sandstones.—The sandstones are white and are composed almost exclusively of quartz, clear and opaque white; minute grains of black chert and rare traces of feldspar and mica are the only associates. The material is somewhat loosely held together by a cement, usually white, but occasionally tinged brown by iron oxide. The chert is characteristic.

The three important sandstones of the lower division of the Laramie may, for convenience, be designated from base upward, A, B, and C. A and B are each about 60 feet thick, are separated by from 2 to 4 feet of shale, and with the underlying Fox Hills sandstone often form a single continuous outcrop. Although of nearly the same materials, the A and B sandstones are distinguishable from each other by their stratigraphical relations to the overlying and underlying beds; by the presence in the lower bench of a greater amount of ferruginous matter, which imparts to it a faint-yellow tinge, not nearly so deep, however, as that of the underlying Fox Hills; by the occasional development in this bench of a concentric structure; and by the occurrence near the summit of the upper bench of enormous concretions of the same material as the surrounding sandstone, but of extreme hardness. These concretions upon weathering out are of various sizes and shapes, but a common form is one somewhat irregular in outline, of circular or elliptical cross-section, from 2 to 4 feet in diameter and 30 to 40 feet long. A further feature of the upper bench of sandstone (B) is the polygonal structure developed upon its lamination planes in weathering. The shale separating the A and B sandstones is frequently lignitic and in a few localities, as in the bluffs north of North Boulder Creek and in the Erie coal field, is partially replaced by coal.

Sandstone C occurs about 60 feet above the basal sandstones A and B. Its thickness averages 8 or 10 feet. The upper half is usually the whiter and more solid; the lower is somewhat ferruginous and also strongly ripple-marked. As there are several bands at about this horizon, it is not always possible to recognize this particular bed, but the presence of the one or the other is sufficient for the determination of the general horizon where a good section is exposed. This sandstone is of importance in coal exploration, all the workable beds in the lower Laramie of the Denver field occurring below it.

Ostrea bed.—This is a sandstone occurring from 12 to 15 feet above sandstone B. It is but slightly developed in many parts of the field, but wherever observed consists of the same material as the other sandstones, with the addition of a considerable amount of lime. It often contains in abundance one of the characteristic Laramie species, *Ostrea glabra*, besides a few indeterminable fragments of shells of other types. Its position is of special importance in working out the coal horizons.

Shales and coal beds.—The remaining portion of the lower Laramie consists, besides the coal beds, of shales which are almost always more or less lignitic and generally somewhat arenaceous. They contain abundant partially carbonized plant remains—bark, wood, leaves, and their impressions. From the presence of the carbonaceous material the shales are frequently dark-gray or brown, and upon its prevalence to the exclusion of clay and sand a bed may become true coal of economic importance.

Ironstones are sometimes present, but they are not so abundant as in the upper division of the Laramie.

Local alteration of Laramie beds.—The sandstones and shales of the lower Laramie have locally undergone considerable alteration from the burning out of associated coal beds, the result of spontaneous combustion or prairie fires.

This is particularly the case in the small hill known as the Burnt Knoll, north of the Marshall-Louisville mesa, about 3 miles west-northwest of Louisville. Here the strata have in some instances been fused, developing both flow and vesicular structure, hand specimens being hardly distinguishable from lavas; in other instances the alteration has been to jasper. A crystalline structure appears in some, while elsewhere the granular texture of the original rock has been maintained. Many are coated with hematite from alteration of the iron originally present. Clinker, resembling that from furnaces, is abundant. Columnar structure has been developed in some of the clays, probably from evaporation of their water. The colors vary—reds, browns, blues, and blacks prevailing. In many of the rocks, even those most altered, leaf impressions are still apparent.

STRATIGRAPHY, UPPER DIVISION.

The thickness of this division, owing to uneven denudation from the top, varies between 400 and 1,000 feet. The strata are chiefly clays, through which are distributed small, lenticular bodies of sandstone, innumerable concretionary ironstones from 2 to 4 feet in diameter, and narrow local seams of impure lignitic material. One or two beds of lignite are also present in its upper portion, east of Denver. Especially fine exposures of these clays occur on the slopes south and east of Rock and Coal creeks, where the strata have a slight dip east or southeast, forming bluffs looking westward, in which colors, lines of stratification, sandstone concretions, and ironstones are all clearly defined.

Clays.—These are dark bluish-gray, relieved by bright bands of red, yellow, brown, drab, and white.

Sandstones.—The sandstones differ somewhat from those of the lower Laramie in containing more or less lime, in their superior hardness, and in their occurrence as lenticular masses from 6 to 30 feet in diameter and 1 to 6 feet in thickness. They contain numerous plant remains and a moderate amount of iron. In weathering they often scale in concentric layers. There are apparently three or four horizons at which they especially prevail, although they may be found anywhere in the series.

Ironstones.—These form one of the distinguishing features of the upper

Laramie. The weathered concretions outwardly resemble limonite, but in their normal condition they are probably carbonate of iron with a larger or smaller admixture of clay. They frequently show concentric structure, the outer coats weathering off in succession, but more generally they break up into angular fragments. They differ from the ferruginous concretions of the Colorado and Montana groups in their superior size, in the abundance of their plant remains, in the far greater amount of iron contained, and in their primary composition. Somewhat similar concretions occur in the overlying Arapahoe; they are, however, less abundant than in the Laramie. An analysis of a purer variety from near Trinidad, Colo., gave—

Analysis of ironstone.[1]

	Per cent.
Silica	9.19
Protoxide of iron	[2]45.01
Alumina	6.29
Lime	4.02
Magnesia	1.37
Phosphoric acid	1.055
Carbonic acid and organic	33.035
	100.000

Although smelted in early times, the ironstones of the Laramie are no longer of economic value.

STRATIGRAPHICAL RELATIONS.

The stratigraphical relations of the Laramie formation to those of younger age are varied. After the period during which the Laramie was laid down, there followed a time of great oscillation and erosion, during which were produced a series of unconformities that included all the post-Laramie and Tertiary formations of the West. To the erosion is due the impossibility of assigning to the Laramie a definite original thickness, much of the deposit having been removed and its surface rendered most undulating before the deposition of the younger beds upon it. Upon this uneven floor

[1] Preliminary notes on the iron resources of Colorado. Prof. Regis Chauvenet, Ann. Rept. State School of Mines, Golden, Colo., 1885, p. 19.

[2] Iron 35.03.

[3] Phosphorus 0.46 by difference.

were laid down in succession and at most varied topographical horizons the overlying formations—at one point, the Arapahoe; at another, the Denver; at a third, the Monument Creek; and finally the Pleistocene. Each rests not only on the next younger formation but also in places on the Laramie itself.

LIFE.

Animal remains.—These, so far as at present known, are limited to two species of mollusks and one of a vertebrate.

The invertebrate remains include the very characteristic Laramie form, *Ostrea glabra*, and a *Unio* sp.?, which are considered decisive as to the age of the formation The occurrence of *Ostrea glabra* is general for the field, and always at the same horizon, a short distance above the basal sandstones of the formation. Two Unios only were found, these occurring in different localities and well up in the shaly portion of the formation.

The vertebrate, according to Professor Marsh, belongs to the order Ornithopoda of the subclass Dinosauria The genus is undetermined. The specimen was found by a ranchman about 30 feet below the surface, in a well sunk through the upper Laramie strata, on the slopes of Dry Creek, about 8 miles west-southwest of the town of Brighton.

Plant remains.—The plant remains in the Laramie are abundant and show a clear differentiation from those of the Arapahoe and Denver beds. Prof. F. H. Knowlton, of the Survey, has made an exhaustive study of the combined floras, and his results are embodied in Chapter VII of this report.

Table of invertebrate fossils in the Denver field.

[Determinations by Dr. C. A. White.]

Fossils.	Cretaceous.												
	Benton.	Niobrara.			Pierre.			Fox Hills.		Laramie.		Arapahoe.	Denver.
		Lower.	Middle.	Upper.	Lower.	Middle.	Upper.	Lower.	Upper.	Lower.	Upper.		
Caryophyllia ——?													
Beaumontia?[1] solitaria													
Serpula ——?													
Crustacean fragments													
Discina ——?													
Lingula nitida													
Ostrea ——? fragments													
congesta													
glabra													
Pecten ——?													
Chlamys (Pecten) nebrascensis									×				
Pteria fibrosa					×		×	×	×				
haydeni													
linguiformis													
Inoceramus ——?													
barabini													
deformis													
problematicus													
Mytilus subarcuatus													
Crenella elegantula													
Nucula ——													
cancellata													
Yoldia evansi													
Unio ——?													
Cardium (Ethmocardium) speciosum													
Solemya ——													
subplicata													
Lucina ——?													
occidentalis													
Sphæriola? ——?													
cordata													
Cyrena holmesii													
Corbicula ——													
Veniella humilis													
Callista ——?													
deweyi													
(Dosinopsis) owenana													
Mactra ——													
alta													
canonensis													
holmesii													
Tellina scitula													
Tancredia americana													
Solen ?													
Liopistha (Cymella) undata													

[1] Occurred as a pebble in the conglomerate of the Arapahoe.

Table of invertebrate fossils in the Denver field—Continued.

Fossils.	Cretaceous.												
	Benton.	Niobrara.			Pierre.			Fox Hills.		Laramie.		Arapahoe.	Denver.
		Lower.	Middle.	Upper.	Lower.	Middle.	Upper.	Lower.	Upper.	Lower.	Upper.		
Fasciolaria ———													
cheyennensis													
Pyrula bairdi													
Fusus ——— ?													
Pseudobuccinum nebrascense													
Lunatia ——— ?													
Anchura americana													
nebrascensis													
Goniobasis tenuicarinata													
Turritella ——— ?													
Viviparus ——— ?													
trochiformis													
Anisomyon ——— ?													
Dentalium ——— ?													
gracile													
Actæon woosteri													
Haminea ? occidentalis													
Cylichna ——— ?													
volvaria													
Physa ——— ?													
Nautilus dekayi													
Ammonites													
Scaphites ——— ?													
cheyennensis													
conradi													
nodosus													
Ptychoceras ——— ?													
mortoni													
Baculites ——— ?													
anceps													
grandis													
ovatus													
Other indet. molluscan forms													
Fish remains													
Selachian teeth													
Lamellibranchiata													
Gasteropoda													

SECTION II.—STRUCTURE.

INTRODUCTION.

The Denver field is separable, structurally as well as topographically, into foothills and prairies, and these are still further divisible into areas that, in their geologic development, are almost wholly independent.

In the following description the foothill region includes not only the foothills proper, but as much of the adjoining prairie—usually a belt about 2 miles wide—as has been involved in the structural development of the former. The prairie region includes all else. Areas of specialized structure in the foothills lie about Golden, Boulder, the South Boulder peaks, and Coal Creek. Within the prairie region there is but a single specialized area, the Boulder Valley.

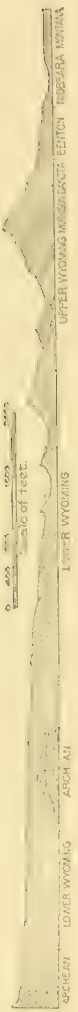


Fig. 3.—Transverse [illegible]tion of foothill strata [illegible] Creek.

THE FOOTHILLS.

GENERAL STRUCTURE.

Normal appearance.—The general structure of the foothills is shown in the several transverse sections of the field (Pl. IV). Somewhat greater detail is afforded in the section at Deer Creek (fig. 3), except that here the fold in the Archean and Trias, near the western limit of the latter, is a local feature.

The normal appearance of the foothills is that of a mountain mass of Archean rocks, fringed at an average distance of one-half or three-quarters of a mile by a sharp serrated ridge of Dakota sandstone, the valley between the two being occupied by the formations of the Trias and Jura. Above the Dakota come, in their geological succession, the Benton, the Niobrara—this generally constituting a second, smaller reef outside the Dakota—the Pierre, the Fox Hills, and the Laramie, the basal sandstones of the Laramie again forming either a low roll in the ground or an actual comb of rock slightly projecting above the surface of the surrounding prairie. To the east of the Laramie, at a distance of between 600 and 1,200 feet from its basal sandstone, appears in the southern portion of the area yet another comb, formed by the conglomerates at the base of the Arapahoe series. Finally, this is followed at about an equal distance by either an outcrop of the lower members of the Denver formation or a peculiar ribbing of the prairie due to their presence beneath the surface.

FOLDS EN ÉCHELON ALONG FRONT OF COLORADO RANGE.

Contour interval 200 ft

QUATERNARY A · LARAMIE L · FOX HILLS F · COLORADO (HAYDEN) Pierre Niobrara Benton C · DAKOTA DK · JURA-TRIAS: JURASSIC (MORRISON) J, RED BEDS (WYOMING) T · ARCHEAN MG

From Atlas of Colorado, U.S. Geol. Survey of the Territories, F. V. Haden in Charge.

In the foothills themselves the sedimentary beds usually maintain an easterly dip of 35° to 50°, varying locally between 15° and 90°. Passing outward from the range, the dip gradually increases until at 1½ or 2 miles from the Dakota, along the outcrops of the Laramie and Arapahoe, it is rarely under 80° and often vertical or slightly overturned. East of the basal sandstones of the Arapahoe the dip rapidly shallows to the gentle degree (3° to 5°) normal for the prairie. In the northwestern corner of the field, where the Laramie and overlying beds have been eroded, the change from steep to gentle inclination appears in the Montana, at the usual distance of 1½ to 2 miles from the foothills.

The flexure suggested in the foregoing change of dip is that general along the foothills, a part of the great fold involved in the uplift of the range.

Folds en échelon.—Besides the fold resulting from the general uplift, and a considerable amount of minor crumpling along lines parallel with this, there occurs in front of the Colorado Range, from the northern to the southern end, a series of folds which, from the successive offsets they cause in the face of the range, have been named by Dr. F. V. Hayden "folds en échelon." Their general outline is represented in the accompanying Plate IX,[1] a reproduction of a series occurring between St. Vrains and Cache la Poudre creeks, 12 to 40 miles north of the limits of the Denver field as mapped.

The folds are anticlines, springing from the main range at angles of 5° to 25° with its axis; they gradually sink beneath the prairie, and finally die out altogether. They usually point to the south, and the reentrant angle between them and the range is occupied by a syncline opening in the same direction. The folds of greatest size occur beyond the limits of the Denver field: some, 12, 17, and 25 miles to the north, in the vicinity of St. Vrains, Little Thompson, and Big Thompson creeks; others, still larger, in the southern part of the State, near the Arkansas and Huerfano rivers. The facts that these folds, with one or two minor exceptions in the last-mentioned region, all point south, and that to their south generally occur streams of considerable importance, are worthy of remark.

[1] From Sheet XII, Hayden's Atlas of Colorado.

Within the Denver field the folds en échelon are of limited size. They are four in number, occurring just north of Ralston, Coal, and South Boulder creeks, and south of Fourmile Creek.

That north of Coal Creek is in a region of special structural irregularity, and will be described in connection therewith.

The fold at Ralston Creek is the most advanced; it shows complete in the Trias, on the southern face of Ralston Peak, where the axes of both anticline and sycline dip steeply south; in the Dakota the fold is less pronounced, while in the Niobrara the effect is limited to merely a slight divergence from the normal trend.

The fold north of South Boulder Creek is of the same character as the foregoing, but less developed. The strata are merely offset to the east, with but slight evidence of actual crumpling. In the line of this fold, however, is the prominent fault twinning the South Boulder Peaks, to be described hereafter.

The northernmost fold in the field is even less developed, and shows in the Dakota only.

THE REGION ABOUT GOLDEN.[1]

INTRODUCTION.

The type of geological structure about to be discussed was worked out by the writer in 1884. Upon detailed study it may prove to be of common occurrence along the base of the Rocky Mountains, a recurrence in a less developed form having already been observed in the vicinity of Boulder, a few miles north of the present area. The type consists in a succession of unconformities appearing one after another at various geological horizons, the explanation of which is found in the forces acting in the general uplift of the Colorado Range, from which have been developed certain secondary forces that have from point to point brought about the elevations upon which the unconformities depend.

[1] The accompanying geological map is an enlarged portion of the general map of the Denver Basin. The profiles are based upon this, and are developed by construction from it and from one another by actual measurements, with the necessary reductions for thickness. The two sketches on pages 98 and 99 illustrative of the manner in which the folding occurred and its relations to that of the main range, are, however, diagrammatic, although based upon the historical facts developed in the text.


GEOLOGIC MAP OF THE VICINITY OF GOLDEN, COLO.
BY GEO. H. ELDRIDGE
Contour Interval 100 Feet
I Condition at close of Wyoming (Trias)
II " " " Morrison (Jura)
III " " " Benton
IV " " " Arapahoe
Scale of Miles
PLEISTOCENE
ALLUVIUM Pal
CRETACEOUS
DENVER Kdv
ARAPAHOE Ka
LARAMIE Kl
MONTANA (FOX HILLS PIERRE) Km
COLORADO GROUP
NIOBRARA Kn
BENTON Kb
DAKOTA Kd
JURATRIAS
MORRISON Jm
WYOMING (UPPER) Jwu
WYOMING (LOWER) Jwl
BASALT
PRE CAMBRIAN GRANITES GNEISSES AND METAMORPHIC ROCKS gn
GOLDEN
N. TABLE MT.
S. TABLE MT.
GREEN MT.
MT CARBON
Ralston Creek
Van Bibber Creek
Clear Creek
Coal Creek
Bear Creek
Turkey Creek

GENERAL FEATURES OF THE AREA AFFECTED.

The area affected by the phenomena now to be discussed extends along the base of the foothills of the Colorado Range west of Denver, from a point about a mile south of Bear Creek northward to Coal Creek, a distance of 21 miles, with a breadth varying from $2\frac{1}{2}$ to 4 miles, the greater occurring along its northern and southern edges. It involves the hogbacks of the Dakota and the region within to the Archean, and includes the prairies as far to the east as Mount Carbon, the western slopes of Green Mountain, the Table Mountains, and the vicinity of the Ralston dike.

Topography.—The topography shows a marked variation from that normal for the foothills region in general, and its relations to the geology of the tract as displayed from point to point are so close as to warrant the assertion that for every topographical lineament there is to be discovered an equivalent geological incident that has led to its development. For mile after mile along the mountains the normal topographical features may be traced with unswerving regularity, but within the area to be described they undergo rapid change, and midway the length of the tract, in the vicinity of the town of Golden, they are lost to recognition. For a distance of over a mile north of the town, and an equal distance south of it, the Dakota hogbacks have completely disappeared; the low Niobrara ridges cease to exist at a point about a mile north of Bear Creek, not to appear again until the region of Van Bibber Creek, 10 miles to the north, is reached; the Laramie sandstones with their coal have gradually approached to within 500 feet of the Archean at Clear Creek, the variation in their strike from that of the Triassic and Dakota outcrops below being apparent to the most casual observer; finally, opposite the center of this great topographical gap, appear the two great basalt-capped sedimentary masses of North and South Table Mountain, originally continuous but afterwards cut by the waters of Clear Creek, which debouches from the main range midway their length.

Surface delineations.—Seen from any of the more elevated points within this remarkable area, another set of features, second in prominence only to the ones already referred to, at once strike the eye. These are the clearness with which the lines of stratification are delineated upon the surface and the distinct tendency which they display to group themselves, with respect to direction, into two well-marked assemblages—the one embracing the formations of the Colorado and all below, and maintaining for the greater part of their extent the same parallelism to the general trend of the foothills which they have held beyond the affected area; the other embracing the Montana and younger formations, and though maintaining a parallelism of strike within themselves, nevertheless abutting against the older formations at an angle in places as high even as 20°. The latter formations, in fact, approach the range proper in a broad, well-marked, and regular inward-sweeping curve, the center of its arch lying a short distance north of Clear Creek. The features just noticed again occur in a minor degree and in a manner not at first liable to attract attention, in the relations between the Dakota and underlying beds nearer the middle of the area, where the beds of the younger formation lie across the edges of those of the older.

North of the central portion of the area of unconformity and south of Ralston Creek for the distance of about 2 miles the topographical and geological features are somewhat complicated by the presence of intrusive masses; they are, however, still sufficiently clear to permit interpretation, and with the others in the south and center of the area and in the remainder of the tract to the north form one complete whole.

THE FORMATIONS AND THEIR RELATIONS.

The Archean.—This is but slightly involved in the special geological history of the region. It formed an uneven floor for the deposition of the Trias, and across its truncated edges the latter formation was deposited.

The Trias.—In their strike and dip the beds of both members of the Trias are conformable inter se. Their strike follows approximately the line of the Archean foothills, and their dip is to the east and varies between 35° and 90°, being shallower next the foothills, and increasing as distance from them is gained.

The lower member of this formation, the Red Beds, maintains its usual appearance and, except in two places, a nearly constant thickness over the entire area under consideration. The two variations in thickness are found, the one near the southern extent of the tract, the other for a mile and a half on either side of Clear Creek. The former is of no particular interest in the present discussion. The latter is attributable to two causes—one, nondeposition at the base, due to a rise in the Archean floor and a consequent shallowing of the sea at this point, the beds of the deeper water abutting against this rise; the other, the disappearance from the top of the series of the beds last laid down, including the Creamy sandstone and at least 100 or 200 feet of the beds beneath. The linear extent of the disappearance of the Creamy sandstone is probably somewhat under 1 mile, and is confined chiefly to the region immediately north of Clear Creek, reaching to the south of it but slightly, if at all. In this interval the clays of the Fox Hills are found in close proximity to the Red Beds, the former conformable in strike with the Laramie sandstones above, the latter pursuing their usual trend, approximately parallel with the base of the range.

The upper member of the Trias presents nothing anomalous in its occurrence until within a distance of about 2 miles north and south of Clear Creek, when a rapid disappearance of its beds successively from top downward is found to occur as the center of the region is approached, the limestones and associated beds at its base apparently reaching within a short distance of the limits already assigned for the Creamy sandstones below. An extremely important point in this connection is the fact that this disappearance occurs where the overlying Jura is not only still present, but where it maintains even the greater part of its thickness; it occurs, in fact, between the Jura above and the lower member of the Trias, the Red Beds, beneath. The disappearance of this series of strata is most marked, because more sudden, to the north of Clear Creek and Gold Run, where, within a distance of between one-half and three-fourths of a mile, it has decreased in thickness from 650 to 270 feet. The diminution in thickness to the south of Clear Creek is also rapid, but over this portion of the region the Upper Triassic member is not limited altogether by the Jura above, but in part by the Dakota, with a discrepancy of at least 10° in their strike. Farther to the south, where the Jura is present in nearly its full thickness, the variation in thickness of the Upper Trias is more gradual, but still to be associated with the local phenomena of the region.

The Jura.—No extraordinary discrepancy in strike or in general relations between this formation and either the underlying or overlying one is apparent until upon near approach to the confines of the region presenting the anomalies just described for the Trias. Any decrease in the thickness of the Jura beyond is little more than is usually met with from point to point along the range. From about a mile south and a mile and a half north of Clear Creek, however, the beds of the formation disappear in rapid succession as the center of the region is gained. Their strike is, moreover, at variance with the formations both above and below; in the southern part it is in noticeable contrast with that of the Dakota, being some 10° or 15° to the east of the latter; in the northern portion not only is the same discrepancy probable between these two formations, but an equal one also appears between the beds of the Jura and those of the Trias below. The thinning of the Jura is in part probably due to the absence of some of its lower beds, while the cause of its sudden and final thinning is found in the rapid and successive disappearance of, first, its upper beds, followed in turn by those lying beneath.

The Dakota.—As ascent is gained in the series of formations, the region of anomalies becomes more and more extended in north and south directions. The Dakota begins to display irregularities as far south as the northern end of the high hogback just south of Coon Gulch, and in the north at the southern end of the chain of hogbacks north of Golden. The noticeable points in the behavior of the southern half of the formation are, first, the disappearance of the characteristic hogback; second, the gradual decrease in thickness, which the outcrops of the remaining portions show to be both from above and from below, the fire-clays in the middle of the formation being the last to disappear, as evidenced at the bluffs of both Clear Creek and Gold Run; third, the discrepancy in strike between this formation and those below and above, its beds in the region of more pronounced irregularity lying across the edges of the former, and abutted from above by the ends of the successive strata of the Montana group throughout much of their line of contact; finally, frequent changes in the strike of its beds over the central portion of the affected area, which changes are not paralleled by corresponding ones in the prominent sandstones at the base of the Laramie, lying but a short distance to the east.

In the northern half these same peculiarities are again met with, but in some particulars they are more strongly accented than in the southern. These are, the more sudden disappearance of the hogback; the rapidity with which the formation thins; and the marked crumpling, as shown in their strikes, to which its beds have been subjected without the overlying strata being in the least affected. In dip the Dakota varies from 45° in its more normal occurrence to vertical over the more disturbed, middle portion of the field.

The Benton.—This formation completely disappears a short distance north of Coon Gulch, and also at a point about opposite the middle of the first hogback north of Golden. The southern portion thins very gradually throughout a distance of $3\frac{1}{2}$ miles, while the disappearance of the northern member is completed in a little less than a mile. The Benton conforms in strike and dip to the Dakota, but is overlain, after the disappearance of the Niobrara, by successively higher strata of the Pierre and Fox Hills formations as the center of the disturbed region is approached.

The Niobrara.—This, like the Benton, disappears only from above downward, but its limits are found considerably to the north and south of those of the corresponding members of the older formations. In strike and dip it conforms with the Benton and Dakota, and, like them, in passing from without inward, is overlain by successive strata of the Pierre, though it is nowhere brought in contact with the higher member of the Montana group, the Fox Hills. The disappearance of this formation is especially well shown both in the north and south by the physical character of its sediments: the upper, bright-yellow or buff, sandy measures, which often form a well-marked outcrop, are first lost; then follows the destruction of the argillaceous middle part of the series; and finally the prominent basal limestones are themselves cut out. The disappearance occurs in the south only a short distance north of Bear Creek, and in the north a quarter mile north of Van Bibber Creek.

The Montana.—This group in strike conforms strictly with the overlying Laramie, the basal sandstones of which afford a prominent and reliable key to the relations of these upper formations with the ones already considered. The dip of the component beds of the group, where all are present and in normal occurrence, shows a gradual increase from 45° to 90° as the distance increases from the base toward the summit. Over the middle of the anomalous tract, however, a vertical dip prevails, as in the case of nearly all the formations in this portion of the area.

The fact of chief interest regarding the Montana group is its remarkable and rapid disappearance between Bear and Coal creeks as distance is gained from either of these streams toward the center of the region at Golden. Immediately north of Bear Creek its strike relations with the underlying formations are rather more exaggerated than at most other points, and consequently more clearly brought out in the surface exposures there occurring. In this vicinity successive beds of the Pierre may be traced over their general line of strike by means of their lithological characteristics and the general prevalence of certain fossils at particular horizons, from points 1,000 feet or more to the east of the Niobrara at the bluffs of Bear Creek to others within only 200 or 300 feet of the older formation, 1 or 2 miles to the north. The angle thus made by the difference in strike between the Niobrara and Pierre is on an average about 15°, but decreases to the north, opposite the middle of the Dakota hogback, beyond which the strikes are, for a considerable distance, more nearly parallel.

In the northern part of the region, opposite the first hogback north of Golden, the exposures of the Montana group are rare, but a half mile north of Van Bibber Creek, and from this point to Ralston, the discrepancy in strike observable to the south has for a time almost wholly disappeared; beyond Ralston Creek, however, a divergence of 20° is still noticed in the general trend of the Laramie and Dakota sandstones, which extends to a line due east from the entrance to the canyon of Coal Creek. This area is regarded as corresponding to that in the vicinity of Bear Creek in the south, over which a thickness of Montana beds equivalent to that on the southern border of the field is regained, by which the geological symmetry of the region is rendered complete.

Over the middle portion of the region the Montana beds follow closely the behavior of the Laramie, but show frequent variations in thickness and corresponding changes in their strike relations with the beds below. Regarding the individual members of the Montana group, if the general thickness of the Fox Hills is taken at between 800 and 1,000 feet, the Pierre has not been deposited for a long distance in the middle portion of the region, having gradually thinned from the confines of the area toward the center of Golden by successive losses of its lower beds. The Fox Hills alone is of general occurrence, although its thickness also over the central portion varies greatly and often.

The Laramie.—The prominent feature of this formation is its remarkable bend from a course approximately parallel to the foothills and to the formations below to a broad, sweeping curve, by which it is gradually carried to the westward until at Golden, its point of greatest deviation, it lies between 2 and 3 miles to the west of its former course. The general trend is slightly wavy, but with reference to the early Cretaceous and older formations is of notable steadiness, passing all their individual deviations without the least disturbance of its own. Its dip is vertical or slightly overthrown for the entire length of the area under consideration, and its basal sandstones form along their trend a characteristic series of combs.

Arapahoe and Denver.—The formations above the Laramie, although in reality markedly unconformable with it and with each other throughout the broad area over which they have been deposited, nevertheless in the present tract so closely follow the former in strike and dip that they display no peculiarities worthy of note in the present discussion, and, in fact, are only incidentally connected with the special geological history here discussed.

STRUCTURAL FEATURES.

Dips.—A geological cross-section along Bear Creek would present a gradual increase in the dip of the several formations from the Archean outward at a rate about as follows: 35° E. for the Trias; 38° to 40° for the Dakota, Benton, and Niobrara; 45° for the lower part of the Pierre, increasing to 55° to 65° in the upper part; 65° to 80° from base to summit for the Fox Hills; and 80° to 90° and overthrown for the Laramie, Arapahoe, and lower members of the Denver formation. Three or four miles north of Bear Creek, 10° to 15° may be added to the lesser of the foregoing dips, while from Coon Gulch to the vicinity of the hogback first north of Golden the formations of higher dip, having now become vertical or slightly overthrown, remain so, and the Triassic beds alone have an inclination under 80° or 90°. North of this, where regularity in the formations once more prevails, the dips settle back approximately to their normal amounts as given at Bear Creek.

The general fold parallel with the base of the Colorado Range.—The surface exposures of the prominent and sharply defined fold occurring generally along the base of the Colorado Range and resulting from its uplift are, for the greater part of the area under consideration, to be found within a short distance of the line of union of the Denver and Arapahoe formations. North of Van Bibber Creek, however—where the Denver formation ceases to exist, and where, 2 or 3 miles farther, the Arapahoe also disappears—the bend is almost entirely transferred to the Laramie, the Arapahoe for that part of the distance over which it is present entering into it only in the slightest degree.

Faults.—There are along the line of the older formations in this region four easily recognized fault localities: One near the termination of the Niobrara just north of Bear Creek; a second in the isolated Dakota hill 2 miles south of Clear Creek; a third near the southern end of the Dakota hogback first north of Golden; and a fourth one-half mile to the south of the latter, near the line of union of the lower and upper divisions of the Trias. The faults of each region have the present appearance of approximately east-and-west cross fractures, along which the ends of the upturned strata are thrown to one side or the other. In the southern half of the field the northern ends of the interfault blocks are carried westward, while in the northern half it is the southern ends that are carried westward. The fractures in the isolated Dakota hill south of Clear Creek are irregular and apparently local in their character. As a rule, the extent of throw of the faults mentioned is slight and is confined to a single formation, one fracture only—of the group in the southern portion of the area—extending beyond 100 or 200 feet, this including the Niobrara, Benton, and Dakota, but being much less pronounced in the older formations than in the Niobrara.

The faults in the vicinity of the Ralston dike and the foothills of Coal Creek will be discussed in a separate section.

STRUCTURAL DEVELOPMENT OF THE AREA.

Introductory.—The abnormal conditions which have been noted in the relations of the several formations to one another are directly traceable to a series of unconformities that exist at the particular horizons at which these conditions occur. Excluding the higher ones of general occurrence along the base of the mountains in this portion of Colorado—that is, those between the Laramie and Arapahoe, and the latter formation and the Denver beds—there are still to be found four which are in some respects peculiar to this locality: One between the Archean and Trias, of special development in this area; a second at or near the close of the Trias; a third at the top of the Jura; and a fourth in the Cretaceous at the close of the Colorado.

Entering most prominently into the history of these unconformities are as many folds, all of which occurred prior to the general uplift of the Rocky Mountains, and hence, with the erosion going on at the time, represented a topography for the region completely different from that of the present day. When the great uplift of the Rocky Mountains brought the beds into the position they now have, all hills resulting from previous folding were changed in their individual positions from one in which the plane of their bases was horizontal to one in which it became vertical, or at least inclined at a high angle, and parallel to the direction of the mountains. In the subsequent erosion of the region, therefore, what would originally have been a profile section of the strata constituting these folds now appears in plan on the present surface of the ground, all originally north and south dips becoming present north-and-south strikes—in some cases slightly altered in character by incidental variations in the amount of folding in the general uplift of later times.

The detailed character and the contours of these ancient elevations can not be determined, the two dimensions given in the profiles being naturally the only ones admitting of observation. The profiles, however, afford data quite sufficient to furnish a clear insight into the general character of the unconformities and the movements in the earth's crust which led up to them.

First period.—The several events in the geological history of this region by which it has reached its present state of evolution were as follows: First, that which brought about the unconformity between the Archean and Trias. That there everywhere exists a general unconformity between the rocks of these two ages is well known, but within the region in question there is direct evidence of a special development of the unconformity, which is, furthermore, borne out by the subsequent events which form the successive steps in the geological history of the area. This evidence consists in the observed termination of certain of the lower beds of the Trias against a slightly projecting portion of the Archean; in the impossibility on structural grounds of the whole amount of thinning which the Triassic beds have undergone being attributable to disappearance from the top and the consequent necessity for its having taken place from below; and in the graphical development of an Archean eminence, as represented in Profile I, Pl. X, by tracing backward from their present positions through the series of figures given the relative movements of the rocks of the several ages by which they have been brought into these positions. The evidence is found to lead directly to the following conclusions regarding the first of the periods in the special history of this region.

Prior to the deposition of the Trias there had been developed in the Archean, partly by erosion and partly, perhaps, by compression, the elevation shown in section in Profile I, Pl. X. Its height was probably 800 feet, and it had a linear extent in a north-and-south direction of nearly 4 miles. Against the sides of this Archean elevation were laid down the coarse sediments of the lower division of the Trias—the Red Beds—which in time completely capped the hill along the line of profile given, and finally buried its summit deep beneath the accumulated material. General subsidence and sedimentation continued uninterruptedly to, or nearly to, the close of Triassic times, completing the first stage in the history of events here considered.

Second period.—At the close of the Trias the region which embraced the above events yielded a second time in a marked degree to the forces of elevation and developed the gentle arch of Triassic and Archean strata shown in Profile II, Pl. X. The north-and-south extent of this arch was but slightly greater than that of the one already described in Archean times, its crown—coincident with that of the earlier one—lying about a half mile to the north of the present position of Clear Creek. The rise of the arch, as indicated by its upper beds, was apparently about 420 feet, but subsequent erosion must have planed it down from its original height and shape to approximately the level line drawn across it in the figure as the base of the Jurassic formation.

The evidence for the occurrence of the unconformity at this horizon and the fold which preceded it is found in the disappearance of most of the upper members of the Trias within the region of its influence, and in the divergence between the present strikes of the formations on either side of the line of unconformity—a divergence in strikes, it being remembered, corresponding to an equivalent discrepancy in the ancient dips, as shown in the profiles.

This line of unconformity is naturally somewhat wavy, and it is possible, indeed, that at some points along the middle portion of the existing arch, through insufficient erosion, the deposition of a part or even of the whole of the Jura may not have taken place. The weight of the evidence, however, is in favor of nearly complete deposition over the entire section, from the fact that wherever the formation now exists it displays no tendency whatever to a protracted, gradual thinning, as is the case in the disappearance of certain of the other formations, but, on the contrary, disappears by the sudden truncation of its strata in almost their full normal thickness, clearly the effect of subsequent erosion.

The movement which brought about the elevation of the Triassic strata must be regarded as synchronous with at least a portion of that more prolonged or extensive movement by which the sea was sooner or later shut out from certain areas in the Rocky Mountain region of Colorado, causing either a partial or an entire absence of marine beds, according to circumstances, with a succeeding deposition of fresh-water strata in which a lacustrine life appeared. In the area under discussion the fresh-water Jurassic alone was laid down.

General subsidence of the entire region continued during the deposition of the Jura upon and against the sides of the Triassic eminence, and at its close the second period in the geological development of the area was completed.

Third period.—This opened with still another uplift of all the preexisting sediments into the fold traced in Profile III, Pl. X, the rise of the arch in this case being approximately 1,000 feet. The figure shows the character of the fold on the line of profile given to have been that of a long, gentle slope from the confines well toward the center, where, on further yielding to the compressive forces, a clearly defined median ridge was produced. Erosion naturally went on in a more or less irregular manner, but the general position of the hill and its component strata relative to erosive forces was apparently such as to cause the disappearance from the top of the Jura, over those parts of the slopes of gentle inclination, of only the most insignificant amounts of material, while over the central or sharper portion of the fold the probable effect was the complete removal of the beds of the Jura and Upper Trias, together with a partial removal of those of the Lower Trias, from the crown of the arch, and of the material from the adjoining flanks down to the gently sloping line of union shown between these formations and the Dakota lying across their edges. Whether erosion reached an extent sufficient to permit the deposition of the Dakota and the lower part of the Benton entirely across this rise is doubtful, but from the rate of disappearance of the Dakota from below, it is probable that neither this formation nor the lower half of the Benton was here laid down.

The evidence for the conclusions given in the preceding statement is clearly brought out in the strikes (ancient dips) and surface relations of the formations to one another, notably, in the divergence in strike and the truncation of the edges of the Jura by the Dakota on the southern side of the gap (Profile III, Pl. X); in the thinning of the Dakota in such a manner as to eventually leave the fire-clay in its upper half in contact with the older sediments at the two points where the formation appears to end, in the south bank of Clear Creek and the north one of Gold Run; and in the ready reproduction by graphic methods of the structural conditions observed in the field and the natural sequence of events based thereon.

Sedimentation of the Dakota, Benton, and Niobrara continued uninterruptedly to the close of the latter time, subsidence probably keeping pace. With this the third period of development ended.

Fourth period.—The fourth period embraces the time during which the great elevation shown in Profile IV, Pl. X, was created, and in which the sediments of the Montana and overlying formations were laid down. The uplift of this time was of much greater vertical and areal extent than any of those which preceded it, the rise of the arch on the line of section given reaching at least 9,500 feet, while its lateral extent was not far from 21 miles. It is broadly symmetrical, though there are several sub-flexures of more or less pronounced curvature. The two of greatest prominence occur midway either flank. The others, of minor development, are confined chiefly to the higher part of the arch, and represent a crumpling of a secondary nature along this portion of the fold. This crumpling is well shown upon the present surface of the region in the changes in strike of the affected beds, which are in strong contrast with the unbroken direction to which the strata of younger age hold. The possibility of the presence of an occasional fault in the place of an unbroken flexure as drawn in the profile is to be remarked, notably, in the vicinity of Gold Run and again at points north of Coon Gulch. It so happens that here and there a space intervening between two outcrops of the same bed, lying in an indirect line from each other, is so covered that it is quite impossible to observe the position of the underlying strata; but since in no case a sharp break in the beds of the Archean and Trias lying below the more affected ones has been discovered, it is preferable to sketch the irregularities as flexures rather than as faults.

Concerning the recognized faults in the northern and southern halves of the arch, described on page 90, their true character now readily appears in Profile IV, where, upon the restoration of the beds to their position in pre-Montana times, the fractures are, with the local exception at the south end of the Dakota hogback north of Coon Gulch, all found to be a series of slip faults of the normal type, either vertical or hading to the downthrown side and away from the center of the uplift, and similarly developed on either flank of the elevation. The explanation of the normal type of fault under the attendant conditions may possibly be found in the readjustment of the strata, brought about by subsidence during a later period.

The profile of this ancient hill, at least on the line given in the figure, is one of structure rather than erosion, the unevenness in its outline being clearly traceable to the flexures underlying, the comparatively little erosion that has taken place over the higher portion of the arch having been regular in distribution, and thus having but slightly altered the original outline of the upheaval. The height of the elevation, however, has been reduced over 1,000 feet—to 8,481—by the removal of the Niobrara, Benton, and Dakota.

The succession of events in the erosion, the transportation of the derived material, the sedimentation in the adjacent Montana seas, and the conditions which led up to each are in a degree speculative; but the inferences are, first, that soon after the completion of the Niobrara period elevation began, and so much of the hill as is above the altitude indicated in the section (Profile IV, Pl. X) by the line marking the upper layers of the Niobrara was then, sooner or later, brought within the erosive power of waves or currents, and the sediments last laid down, being now brought into a favorable position, and still in a condition sufficiently soft to permit their being easily broken down and comminuted, were removed by the transporting powers of the waters washing them; secondly, that the conditions of sedimentation in the immediate seas were the same as those in all mediterranean or large inland seas or along the margins of the continents at the present day—that is, there was comparatively deep and quiet water at a distance somewhat remote from the nearest coast line, which permitted the quiet settling of the sediments forming the clays of the Montana group, and corresponded to those under which the blue mud of subcontinental areas is now being deposited.

The apparently complete removal over the space originally covered by them of the materials resulting from the breaking down of the early Cretaceous strata is somewhat striking, but it may readily be accounted for in the nature of the formations removed and in the action of waves and currents throughout the long time the higher parts of the elevation were probably subjected to them. Furthermore, it can not be positively asserted that the line of unconformity is as clear of débris as represented, since on the steeper flanks of the arch it is rare that the beds above this line can be traced to actual contact with those below; still further, it is to be remembered that nothing whatever is known of the conditions on other profiles of this ancient hill. During the deposition of the beds of the Montana group gradual subsidence of the area at a generally uniform rate must have taken place, the sedimentation, with two exceptions, being that of quiet and deep water. The exceptions noted—the sandy zone midway the Pierre and the more arenaceous beds of the Fox Hills—are, however, not confined to the area under consideration, and therefore bear no relation to the phenomena here discussed.

With the general movement at the close of the Laramie and that which produced the unconformity between the Arapahoe and Denver formations along the range, the peculiar structural features here described have nothing to do.

Fifth period.—Upon comparing Profile IV, Pl. X, with the present surface section of the same beds upon the general map of the region (Pl. X), the early relations between the arched and horizontal strata, as shown in the profile, are observed in later times to have completely interchanged. The once highly arched strata below the line of unconformity have now assumed a practically direct trend, while the strata above the line of unconformity, originally horizontal, have at the present time a well-defined inward sweep toward the mountains, reaching their limit of deviation in the vicinity of Golden, or, the latter feature being considered with reference to the profile itself, the Laramie and overlying strata have acquired a downward bend at the center of the area, directly over the crown of the arch of post-Niobrara times. Compare also figs. 4 and 5, following.

The final movement which produced the present structural conditions, and the outpouring of the lavas of Table Mountain midway the period of the Denver formation, is regarded as constituting the fifth and closing stage in the geological development of the area under discussion.

DISCUSSION OF MOVEMENTS PRODUCING THE PRESENT STRUCTURE.

Statement of the hypothesis upon which the argument rests.—From the not infrequent occurrence, either within the present area or in other parts of the Rocky Mountains, of compound folds of the S type and of otherwise contorted strata, from the presence of reversed faults, and from the occurrence of the well-known folds en échelon, it is believed that the theory of lateral compression as the means by which the forces uplifting the range were generated, although not accepted by all scientists, does, nevertheless, more completely and satisfactorily fall in with the observed facts than any other which can be suggested. It is not intended, however, that this shall preclude the acceptance in the future of any other grounds upon which it may be possible to establish a still more satisfactory explanation of the phenomena forming the subject of this section.

Manner in which the forces of elevation have locally manifested themselves.—At various points along the base of the Colorado Range occur strongly pronounced local peculiarities of structure, either faults, or folds of varying shape and character, both secondary as to the general uplift of the range. It is highly probable that these structural peculiarities are attributable to the general forces of elevation that are acknowledged to have been in action throughout the several geological periods here represented.

The unequal distribution of, or resistance to, the general force of elevation.—Still further, it may unhesitatingly be granted that the general force of elevation or the resistance opposed to it has been more or less unevenly distributed from point

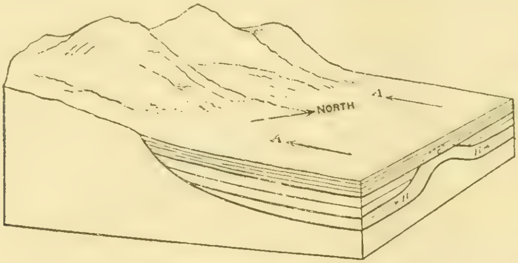


FIG. 4.—Illustration of unconformity near Golden.

to point, and has acted, not always at an absolutely right angle to the axis of the range, but diagonally to it, in one or more directions at the same time. Its direction has in fact varied according to circumstances.

The development of the post-Niobrara fold.—In the present area the distribution and directions of this force up to immediate post-Niobrara time had been such as to eventually bring into existence the fold of the general character represented in the profiles, and in fig. 4.

An analysis of this distribution and its effects shows that, of the various components of this force, the major, which exceeded all the others combined, was that acting in the general elevation of the range and directly against its axis—that is, for the eastern base, with the arrows A (fig. 4), westward. This had undoubtedly been in action with probably but little interruption from earliest time. The other components, secondary to that just noted, and acting in directions more or less normal to it, B (fig. 4), were evidently periodical in character. They reasserted themselves with special intensity at the close of the Niobrara, effecting almost entirely at this time the pronounced elevation under discussion, *c* (fig. 4), the cross-section of which is that in Profile IV, Pl. X. The Montana, Laramie, Arapahoe, and early Denver beds were then deposited upon this fold, closing the first four periods of history discussed above.

The Profiles I–IV, Pl. X, inclusive, may be regarded as transverse (north-and-south) sections of this secondary fold in the several stages of its development according to the geological time represented by each. Fig. 4 is more particularly a diagrammatic representation of the condition of affairs at the close of the Laramie or at a point in time somewhere between this and a stage early in the deposition of the Denver formation.

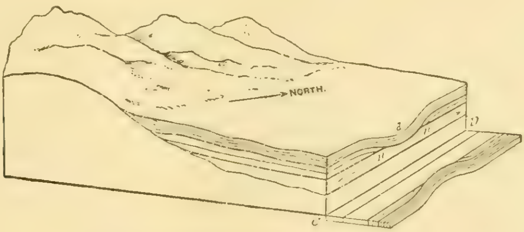


FIG. 5.—Illustration of unconformity near Golden.

By the post-Laramie movement the strata were bent up against the range nearly at right angles and afterwards truncated by erosion. This effect is produced in fig. 5 by supposing a slice of the block represented to have been turned down through an angle of 90°, as if hinged along the line C D. The hinged portion is thus a diagrammatic representation of the superficial outlines, as shown in detail by the map.

The readjustment of forces by which the structure of post-Niobrara and Laramie times was changed to that of the present day.—At the close of the events constituting the fourth period there began a readjustment of the major forces acting against the range, by which the fold of pre-Montana age and its cap of horizontal strata gradually gave way to the structure of later times. The results of this readjustment may have been developed prior to the time of the inclusion of the affected area within the general uplift of the range, but were more probably synchronous with it.

The complex movement which brought about these results may properly be resolved into two chief components. The first of these includes the movement by which the strata composing the pre-Montana fold were brought from their position, as represented in Profile IV, Pl. X, to that which they hold in the natural section given by the outlines on the map. The effect of this movement can be seen in diagrammatic representation, shorn of all complicated details, by comparing fig. 4, which shows the conditions previous to the movement, with fig. 5, which shows those subsequent to it. In this movement the strata resting horizontally upon the pre-Montana fold of necessity followed the recession of the beds beneath, assuming the position of the synclinal depression *d* in fig. 5, or the highly curved position—the result of the synclinal position—which they hold in the section on the map. The second component is the movement specially involved in the elevation of the range, by which the strata were brought into the highly inclined position they hold along its base at the present time.

Readjustment of the forces accounted for.—The readjustment of the forces effecting such important structural changes can be accounted for by relief from the compression to which the strata had been subjected, brought about beyond the immediate region here considered. The exciting cause may have been elevations in other areas, or even an increase in the force of the general lateral thrust to the north and south of the field, accompanied by a variation from its normal western direction to directions diagonal to the range and divergent as this is approached, by which the original north-and-south compressive forces would have been compensated by the components of the later one acting in the reverse direction respectively (B, fig. 5). Equilibrium having been restored over the area in question, and a portion of the affected region having become involved in the general uplift of the range, which still continued, subsequent erosion and the formation of the plane surface of the present day exposed the underlying strata in the superficial section now existing.

Relation of the basalt eruption to the above events.—The eruption of the Table Mountain basalt took place early in the period of the Denver formation, approximately after the deposition of about one-third of the series had been completed and some time before the strata had assumed the extremely high angles they now have. With regard to its relations to the phenomena forming the subject of this section, it is possible that the subsidence of the Niobrara fold and the horizontal beds capping it may have been, in its later stages, synchronous with the eruption of the basalt masses in Denver times and perhaps, in a measure, due to it. The fissures through which the pent-up lavas found egress may have been the result of the almost constant bending to which the rocks were subjected, and their ejection may have thus constituted the final event in the history of a region remarkable for its dynamic movements.

VIEWS OF OTHERS ON THE STRUCTURE OF THIS REGION.

The views of Marvine.—These are given in Vol. VII (1873) of the Hayden Reports, where he has expressed, in the briefest possible manner, the idea of nonappearance of strata due to an actual "thinning of the original deposits * * * from conditions naturally attending the laying down of new formations upon the newly prepared and hence uneven surfaces of older rocks." He also mentions, as an alternative, the possibility of a fault accounting for the structural peculiarities, but remarks the limited knowledge of the locality which he then possessed. The unpublished results of his work during the season of 1874 unfortunately can not be traced, and therefore his final views must remain unknown; but the brief statement given above leads one to believe that he would in the end have reached a solution not far different from the one presented in the foregoing pages.

The views of Ward.—These are to be found in the Sixth Annual Report of the present Geological Survey of the United States, pp. 537–538, where, referring to the strata in the vicinity of Golden, between Table Mountain and the Cretaceous (Montana group)—which embrace the Denver, Arapahoe, and Laramie formations, but which are all included by him in the Laramie, irrespective of stratigraphical evidence—he remarks:

The strata are conformable, and both the Cretaceous and the Laramie are tilted so as to be approximately vertical. At the base of South Table Mountain the strata are horizontal, and the line dividing the vertical from the horizontal strata could be detected at certain points. A measurement from this line to the base of the coal seam was made at one place and showed 1,700 feet of the upturned edges of Laramie strata. It is probable that we here have the very base of the formation.

The geology of Golden is very complicated, but my observations led me to conclude that during the upheaval of the Front Range a break must have occurred along a line near the western base of Table Mountain, forming a crevice through which issued the matter that forms the basaltic cap of these hills. The eastern edge of a broad strip of land lying to the west of this break dropped down until the entire strip of land assumed a vertical position or was tilted somewhat beyond the perpendicular. This brought the Laramie on the east side of the Cretaceous, with its upper strata at the extreme eastern, while the coal seam at its base occupied the extreme western side of the displaced rock. The degree of inversion varies slightly at different points and may have been much greater in some places. This will probably account for the discovery at one time of a certain Cretaceous shell (Mactra) *above* a vein of coal in a shaft about 4 miles north of Golden, and about which considerable has been said in discussing the age of the Laramie group. I visited the spot, but found the strata so covered by wash that I was unable to determine their nature.

In the above views there are four points requiring notice, although one—that regarding a certain Cretaceous shell—is somewhat irrelevant. The first point is the remark as to the conformability of all the strata from the Denver beds to the Montana group. Although no discrepancy in dip or strike is noticed between them in the vicinity of the Table Mountains, a study of the whole region has abundantly proved the existence of several unconformities, by evidences of erosion, by the areal distribution of the outcrops, and by the character of the component materials of the various formations. The second point is the crevice near the western base of Table Mountain, through which issued the basalt of the region. As a matter of fact, no evidence of such a crevice, nor of the dike which would still remain as its filling, exists along the well-exposed base of the hills. Furthermore, the outpouring of the basaltic sheets is entirely accounted for by the great Ralston dike and the irregular eruptive body near its southern end, and hence there is no necessity for assuming a further fracturing of the strata to give it a vent at some other point in the field. The third point, the fault, into which Professor Ward has developed the break, beyond a doubt coincides in locality with the great fold which occurs all along the eastern base of the Colorado Range, by which the beds to the west of it are sharply upturned, often to a vertical or reversed dip, while their continuance to the east of the axis is at a dip of but the slightest amount. This curve may at times be complete within a distance of 50 feet. A fault is therefore unnecessary to explain the abrupt change from the vertical to the horizontal position. Moreover, observations show that the Denver and Arapahoe beds actually take part in this fold at a point directly opposite South Table Mountain. The complicated geology of the region would very naturally lead one to mistaken conclusions unless a thorough knowledge were possessed not only of the area of disturbance here considered, but also of the general structure of the region far beyond. The fourth point in the quoted remarks of Professor Ward relates to the manner in which he accounts foi the fossil Mactra found, according to prior statements, "over" the coal. As a matter of fact, the fossil does not occur over the coal, but beneath it, in its usual position in the Pierre bed, its apparent position being due to its lying within a locally faulted area, the beds of which have been thrown to the eastward of the general trend of the coal in the unaffected area to the south and north.

The views of others.—In addition to the views of the above writers, others have from time to time been expressed, implying belief in a fault in the vicinity of Golden to account for the peculiarities of structure there displayed. In reply to this it need only be stated that no fault can be conceived which will at once account for the several features in the geology of this region as exposed over the present surface of the area and set forth in the preceding pages.

SPECIAL IRREGULARITIES IN THE GOLDEN REGION.

The Ralston faults.—These occur in the vicinity of the Ralston dike, midway between North Table Mountain and Ralston Creek. They entered only into the later development of the region in a manner incidental to rather than as a primary factor in the events that transpired.

There are three fractures, and their peculiar features are due chiefly to exceptional local conditions connected with the neighboring eruptive phenomena. The fractures bound the western, northern, and southern sides of a rectangular block of strata of indefinite but not great thickness, beneath which there is probably a large mass of eruptive rock, a part of that which occupies the western of the three rents and forms the prominent north-and-south dike of this locality. The block of strata inclosed by the fractures extends north and south a little over a mile, east and west about 2 miles. Its component strata include rocks of the Pierre, Fox Hills, Laramie, and Arapahoe formations, completely shattered and in a most chaotic state, except in the extreme eastern part of the area, where their dip becomes more regular, and gradually shallows to the horizontal beyond the disturbed region. The amount of displacement which the interfault block has suffered is variable for the east-and-west fractures, while an actual estimate along the north-and-south fracture can not be made, on account of the shattered condition of the beds and the impossibility of recognizing definite horizons.

The north-and-south fracture approximately coincides with a stratification plane, the planes of the east-and-west faults intersecting this. The north-and-south plane is now nearly vertical, though at the time of eruption it was probably more or less inclined, the strata having suffered some folding since. The east-and-west fractures are apparently vertical.

The development of the three fractures is probably the combined result of the general folding that took place along the Colorado Range and of the presence of a mass of eruptive material seeking an outlet at the surface through the channel of least resistance. The north-and-south fracture, occupied by the main dike, probably antedates the others and was primarily of slight displacement, the more extensive throw of its southern half being due to a local enlargement of the eruptive body. The east-and-west displacements were concomitant features. The presence of the locally enlarged mass of eruptive material, the increasing pressure as the folding advanced, the yielding nature of the overlying clays, which also dipped toward the east, all united to at last compel a rupture and dislocation of the overlying beds in the location and directions platted. The resistance to the strain developed by this condition of affairs is well shown at several points in the disturbed area, but especially along the northern fault line, where there is abundant evidence in the normally flexed ends of the opposing beds, of distortion and bending before the strata finally yielded to the force of compression brought to bear upon them.

THE REGION ABOUT BOULDER.

The structural features of the region about Boulder are of the same general type, except for the absence of eruptive phenomena, as at Golden—that is, there is here another series of unconformities occurring at various horizons from Archean to Montana. The area affected by this series of unconformities extends along the foothills from a point a little over 2 miles south of North Boulder Creek to one about 1½ miles north; its breadth is nowhere much over 1 mile, and the phenomena are confined to the open slopes of the foothills and the bench lands and prairies adjoining.

TOPOGRAPHICAL FEATURES.

As about Golden, the topographical features, through influence of the geological phenomena involved in the region's development, again diverge from normal. Instead of the fringing reefs of Dakota and Niobrara, the Triassic and Archean slopes directly overlook the prairie. The disappearance of the hogbacks, the wavy trend of the strata in actual outcrop or in soil delineations, the approach of formations in converging strikes, and the occurrence of short east-and-west faults all contribute to variation from the usual foothill character.

GEOLOGICAL FEATURES

The formations involved in the geology of the area include all that occur in the Denver field from Archean to Pierre.

The Archean.—This presents the usual wavy line of union with the Trias, significant of the unevenness of the floor receiving the deposits of the latter, but no feature of structure or sedimentation peculiar to this region alone appears.

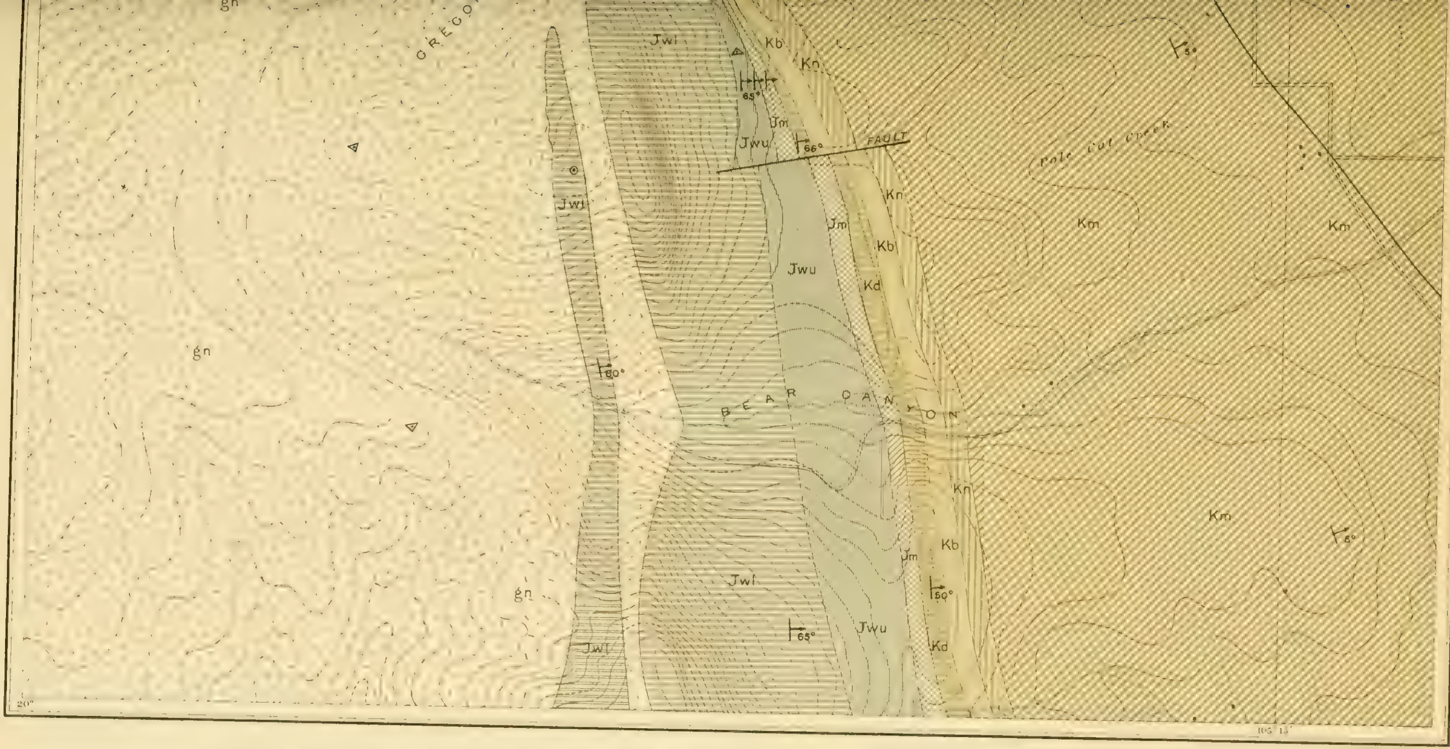
The Trias.—The lower member, so far as the phenomena under discussion are concerned, has been unaffected, unless, perhaps, in the thinning which is observed in the vicinity of Boulder Creek, due to a rise in the Archean floor, which may have been the incipient movement of the series to follow. The local fold developed on the face of the Triassic slopes between Boulder Creek and Gregory Canyon is of an origin later than the phenomena here discussed, and unrelated to them.

The upper member of the Trias, within the limits of the area under consideration, rapidly diminishes from its normal thickness of about 600 feet at either end to complete disappearance at Gregory Canyon, near the center of the affected region. Measurements at two points along the line of gradual disappearance—one just north of Boulder Creek, between it and the wagon road leading to Sunshine, the other a few hundred yards south of Gregory Canyon, near the northern termination of its southern outcrop—gave a thickness, respectively, of 350 and 50 feet. It is the lower beds of the member that are the last to disappear, the limestones near its base appearing at several points after the formation has begun to thin out. Destruction of its beds has apparently been carried to its very base, though not beyond.

The Jura.—This formation, for the greater portion of its outcrop within the affected area, shows a marked decrease from the normal thickness, but nowhere disappears entirely. The decrease first becomes apparent, at the north, in the vicinity of the Sunshine road; at the south, in a gulch about three-fourths of a mile south of Gregory Canyon. The diminution almost wholly occurs near the limits of the area of unconformity, a considerable distance along the center showing a constant thickness of about 50 feet. The evidence of the strata in explanation of the thinning is in favor of non-deposition of the lower beds, the characteristic conglomerate and mottled sandstone near the summit of the formation appearing at several points along the trend of the strata.

The Dakota.—This thins very perceptibly between Polecat Canyon and the gulch next north, having within the intervening half mile decreased in thickness from nearly normal to about 100 feet, with a complete disappearance of the hogback features. At Gregory Canyon the decrease is still greater, the actual exposure of Dakota here being only about 4 feet, but with a covered thickness of probably 30 feet more. Immediately north of Boulder Creek it is still at its minimum, but at Sunshine Gulch it is rapidly regaining its width—at this point being approximately 150 feet—while a half mile farther north it has again reached its normal thickness. Over the area of minimum thickness it is quite impossible to determine whether it is the upper, middle, or lower portion of the formation which remains, but


BOULDER
North
Boulder
Creek
to Sunshine
Pal
Km
Kn
Kb
Kd
Jm
Jwu
Jwl
gn
N
B



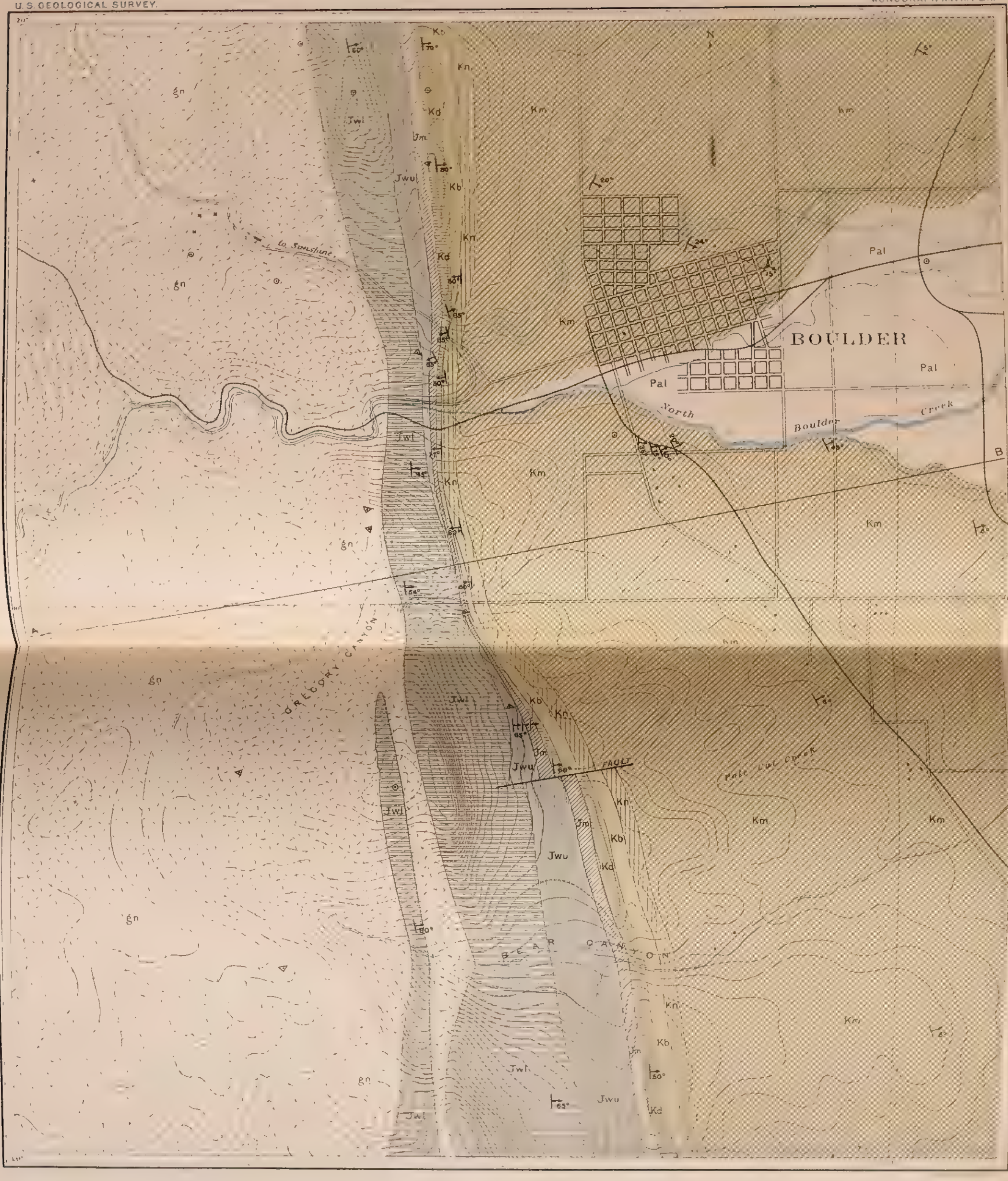
BOULDER AND ADJOINING REGION, SHOWING NON-CONFORMITIES.

Scale

0 — ½ — 1 — 2 MILES.

Contour Interval 100 Feet.

PLEISTOCENE	CRETACEOUS				JURATRIAS.			
ALLUVIUM	MONTANA	NIOBRARA	BENTON	DAKOTA	MORRISON	UPPER WYOMING	LOWER WYOMING	PRE-CAMBRIAN GRANITES, GNEISSES AND METAMORPHIC ROCKS
Pal	Km.	Kn	Kb	Kd.	Jm	Jwu.	Jwl.	gn



BOULDER AND ADJOINING REGION, SHOWING NON-CONFORMITIES.

Scale

0 ½ 1 2 MILES

Contour Interval 100 Feet.

PLEISTOCENE — ALLUVIUM: Pal

CRETACEOUS — MONTANA: Km; NIOBRARA: Kn; BENTON: Kb; DAKOTA: Kd

JURATRIAS — MORRISON: Jm; Jwu; LOWER WYOMING: Jwl

gn

where the outcrops are stronger, to the south and north, it is evidently the upper beds which first disappear, the basal conglomerate being prominently exposed, and occasionally, as well, the fire-clay in the middle of the formation. Upon the formation regaining its normal development, the characteristic hogbacks at once reappear.

The Benton.—The occurrence of this formation is greatly obscured except in respect to the points at which it finally disappears, which are, respectively, for its northern and southern segments, immediately north of Sunshine Gulch, and midway between Gregory Canyon and Boulder Creek. Its outcrops are rare, and the basis upon which it has been represented in Section III, Pl. XII, as laid down against and upon the sides of the Dakota elevation, is found in the stratigraphical relations which it holds to the Dakota, the Dakota disappearing from the summit, while the Benton still overlies—a condition which thus precludes the possibility of conformity between the two formations and necessitates the deposition as figured.

The Niobrara.—This formation, with the exception of a very short interval in the vicinity of Boulder Creek, was laid down entire over the area under consideration. At Boulder Creek, however, the width of the outcrop is considerably less than normal, and it is probable that the lower layers were never deposited, although some portions of its basal limestone are still present.

The Pierre and overlying formations, having been laid down subsequent to the periods of unconformity in this region, will be alluded to only as occasion demands.

Dips and strikes of the formations.—In their dips the formations involved in this area of abnormal structure vary from 45° east, at the northern and southern limits, to vertical and overthrown along the central portion. The younger formations undergo the greater displacement, possibly on account of the relatively greater proportion of clay beds and the consequent more yielding nature of the strata. The heavy sandstones of the Red Beds alone have everywhere dips less than 90°. The general easterly dip of the strata is regained in the Montana, from a half mile to 1 mile east of the range.

The strikes of the several formations present relations with each other which are, in a high degree, significant of the history of the region. The strike of the Trias is the same throughout its upper and lower members—in general about N. 10° W., with occasional local variations due to local or accidental causes. The strike of the Jura is difficult of observation, but from the few exposures existing it is probably in general accord with the Dakota. The latter formation varies in strike from the normal, N. 10° W., beyond the area of unconformities, to N. 25° W. in the southern third of the affected area, N. 10° W. in the middle third, and north to N. 5° E. in the northern third. At a number of points within the region there is also local divergence from the strike given, due to crushing, crumpling, and minor faulting of the beds.

Of the strike relations of the Dakota to overlying and underlying formations, two particular instances require notice. The first is with reference to the Jura, in the gulch between Gregory and Polecat canyons in the southern portion of the field; there is here an apparent discrepancy in strike between the two formations of 25°, the Jura conforming to the older beds, the Dakota and beds above striking obliquely to this in a direction N. 3° W. This discrepancy is probably the result of local displacement, perhaps occurring during the erosion of the gulch. The second instance, involving the strike relations of the Dakota and Niobrara, occurs immediately south of the Sunshine road, where the absence of the Benton has brought the two formations in direct contact at an angle of 27°, the Niobrara crossing the edges of the Dakota beds. This is probably due to a displacement of the Dakota prior to deposition of the Niobrara. The general angle of divergence is plainly visible in the trend of the two formations northward from this point.

The Benton presents but few opportunities for the determination of its strike, and it is chiefly on broad stratigraphical observations already mentioned that it has been drawn coincident with that of the Niobrara.

The Niobrara displays the same great bend to the westward that has been noted for the Dakota, with the additional degree of curvature resulting from the absence of the Benton over its central portion. With the Pierre it is conformable.

General geological deductions.—From the foregoing facts the existence of two well-defined unconformities within the series of formations in the vicinity of Boulder is deduced. Of these, one occurs between the Trias and Jura; the other between the Dakota and Benton.

The existence of the unconformity between the Trias and Jura is established, (*a*) by the gradual disappearance over the middle portion of the area of the upper member of the Trias, in which the order of disappearance is from the top downward as the center of the region is approached, the lowest beds of the series, as, for instance, the characteristic limestones near the base, being the longest retained; (*b*) by divergence in strike shown in the inward or westward curve of the Jura and overlying beds, while the Triassic beds continue their normal trend, parallel to the general direction of the foothills; (*c*) by the direct contact of the Jura with the lower member of the Trias, the Red Beds; (*d*) by the fact that the Jura, which is partially present over the entire area, is, where thinnest, recognized in its upper beds, showing conclusively the nondeposition of its basal members over the central portion of the affected region.

The deductions regarding the unconformity between the Dakota and overlying formations are less firmly established. That an unconformity exists is evident (*a*) from the gradual thinning of the Dakota, which took place from above as the center of the region is approached, the lower beds of the formation holding completely across the affected area; and (*b*) by the complete disappearance of the Benton, with probably also the very base of the Niobrara. The only doubt that can arise in the deductions as sketched in Profile III, Pl. XII, rests upon the question whether the strata of the Benton retain a parallelism with the Dakota or with the Niobrara. In the former case the unconformity would have occurred at the close of the Benton; in the latter, at the close of the Dakota. This question the outcrops fail to answer definitely, although the preponderance of evidence is in favor of the occurrence at the close of the Dakota. The fact that the very lowest beds of the Niobrara are wanting argues nothing, as the pre-Niobrara hill might readily have been of a height to prevent their deposition whether of Dakota entirely or partly of Dakota and partly of Benton.

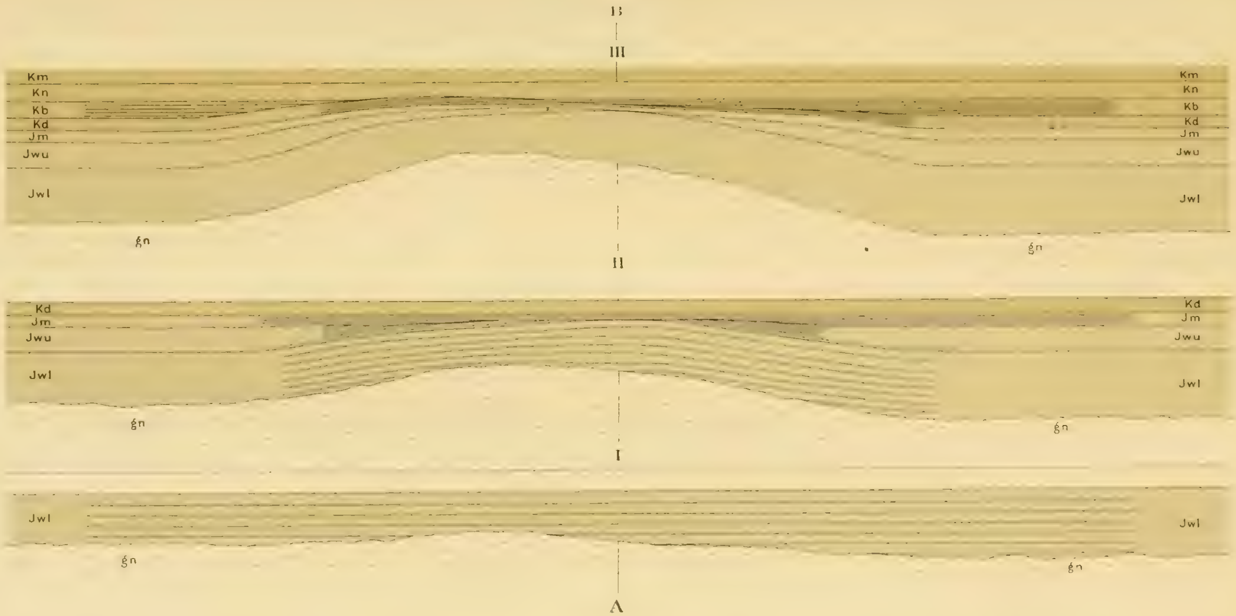
That no other breaks in the continuity of deposition exist in this series of beds is evidenced by direct observation of conformability at the remaining horizons.

STRUCTURAL DEVELOPMENT OF THE BOULDER REGION.

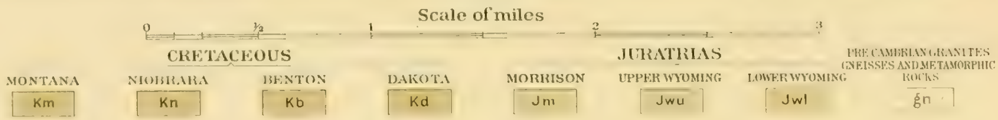
In the geological history of this region there again appear the same conditions of post-Cretaceous development that brought about present surface delineations of ancient Mesozoic profiles in the vicinity of Golden. The character of the elevations, the features of stratigraphy, and the nature of the unconformities prior to the general uplift of the range, which would then have required in representation vertical profiles, are now, by reason of this uplift and subsequent reduction of the region to its present configuration, clearly delineated in plan upon the prairie. The profiles, therefore, are like those illustrating the unconformities at Golden—simply reduced transfers of surface delineations

Prior to the movements which brought about the above conditions the succession of events was approximately as follows: For the reception of the Trias the Archean presented the usual uneven floor, with possibly an incipient rise (shown in Profile I, Pl. XII), which later developed into the fold of the region. Deposition of both members of the Trias was carried to completion without interruption. At the close of the Trias compression began to take place in much the same way as at Golden, resulting in the uplift represented in cross-section in Profile II, Pl. XII, after the influences of erosion had been at work. On this profile the full rise of the original arch was probably about 750 feet, but the height of the elevation was diminished by denudation until, when closed over by the succeeding formation, it barely reached 150 feet. Deposition of the Jurassic and Dakota followed, and with their completion the first period in the development of the geological history of the region closed.

The second period in the developmental history of this region opens with the elevation of the Dakota and underlying beds into the gentle hill indicated in Profile III, Pl. XII. The rise of the arch was approximately 600 feet, but erosion subsequently reduced the summit of the hill to about 350 feet. The axis of the post-Dakota fold on this line of profile was not coincident with that of the earlier fold, being fully a half mile to the north of the latter. Both folds are unsymmetrical in the section exposed, the earlier fold having the longer slope to the north, the more recent fold to south. Deposition of the Benton upon the eroded sides and crests of this



SECTIONS ILLUSTRATING GEOLOGIC DEVELOPMENT OF REGION ABOUT BOULDER, COLO.



I. Condition at close of Lower Wyoming
II. " " " " Dakota
III. " " " " Niobrara

elevation followed, succeeded in turn by that of the Niobrara and Pierre formations, the lower 10 to 15 feet of Niobrara possibly not having been laid down upon the crown of the arch owing to the height of the pre-Benton hill.

The third period of development embraces the time in which the strata were brought from the position they held at the close of the second period into approximately that which they hold at the present day. The dynamic causes to which the geological development of this region is due were of the same nature as those originating the development of the Golden geology—that is, the positions which the strata have held during the several periods in the history of the area are attributable to the unequal compression locally manifesting itself, the result of forces which are secondary in their relations to, and developed from, the general forces which brought about the uplift of the Colorado Range. The elevations of the two regions are indeed reduplications of each other, synchronism in their occurrence alone being absent. The folds induced by the action of the earlier forces of compression were, upon the readjustment of these forces in Tertiary times, or during the period of the great Rocky Mountain uplift, brought into the structural relations they now hold. The denudation which has taken place since the uplift of the range has afforded their sections in plan as delineated upon the surface of the prairies at the present time.

INFERENCES FROM THE SERIES OF UNCONFORMITIES AT BOULDER AND GOLDEN.

Joint consideration of the Boulder and Golden series of unconformities leads to the following possible conclusion: That along the prairie region bordering the early elevations of the Rocky Mountains, and even extending through the several geological ages during which the gradual uplift took place, there occurred a constant succession of oscillatory movements in one locality or another, either contemporaneous, as, for instance, at the close of the Trias in both the Boulder and the Golden area, or alternating—the movement in one region followed at a little later period by that in another—as when the specially developed elevation at the close of the Jura in the Golden region was followed by that at the close of the Dakota in the Boulder, the latter again by the movement which took place in the Golden region at the close of the Niobrara.

THE REGION OF COAL CREEK PEAK.

SURFACE FEATURES.

Structurally, the region to be described extends along the foothills from a point a mile south of Coal Creek to one 2 miles north of it. Geologic interest centers about Coal Creek Peak, a high, conical mass of granite immediately north of the creek, that stands conspicuously forth from the great body of Archean rocks to the west but with which it is still connected by a long, narrow, granite ridge. The northern or northeastern base of the peak is marked by a small stream which rises just within the Triassic beds, and to the north of this, except for local faulting, the normal foothill topography prevails; the steeply inclined Red Beds form a lofty ridge, separated by a sharply eroded gulch from the Archean hills; the Dakota hogback confines a small valley in the Jura, and to the east come in order the Benton, Niobrara, and Pierre formations. Opposite the peak the topography completely changes; the granite stands well to the east of the range proper, and the Trias, Jura, and Dakota almost wholly disappear. The Dakota occurs only as a low comb well down on the face of the mountain, in places disappearing altogether, the slope from peak to plain being unbroken. Although the formation is present, it is not until nearly 2 miles south of Coal Creek that it reappears in hogbacks. The Red Beds of the Trias reappear at the northern bank of Coal Creek and south of the stream again form a prominent ridge that finally constitutes the northern spur of the Ralston Peaks, separated by a deep valley from the granite hills to the west, and to the east directly overlooking the prairie.

STRUCTURAL RELATIONS OF THE FORMATIONS.

In the southern portion of the region under discussion the Red Beds successively disappear against the projecting mass of crystalline rocks, the lowest first, at a distance of about a mile south of Coal Creek. The measures are here overturned, the youngest the farthest, the Dakota at one or two points showing a westerly dip as low as 25°. The fold is, however, a comparatively sharp one, and it is probably but a few hundred feet below the surface that the normal easterly dip is attained.

From a point a few hundred feet north of Coal Creek to the northeastern slope of the peak, although there is great obscurity from the presence of débris, it is doubtful if any but the higher formations are present. It is furthermore impossible to determine the manner in which the strata take up the conditions that prevail to the north and northeast of the peak.

At the northeastern base of the peak is an outcrop of Red Beds, forming a low cliff just south and west of the small stream there flowing. The strata to the south of the stream dip gently south; west of the stream, west; near the eastern edge of the outcrop, east, here indicating beneath the débris a union with the beds of regular dip to the north of the creek; there is, in short, in the Trias of this locality, a small anticlinal fold. Passing directly up the slopes of the peak several hundred feet above the outcrop of Trias, a small patch of Dakota is seen adhering to the side of the granite mass. On following around the face of the mountain, east, other fragmentary remains of the Dakota are found, at successively lower levels, until the slightly projecting crest of the main north-and-south body of the formation is reached. Beneath the Dakota outcrops on the northern and northeastern sides are also found fragments of the Jura mottled sandstones, together with occasional traces of the gray and purple shales of the same formation. No dips or strikes appear in any of the fragmentary outcrops, unless in the Dakota, where there are indications of gentle inclination to the west. From this, and from the relative position of the formations found on the side of the mountain, it seems probable that the anticlinal fold first seen in the Trias must also include some of the younger formations—to the top of the Dakota at least. The axis of the fold has a trend to the west of north, at an acute angle with that of the range, and in the same direction as the axes of the échelon folds to the north and south. The axis dips rapidly to the south, and it is doubtful if the anticline extends much beyond the eastern base of the mountain.

GEOLOGICAL DEVELOPMENT OF THE AREA.

The foregoing structural conditions indicate for their development a peculiar combination of events. In the first place, there apparently existed in the floor of the Triassic sea in this locality an important Archean elevation, now the mass of Coal Creek Peak. Around this early eminence were laid down, in probably uninterrupted succession, sediments of the Triassic, Jurassic, Dakota, and even younger formations, the later beds overlapping the older on the slopes of the elevation. By the uplift of the Colorado Range the beds were brought approximately into their present positions, and by erosion have been brought into the surface relations they now hold. In short, there exists here another of the unconformities so frequent along the Colorado Range in the Denver field, with the difference that in this case the unconformity is probably confined to the line of the Archean and sedimentaries.

In the uplift of the range, however, there appeared in the northern portion of this locality, close to the line of union between the sedimentary beds and the granite, a crumple similar in structure to a fold en échelon, the remnants of which now exist only in the small anticline in the Triassic rocks and in the isolated outcrops of the Jura and Dakota on the mountain side, erosion subsequent to the uplift of the range having destroyed all other traces.

THE REGION FROM THE BOULDER UNCONFORMITIES TO COAL CREEK PEAK.

THE FAULT AT THE SOUTHERN LIMIT OF THE REGION OF THE BOULDER UNCONFORMITIES.

This appears at a point about $2\frac{1}{2}$ miles south of Boulder, as an east-and-west lateral displacement of about 500 feet, in the Dakota and adjoining measures, the line of the fracture being now occupied by a mountain stream. Notwithstanding the very considerable displacement in the Dakota, neither the Trias below nor the Pierre above seems to have been involved in an important degree. The fracture is at right angles to the present strike of the beds, and the fault plane is apparently vertical. The strata to the south of the break are thrown to the east, the reverse of the throws in the similarly disposed faults in the southern half of the Golden region. This fact, in connection with the location of the fault—at the very limit of the affected area of unconformity, yet at an early bend in the strata—while indicating indirect influence by attendant structural conditions, points to a time of actual development subsequent to the early folds and synchronous with the uplift of the range and the assumption by the strata of their present position.

THE FAULT OF THE SOUTH BOULDER PEAKS.

General description.—The very characteristic double peak of South Boulder, which forms a prominent landmark from the plains, owes its twinning to a strike fault in the higher foothills of the Front Range overlooking the prairie. Reduplications of this nature are not infrequent in this range, but through topographic position or extended erosion they are rarely prominent.

The linear extent of the South Boulder Peaks fault is between 3 and 4 miles, the southern end being well defined, the northern passing into granite and becoming difficult to trace. The break has the appearance of a normal strike fault, the plane, where observed in Bear Canyon, inclined to the west—against the dip of the beds—at an angle with the horizon of from 60° to 80°.[1] Notwithstanding its "normal" appearance, however, it will be shown beyond that it is of the "reverse" type, the deception occurring through the position of the beds and the topographic features of the region. The downthrow is on the west of the fault plane, the displacement varying from 0 at the ends to approximately 1,400 feet at the point where the Profile II of the general sections crosses it, to 3,250 feet, as observed in the gorge of Bear Canyon, and to a figure perhaps somewhat in excess of this at other points along its line.

FIG. 6.—The South Boulder Peaks twinned by fault. From U. S. Geological Survey of the Territories, by F. V. Hayden.

The fault, in its surface appearance, resembles an extensive rent in the Red Beds, occupied by the granites of the Archean. The southern end is well shown in the ridge just north of South Boulder Creek, which connects the Dakota hogback with the main mass of the Trias. The first suggestion of a possible fracture is here found in the tendency displayed by the Dakota sandstone to the structure "en échelon" so frequently met with along the front of the Colorado Range. On passing to the deeply eroded

[1] In fig. 7, from the Hayden Survey, the hade is given east.

gulch just north of the cross ridge, an actual break is recognized in the Red Beds, having rapidly developed from what was at first but a slight fold or displacement of the beds to the eastward to a condition in which the strata on either side of the fault have become strongly divergent, both in strike and in the degree of dislocation along the fault plane. This divergence continues to increase to the northward until the summit of the peak is reached, when the beds on the two sides of the fault become parallel in trend and so continue well toward the northern end of the disturbed area. The northern end of the rent, so far as the sedimentaries are concerned, may be regarded as open, the beds on either side of the fault, through the agency of erosion, failing to join.

The fault is apparently the result of the forces of compression acting at the time of the general uplift of the Colorado Range. Traces of this early crumple are still visible in the southern face of the South Boulder

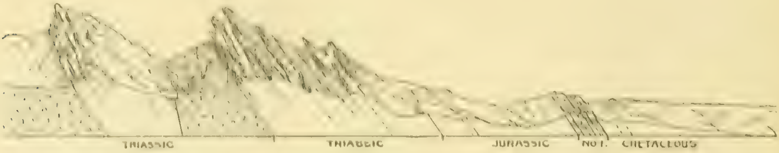
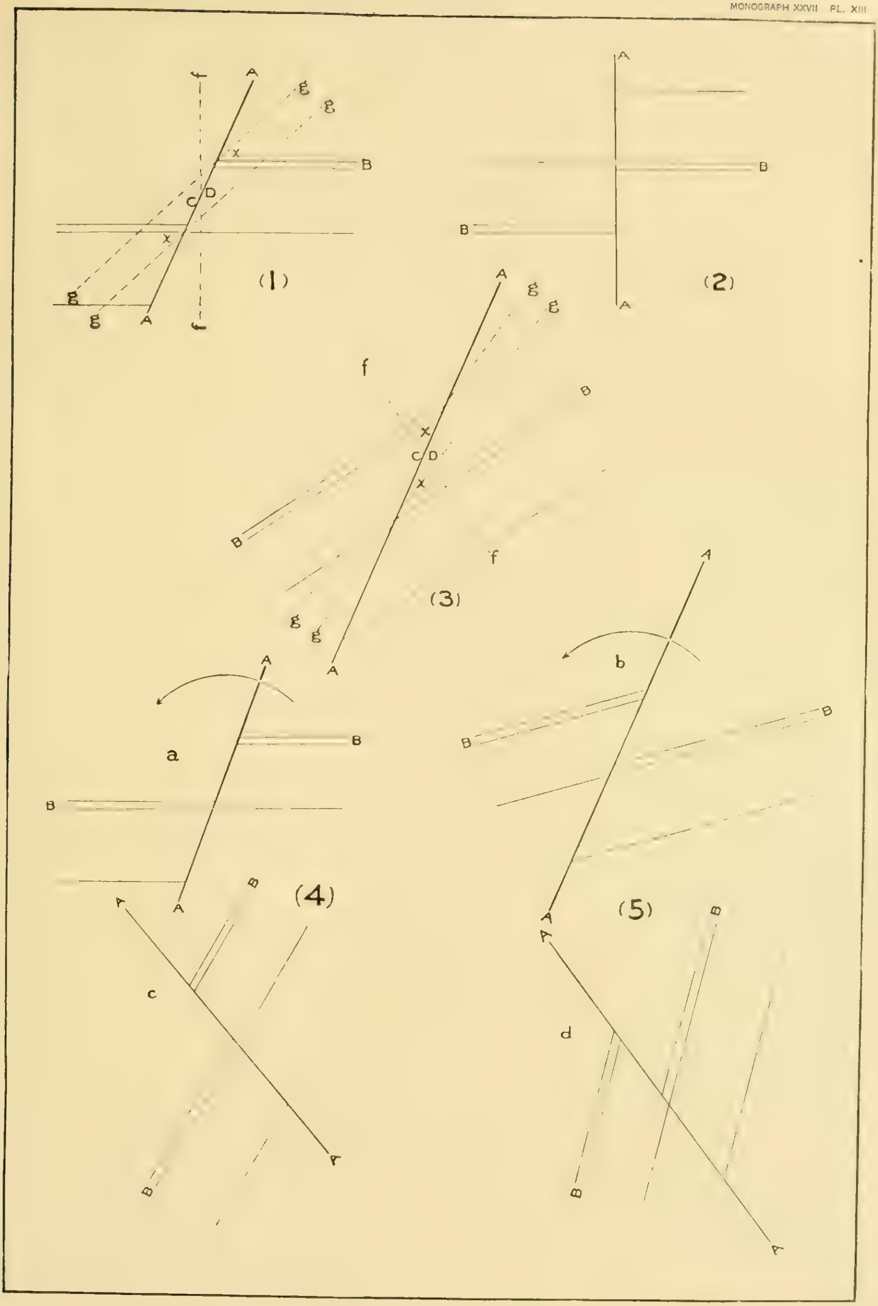


FIG. 7.—The South Boulder Peaks fault in Bear Canyon. From U. S. Geological Survey of the Territories, by F. V. Hayden.

Peaks, the strata upon the west of the fault plane showing an upward bend, those to the east of the plane with their possible downward flexure having, however, been eroded.

Analysis of faults.—The basis of fault classification is a satisfying definition of the several types of fracture which are recognized as existing. There is, even at the present day, a lack of precision in this particular, and it is desirable, in connection with the discussion of the fault, to state the manner in which the ordinary descriptive terms are employed in this report. The three terms "normal," "vertical," and "reverse" are here based upon the position of the fault plane with reference to the lines of stratification in the South Boulder Peaks, and the relative movement of the beds on either side of the plane with reference to a single stratum. Ordinarily the inclination of the fault plane is referred to the earth's horizon or to a line vertical to it—a distinction between "normal" and "reverse" faults that will not hold for all cases.



DIAGRAMS FOR USE IN FAULT ANALYSIS.

The normal fault (Pl. XIII, fig. 1) is a fracture of which the plane A A is inclined to the planes of stratification B B, and along which the hanging wall C has glided upon the foot wall D with reference to a given stratum in such a manner as to form the downthrown side; it must furthermore be made a part of the definition that under those conditions any line *f f*—no part of which lies within either of the acute angles formed by the planes of the fault and stratification in such a manner as to make with either plane a second acute angle of smaller value than the former, and wholly contained within it—will fail to cut a given thickness or series of beds equal in amount to the stratigraphical throw of the fault; on the contrary, a line *g g* lying within either of the acute angles *x x*, as above described, would, if produced, twice cut a series of beds equal to the stratigraphical throw. The normal fault may also be designated as one of extension, from the stretching apart laterally of the beds.

The vertical fault (Pl. XIII, fig. 2) is one of which the plane is perpendicular to the stratification planes, either side being downthrown without effect upon the definition. The beds are neither stretched nor compressed laterally.

In the reverse fault (Pl. XIII, fig. 3) the plane A A is also inclined to the planes of stratification B B—but not of necessity to the plane of the horizon or to a vertical line—and along the fault plane the hanging wall C has glided upon the foot wall D, with reference to a given stratum, in such a manner as to form the upthrown side; it must furthermore be made a part of the definition that under these conditions any line—no part of which lies within either of the acute angles formed by the planes of the fault and stratification in such a manner as to make with either plane a second acute angle of smaller value than the former, and wholly contained within it—will twice cut a given thickness or series of beds equal in amount to the stratigraphical throw of the fault; on the contrary, a line *g g* lying within either of the acute angles, as above described, would fail, if produced, to cut a series of beds equal to the stratigraphical throw. The "reverse" fault may also be designated as one of compression.

Professor de Margerie and Heim[1] and O. Fisher[2] have defined the three

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[1] Les dislocations de l'ecorce terrestre. p. 22.

[2] Geological Magazine, 1884, pp. 204 et seq.

types of faults mentioned here, but their definitions do not appear to the writer to be sufficiently broad to cover all cases, especially in regard to the omission or repetition of beds along a certain line.

From the definitions given above it is evident that the "normal" and "reverse" types of faults bear a supplemental relation to each other. There are also certain interesting conditions under which these types are liable to be confounded with each other. This may be shown graphically by constructing ideal fault sections of the two types, as *a* and *b* in figs. 4 and 5, Pl. XIII.

Revolve these sections in the direction of the arrows, bringing them into the positions *c* and *d*, respectively, or, more generally, revolve each section through the several quadrants of a circle, and the conditions giving rise to the confusion of types at once become evident. Indeed, were it not for the arbitrary decision as to what characteristics should serve to distinguish the two varieties of faults, especially those characteristics given in the second part of the definition, which are really to be regarded in the light of tests, it should be an easy matter to assign either of the faults in the above figures to that type with which in reality it had no direct affinity whatever. It is possible, moreover, for either type of fault to have originated from compression or from a sinking of the strata on the downthrow side of the plane. In this event, however, one of the guides to a correct solution of connected problems will be found in the law of geographical occurrence of the two types, which is, for mountain regions and regions of well-developed folds, the "reverse" fault, resulting from compression; for prairie regions or regions devoid of sharp folds, the normal fault derived from monoclinal fractures and a sinking of the earth's crust.

A fourth type of fault, in which the plane coincides with the plane of stratification, the movement taking place in either direction along such plane, has not been described here, owing to its not having been observed in the Denver field. In its reference it might be regarded as belonging to any one of the foregoing types, the line of fracture taking place along instead of across a stratification plane.

Analysis of the South Boulder Peaks fault.—An analysis of the structural features of this fault refers it to the "reverse" type. If the fault plane, with westerly hade of 60° to 70°, and the planes of stratification to the east be produced until they intersect above the mountain profile, and the whole series of beds be then imagined as turned back from their inclined position through their angle of dip to a horizontal position, the strata are found to be compressed on the fracture plane, the beds above or east of this plane having been moved up relatively on those beneath or west; the hade is distinctly from the downthrown side. Moreover, if the tests which are given in the analysis of faults under the preceding heading be applied, the evidence for the reverse type of the fault is still more conclusive, for a trial line—for instance, one perpendicular to stratification planes not within either of the acute angles in such a manner as to make with the planes a smaller angle—would penetrate the same series of beds twice, a series reduplicated to an extent equal to the stratigraphic throw of the fault itself; on the other hand, a line falling within the acute angles of the stratification and fault planes, the vertical line of the figure, for instance, would fail to cut the same series of beds at any point whatever. The obscurity in the proper reference of this fault arises chiefly from the position of the fault plane and the planes of stratification with regard to the earth's horizon, but it is influenced in a measure, also, by the amount of erosion to which the rocks involved have been subjected.

From the analysis of the South Boulder Peaks fault, it is evident that it is a fault of compression induced at the time of the general uplift of the range.

THE FAULT IN THE FOOTHILLS SOUTH OF SOUTH BOULDER CREEK.

This is similar in character to the South Boulder Peaks fault, but has not been studied in detail owing to its lying beyond the established limits of the survey. Its length is unknown, the ends being obscured in granite. The maximum throw is estimated at approximately 3,000 feet. The inclination of the fracture plane, as seen in the walls of the deeply eroded gulch near its southern end, is to the west at an angle of about 80° with the horizon, and the occurrence is apparently in strict accord with that of the fault to the north—that is, it is a "reverse" fault.

THE DEER CREEK FAULT.

The greatest displacement along the Deer Creek fault is about 1,200 feet, midway its length, from which point it gradually diminishes to either end, both of which are, however, concealed by débris from the foothills. The inclination of the fracture plane can not be seen, but the fault is probably of the same class as that at the South Boulder Peaks and the one to the south—that is, a compression fault. Though without direct connection with the dome-shaped fold in Deer Creek, a little farther to the south, it is likely that the same or a closely contemporaneous force was accountable for both.

THE PLAINS.

THE BOULDER VALLEY REGION.

INTRODUCTION.

Surface features.—This is a region of more or less disturbed Cretaceous strata and embraces about 100 square miles of prairie in the northwestern portion of the Denver field, confined to the drainage slopes of Boulder Creek and its important tributaries to the south—South Boulder, Coal, and Rock creeks. The surface is gently rolling, but in the southwestern part and along the southern border are mesa-like remnants of the earlier bench lands, which characteristically project at intervals from the foothills, not only in the Denver field but throughout the whole extent of the Colorado Range. The stream depressions, which are all comparatively shallow, have a course between north and east, and their profiles show long, even slopes broken at the water's edge by low bluffs of the Quaternary or by the clays and light-colored sandstones peculiar to the Laramie and Fox Hills. At the confluences of the larger streams occur broad, low, rich, alluvial plains, the extent of which is indicated on the general map by the Quaternary symbol. Much of the area is under high cultivation, and its streams and ditch sections afford many details of geological structure. The geologic and topographic confines of the area are coincident. Beyond the area there is no evidence of the dynamic forces which were so active within, as expressed in existing folds and faults.

Geological formations involved.—These include the Pierre, Fox Hills, Laramie, Arapahoe, and Quaternary, of which the Fox Hills and Laramie are the most important, from the presence of coal near their line of union. The Pierre is confined to the northwestern and western portions of the area. The Fox Hills appears entire along the western edge of the more disturbed portion, but in the numerous interfault blocks within this, the upper part of the formation alone reaches the surface.

The Laramie, in the eastern part of the region, is fully developed, except what may have been eroded prior to the deposition of the Arapahoe; in other portions of the area much of it has been removed by the erosion of recent times. The Arapahoe is represented by the lower 100 feet—the basal conglomerate and sandstones, together with a small thickness of the overlying clays. The Quaternary sands and gravels occur both along the river bottoms and upon the higher mesa lands.

Surface distribution of the formations.—The areas of Laramie and Fox Hills strata in the disturbed portion rapidly succeed each other, owing to a succession of gentle rolls and faults, to the short, vertical range within which the Fox Hills sandstones and the basal sandstones and coal measures of the Laramie occur, and to the general level to which erosion has taken place. The slightest variation one way or the other in the amount of movement, dip, or erosion has been sufficient to bring one or another of these beds to the surface. This rapid change in the superficial relations of the formations constitutes a most prominent feature of the region and has an important bearing on the distribution of coal and artesian water.

With the exception of two narrow belts of the lower part of the upper Laramie measures, one in the Coal Creek Valley, the other diagonally crossing the Davidson and Lake mesas, the surface of the region west and north of Coal Creek is occupied by either one or another of the series of beds near the line of the Laramie and Fox Hills—that is, by the upper portion of the Fox Hills, or by the basal sandstones or coal measures of the Laramie. South and east of Coal Creek, except the small area of coal measures in the vicinity of the Baker mine, near the confluence of Coal and Rock creeks, and the narrow strip of Fox Hills and lower Laramie leading along the former creek to the Erie mines, the upper division of the Laramie prevails, capped by Arapahoe at the summit of the ridge between Rock and Little Dry creeks. The homogeneity of the Laramie clays, the unconformity at their summit, and the gentle folding which the strata of this region have undergone, prevent for it recognition of definite horizons or an estimate of the thickness of the underlying beds, and consequently preclude reliable suggestion as to the depth at which coal measures or water-bearing sandstones may be found.

Structure.—The strata underlying the Boulder Valley display numerous folds and faults, which probably had a common origin and were approximately contemporaneous with one another. While the results of the once active forces are visible over the whole area, the general effects are not marked, the rolls being gentle, the folds without sharpness, the interfault blocks but slightly tilted—3° to 20°—and the faults showing stratigraphical displacement rarely above 300 feet. These phenomena are probably the results of compression, the forces of which, from the evidence adduced in the disposition of the rolls and fractures, must have acted along three different lines—E.—W., N. 60° W.—S. 60° E., and N. 30° W.—S. 30° E., these being the directions at right angles to the three systems of trends that distinctly appear in the field. There is much regularity in the occurrence of both folds and faults; the latter are, with the exception of a few minor cross-fractures, all strike faults; the interfault blocks, where simply tilted and not folded, dip eastward; and the leading synclines closely resemble one another in structure and manner of development.

THE SYSTEM OF FOLDS.

The important synclines of the Boulder Valley are: (*a*) The Davidson, lying between the main fault of the Marshall subsystem and the Davidson fault, diagonally crossing the mesa of this name and extending beyond southwestward; (*b*) the Eggleston syncline, at the eastern end of the Lake mesa; (*c*) the Coal Creek syncline, divisible into five subsynclines, together occupying the valley of both upper and lower Coal Creek and the broad, low ridge north and west of it. Smaller rolls are numerous, particularly along the western slopes of the divide east of Coal Creek. The region west and north of the Boulder creeks, underlain by the Montana group, gives little evidence of folds, a general easterly dip prevailing, slightly variable from point to point, but distinctly shallowing as distance from the foothills is gained.

The Davidson syncline.—This reaches its greatest development in the Davidson mesa, the broad, sweeping fold showing in both northern and southern faces, its axis, with a S. 23° W. trend, passing across the mesa at the indentation midway the length of its northern face. This degree of development is maintained as far south at least as the artesian well at the mouth of the Lake Basin. The records of this well, which is 645 feet deep, show that the strata passed through were chiefly Laramie shales, with dip very gently north-northwest. The flow of artesian water at the bottom of the hole indicates the presence there of one of the lower sandstones of the Laramie.

The northern extension of the syncline is traceable to the east-and-west road, one mile north of the fortieth parallel. At this point it appears only as the shallowest of depressions in the basal sandstones of the Laramie. Midway between here and the Davidson mesa, in the vicinity of the "Burnt" Knoll, the broad and still shallow arch of the syncline is locally compressed into a double trough with a median fold of low rise. This is represented in the following cross-section.

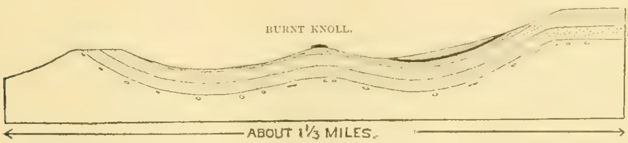


FIG. 8.—Section through Burnt Knoll. A, B, Basal sandstones of Laramie. Heavy black line = coal seam.

The southern extension of the syncline is easily traceable into the Lake Basin and somewhat less definitely beyond to the slopes overlooking Coal Creek; in this latter part of its course its direction is a little more to the west, in conformity with the system of rolls and fractures trending N. 60° E. On the southern rim of the Lake Basin there is evidence of another double fold of the general nature of that of Burnt Knoll, although without its symmetry, the eastern trough in this case being distinctly secondary in size and development to the western, which is plainly the extension of the main syncline. In this southern portion of the syncline its western side or rim is the upturned series of strata belonging to the mountain uplift, the portion involved in it being that lying south of South Boulder Creek; in the northern portion, on the contrary, in and north of the Davidson mesa, opposite which the sharp mountain fold as usually shown in the Laramie basal sandstones has disappeared, the western rim is a secondary fold, west of which, between it and the steeply upturned beds of the foothills, lies a wide area of gentle dip, often not over 10° or 15°. The eastern rim of the syncline is the same throughout.

The Eggleston syncline.—This lies just east of the Davidson syncline, at the eastern end of the Lake mesa. It is exposed as a shallow east-northeast to west-southwest trough in the lower Laramie sandstones and coal measures, the width of which is between one-half and three-fourths of a mile, the axial extent probably between 1 and 2 miles. It is doubtful whether the depression of this syncline is sufficient to permit the horizon of workable coal to appear entire along the center of the trough; in any event the economic value of the coal would be slight on account of proximity to the surface and consequent deterioration by weathering. South and east of this syncline, from the presence of upper Laramie in the bluffs south of Coal Creek and in the valley itself, the beds exposed in the front of the Lake mesa must rapidly dip to the east and become the western rim of the Coal Creek syncline.

The Coal Creek syncline.—This syncline, which is a general depression embracing several subordinate troughs, occupies the valley of Coal Creek from its confluence with the Boulder to a point a little west of the crossing of the Denver, Marshall and Boulder Railroad, about 3 miles west of Louisville. Its longitudinal axis is a little over 12 miles in length, while the width of the trough from rim to rim will average about 3 miles. The syncline occupies the western side of the lower Coal Creek valley and trends diagonally across the upper valley, its axis lying approximately northeast-southwest. The northwestern rim lies in the eastern bluffs of the Lake mesa, crosses the Davidson, and, after the break in its continuity occasioned by the Sand Gulch fault, is in general coincident with the ridge lying between Coal Creek and Sand Gulch. For its northern half the eastern or southeastern rim is clearly defined and lies just west of the lower Coal Creek fault; along its southern half it is less pronounced, but is probably to be found in the low mesa between Coal and Rock creeks, where, however, the northwesterly dip of the strata may have become so slight as almost to render the trough open, and directly continuous in structure with the general country beyond. The southeastern rim, also, is broken in continuity by faulting of the beds, a sharp displacement being observable in the railroad cut, in the bluffs of Coal Creek, south of Louisville. The greatest depth beneath the valley of Coal Creek attained by the base of the Laramie is between 300 and 350 feet, in the region of the Lafayette trough.

The subordinate troughs of the Coal Creek syncline are five, the Superior, Louisville, Lafayette, Mitchell, and Canfield-Erie.

The Superior trough is a shallow depression of somewhat irregular configuration near the northwestern edge of the general syncline. It occupies the eastern end of the Davidson mesa and a portion of the valley and bench lands on the north and south. It is severed from the Louisville trough, which lies just southeast, by the Sand Gulch and Harper faults, against which its beds are slightly upturned. At the southwest end, however, beneath the bottoms of Coal Creek, it is probably continuous with

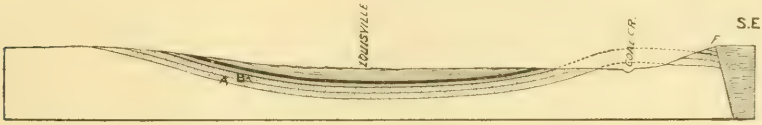


FIG. 9.—Section across Coal Creek syncline at Louisville. A, B, Basal sandstone of the Laramie. F, Fault. Heavy black line = coal seam.

the Louisville depression, the dividing fold or fracture having disappeared. The northern end of the Superior trough is a little north of the fortieth parallel. The amount of depression that the strata have undergone is comparatively slight, but is somewhat greater in the southern half than in the northern. The highest beds present along the center of the trough are the lower strata of the upper Laramie.

The Louisville trough extends from a point a little southwest of the Denver, Marshall and Boulder Railroad, about 3 miles above Louisville, down the valley of Coal Creek a distance of 1 or 2 miles below the town, where it passes diagonally into the ridge to the north and probably merges with the western portion of the Lafayette and Erie synclines. A generalized transverse section of the fold is shown in fig. 9.

The axis of the Louisville syncline lies considerably southeast of the town. The northwestern rim of the trough passes along the western and northern edge of the upper valley of Coal Creek, where for a considerable distance it is sharply defined by the Harper fault; north of Louisville it is formed of the southeasterly dipping beds that occupy the crest of the ridge between Coal Creek and Sand Gulch; farther east it becomes continuous with the rim of the Erie syncline.

The southeastern rim is but indefinitely located along the upper portion of Coal Creek; it probably lies in the bluffs and highlands south of the valley, where, moreover, it has apparently been considerably depressed. Opposite Louisville the trough is defined by the Louisville fault and by the steeply dipping strata involved in a fold which lies immediately northwest of this. Upon the disappearance of the Louisville fault to the north of Coal Creek the syncline probably passes into those of the Lafayette and Mitchell districts.

The depth at which the base of the Laramie is encountered in the trough of the Louisville syncline varies, but in the vicinity of the town is about 250 feet; it is doubtful if it anywhere exceeds 300 feet.

The configuration of the Lafayette trough is less known than that of any of the subdivisions of the Coal Creek syncline. This is particularly the case with the east side, where, from lack of exposures, the position of the rim and the inclination of the strata can only be conjectured from conditions recognized beyond the immediate basin. It is believed that the eastern rim, after a mile or two south of the confluence of Coal and Rock creeks, is considerably depressed, and that but a slight rise separates the basin structurally from the general country beyond. On the northwest the basin is delimited by the Louisville fault, excepting, perhaps, near its northern end, where, the fault having disappeared, the strata become continuous with those of the Louisville depression, passing with them to the western rim of the general syncline. To the south the rim of the Lafayette basin is that of the general Coal Creek syncline, while to the north the trough may be directly continuous with the Mitchell subdivision. The base of the Laramie in the axis of the Lafayette trough lies approximately between 300 and 350 feet beneath the level of Coal Creek.

The Mitchell trough coincides in width with the general Coal Creek syncline. It is probably continuous to the southwest with the Lafayette trough, and at one point, also, with the Louisville. The exposures in this portion of the field, however, are not sufficient to permit a clear insight into the precise structural relations of the three subordinate basins. On the north the Mitchell Basin is separated from the Jackson or Canfield-Erie depression by one of two structures: by the Erie fault, which has a general west-southwest trend from the lower Coal Creek fracture in the vicinity of the old Boulder Valley mine, nearly across the general depression; or by a possible anticline, which has a trend somewhat nearer north than the fault, and by which, combined with erosion, the basal sandstones of the Laramie are brought to the surface in a narrow belt between the two regions. In the latter case, it is probable that between Canfield and Erie the fold disappears. The presence of the anticline is suggested by heavy sands, usually a product of disintegration of the sandstones at the base of the Laramie

In the Mitchell trough the base of the Laramie lies at a depth beneath the surface of about 230 feet—this from measurements in the Mitchell shaft. Within the area mined the strata show a slight general dip southwestward, but there are many minor rolls. The eastern rim of the basin is sharply upturned; the coal outcropping beneath the wash of the valley midway between the Mitchell shaft and Coal Creek, and the basal sandstones of the Laramie showing at several points in the channel. The western rim is a gentle rise to the western face of the low ridge between Coal Creek and Sand Gulch, the coal measures occupying the crest of the ridge. From the Lafayette trough to the northern end of the field there is, also, an apparent rise in the strata, for in the Canfield-Erie depression the coal measures lie at even a shallower depth, 100 feet, than in the Mitchell—this, apart from the natural fall of the surface in the direction of the drainage.

The Canfield-Erie trough occupies the northern end of the Coal Creek syncline. It is coincident with the latter in width, and also in outline except on the south, where it is separated from the Mitchell area by one of the structural alternatives already described.

The several subdivisions of the Coal Creek syncline will be discussed with especial reference to the coal, in Chapter VI of this report, on the economic geology of the basin.

Folds in the ridge east of Coal Creek.—The strata on the western slopes of the ridge between Coal and Dry creeks are compressed into an irregularly distributed series of flexures, which conform in trend with that general for this portion of the field—that is, they lie approximately north-and-south. The flexures are of considerable length, of moderate breadth, and are comparatively slight in the vertical displacement of the beds. They appear wholly in the clays of the upper Laramie.

THE FAULT SYSTEM.

The fault system of the Boulder Valley region comprises no fewer than nineteen individual fractures, enumerated as follows:

- Marshall subsystem, including......
  - Main or Northern fracture.
  - Southern fracture.
  - Middle fracture.
  - Bluff fault.
  - Terminal cross-fault.
- Davidson fault ....
  - South branch.
  - North branch.
- Sand Gulch fault.
- North Boulder faults................
  - No. 1, or west fault.
  - No. 2.
  - No. 3.
  - No. 4, or east fault.
- Lower Coal Creek fault.
- Baker fault.
- Louisville fault.
- Rock Creek fault.
- Canal fault.
- Erie fault.
- Baker cross-fault.
- Jackson-Star fault.
- Valmont dike fissure.

The lines of dislocation, with the exception of certain cross-faults, lie in three directions, the southernmost with a trend of N. 60° E., the median having a direction N. 30° E., and the northernmost a direction north, or a few degrees west of north. A rude though distinct curvilinear arrangement in concentric lines is thus imparted to the system, the distance between the lines varying from 1 to 4 miles. The stratigraphic throws, with one or two exceptions, are between 150 and 250 feet. The faults are nearly all strike faults, and include not only the normal but also the reversed type.

The Marshall subsystem.—This is composed of a main fracture and two lateral branches given off from its southeastern side. The three may be designated the main or northern, the middle, and the southern. The southwestern end of this system of faults is at the point of the mesa, a half mile southwest of the town of Marshall, and lies in the sharp fold of the strata, whereby the series of beds, noticeably the basal sandstones of the Laramie, are reduced from a nearly vertical position with a N. 7° W. strike to one but slightly inclined with a strike of N. 30° to 50° E. and a gentle dip, rarely over 15°, southeast. The northeastern extension of the main fracture is obscure, but is mapped in accordance with the weight of evidence gathered in the field, and not beyond the actually observed occurrence. Of the three, the northern apparently ends by a gradual

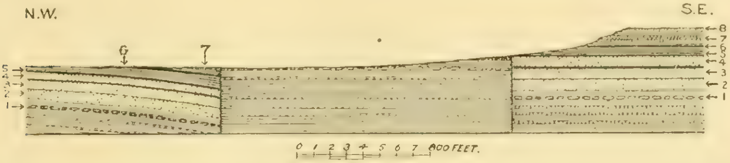


Fig. 10.—Section through northern and middle faults, Marshall system. 1. Concretionary layer of calcareous sandstone. 2. Summit sandstone of Fox Hills. 3. Sandstone A. 4. Sandstone B. A and B form the basal sandstones of the Laramie. A thin carbonaceous shale usually separates A and B. A coal bed locally rests upon B. 5. Ostrea bed. 6. One of the coal seams usually present between sandstones B and C, occurring in a series of shales. 7. Sandstone C. 8. Quaternary cap of mesa.

diminution of the throw; the middle and southern terminate on the northern and southern side, respectively, of the Davidson mesa, in the sharp bend of the strata which forms the western rim of the Davidson syncline.

The main or northern fracture is the most extensive of the three and is probably the westernmost break of the Boulder Valley system, although the Montana clays west of South Boulder Creek would naturally conceal any further occurrences of fractures, owing to the homogeneity of their material. The fracture itself could be seen at the time of examination at but one point in its length, namely, in the Marshall No. 3 mine, but it is also reported in an earlier mine opening, several hundred feet northeast of No. 3. Its surface location, however, is easily established within 100 or 200 feet from local exposures of the rocks on either side—on the west, the Laramie sandstones, coal, and fossil oysters peculiar to this horizon; on the east, in marked contrast, the clays, characteristic concretions, and fossil Mollusca of the Fox Hills or the basal sandstones of the Laramie itself. Toward the northeastern end of the fault Dry Creek occupies the line of fracture, and by its erosion has nearly severed a projecting mass of the Laramie from the main body of the formation to the east.

The trend of the main fault is slightly wavy but approximately N. 30° E. The downthrow is uniformly on the northwest, the stratigraphic throw reaching a maximum of about 350 feet along the middle portion of the fracture. The fault plane, where observed in the Marshall mine, dips 45° S. 28° E., making the fracture a reverse fault. Whether this is local or holds for the entire extent of the break is a matter of conjecture; the reverse type is, however, frequently met with in the Boulder Valley region.

The middle fracture, although of minor economic importance, is nevertheless of much structural interest, both from its relation to the associated fractures and from its own somewhat peculiar genesis. From its point of departure from the main fault, which, as nearly as can be determined, is in the vicinity of the line of the Denver, Marshall and Boulder Railroad, it extends northeastward a distance of about 2 miles along the northern face of the Davidson mesa, where it abruptly terminates in the sharp fold already mentioned as constituting the western rim of the synclinal trough which crosses the mesa diagonally at this point. Its reentrant angle with the fold is very acute, approximately 30°.

The presence of the middle fault is attested by the relative displacement of the beds on either side and by the included, irregularly disposed fragments of rock along its line. In the northern face of the mesa, at the foot of which the fault runs, from the triangulation station on the western point to the synclinal fold at the eastern end of the break, occur the approximately horizontal coal measures of the Laramie. The very base of the bluff shows the summit of the basal sandstones, succeeded in a few feet by the Ostrea bed characteristic of this horizon, this overlain by the usual succession of shaly and lignitic strata, which are in turn followed by the higher sandstones, and a thin layer of the higher clay series above. The whole is capped by a heavy wash of Quaternary. West of the triangulation station the mesa rapidly falls in height, the result of erosion and dislocation and sinking of the strata—beds which to the east have been in full exposure now gradually passing beneath the level of the table at the foot of the mesa—the lower sandstones, coal, and upper sandstones one after another disappearing. The strata north of the fault for the western two-thirds of its extent are the basal sandstones of the Laramie; along the eastern third, the Fox Hills.

The stratigraphic throw near the eastern end of the break is sharp, amounting to about 180 feet; it gradually decreases westward, until in the vicinity of Foxtown it passes into the north fracture.

The movements involved in the production of this fault must have been complex and were probably somewhat as follows: Toward the eastern end of the fault the strata to the south form a part of the relatively undisturbed mass of country; the beds of the interfault block north rose; toward the western end, although the movement of the interfault block may have been diminished in vertical range, the beds south of the middle fracture have themselves here suffered motion and sunk, being cut off from the main body of the strata by the southern branch of the fault system. In these movements the interfault block north of the middle fracture has been especially affected, for in the restoration of the equilibrium between the greater and more unyielding masses upon the north and south it has apparently accommodated itself to their movements and assumed such space and shape as was permitted it in the general crush which took place. The position, as shown in the figure, is one of uneven elevation; the block may be regarded as hinged upon the main mass of beds to the east at the sharp fold forming the rim of the Davidson syncline, and, having been subjected to the extraneous pressure developed at the time of the disturbance, as having relieved itself from the strain by elevation and crumpling.

The southern fracture is simple, with a depression or bowing down of the beds to the north of it from either end toward the center, with a gentle dip for these beds of between 10° and 15° to the southeast. The beds to the south have been but slightly, if at all, disturbed. To this structure is plainly due the character of the topographical depression in which lies the lower coal branch of the Marshall district. The amount of the stratigraphic throw at the center of the fault, the point of its greatest depression, is about 260 feet. The southwestern end of the fault is nearly coincident with that of the main fault, while the eastern end originates in the same fold as that in which the middle break had its origin. As in the case of its associate faults, the position of the present break is not precisely mapped, the fracture itself being obscure. It is, however, distinctly traceable in the field from the succession of the strata on either side and from the fragmentary character of the rock lying in proximity to it.

As alternatives of the foregoing structure it is possible, in the first place, that the main fault and that described as its southern branch may be coincident from their southwest end to a point a few hundred feet east of the Marshall mine No. 3, and that thence they may first begin their divergence, the trend to this point being that of the southern branch, N. 62° E., which is that of the fault plane in the No. 3 mine. Again, it may be that instead of the south fault being actually a branch of the one described as the "main" or north fault, the main fault may originate independently and to the north of this southern fracture, at approximately its point of union with the fault described as the middle one.

The above alternatives are suggested as possible, but in any event the question is of slight economic importance, as the amount of ground involved is small and highly fractured.

The bluff fault, if actually existing, lies along the brow of the bluff on the south side of the Marshall Basin. It is shown as a dotted line on the map. The existence of this fault is not clearly established, but there is a certain amount of evidence pointing to it, consisting in (*a*) the occurrence upon the narrow table above, and to the south or rear of the bluff which carries the upper bench of coal, of what appears to be the upper portion of the basal sandstones of the Laramie; (*b*) the topographic depression which a part of the table itself has suffered and which resembles in kind that of the interfault block to the north; and (*c*) the report that in one of the old openings in the bluff east of the No. 5 mine the fracture was actually encountered. If present, its trend is about N. 62° E.; its extent, half a mile; the maximum dislocation, about 100 feet; the dip of the fault plane, undetermined.

The terminal cross-fault is a simple fracture extending across the brow of the Davidson mesa a few feet west of the triangulation station, between the southern and middle branches of the Marshall system. Its trend is a little west of north, the downthrow on the west, the displacement not over 30 feet. It is probably connected with the sharp anticlinal fold appearing in the southern face of the mesa and forming here a crumple in the western rim of the Davidson syncline.

The Davidson faults.—These embrace the two fractures on the northern slopes of the Davidson mesa, near its eastern end. They intersect at the crossing of the Davidson ditch and Colorado Central Railroad, and run, the one north along the deep cut of the ditch, the other S. 30° W. across the old Davidson coal property.

The southern of these faults belongs to the N. 30° E. series of dislocations, and owes its development to the same forces that threw the strata into the many gentle folds of like trend; the northern fault belongs to the series of north-and-south fractures that characterize the entire breadth of the northern third of the Boulder Valley region, and which owe their development to the forces acting in a due east-and-west direction.

The extent of the southern fault can not be definitely determined. Its single exposure occurs at the deep cut of the Davidson ditch at the railroad crossing, but its presence to the southwest, in the vicinity of the old Davidson mines, is proved in the superficial succession of the beds to be found between the mine openings and the upper part of the Davidson ditch to their east. At the mines and a short distance eastward the beds of the lower Laramie underlie the surface, having a northwesterly dip of 30°; a little to the east they are succeeded by outcrops of the Fox Hills; as the Davidson ditch is approached, however, this formation is abruptly succeeded, with but slight changes of level, by the iron tones and clays which form a portion of the coal measures and which plainly outcrop in the ditch itself at the point where it turns directly northward after its long course from the west around the bluffs of the Davidson mesa. The southern end of the fault is lost in the mesa, but it is probably not far from the north-and-south road that crosses just west of the Davidson property. The northern end has been taken at its intersection with the northern fault, near the railroad, although it is not at all unlikely that one or the other of these fractures may extend a little beyond the point of intersection, especially as both faults were apparently well developed in the immediate vicinity. Indicating this possibility, the southern fault has on the map been extended to the northeast in a dotted line.

The northward extent of the northern fault is unknown; it is completely lost in the lowlands of the valley about 2 miles north of the fortieth parallel.

Both of the Davidson faults are of the reverse type; the downthrow is east and the stratigraphic displacement about 200 feet, though toward the southern end, near the Davidson coal field, it may reach 300 feet. The opposing strata are a horizon of the Fox Hills, about 60 feet below its summit, on the west of both fractures; on the east, along the north fault, the upper portion of the sandstone B; along the south, this sandstone with the overlying coal measures. In the immediate vicinity of the fracture the strata on both sides are locally somewhat disturbed; on the east, the Laramie bend down toward the fault; on the west, the Fox Hills likewise bend downward toward the fault, and also show a number of minor flexures, diagonal to the trend of the fault, notably along the northern break between the railroad and a mile north.

The Sand Gulch and Harper faults.—Of these the Sand Gulch fault is the northernmost and closely follows the topographic depression of this name for its entire length. At the head of the gulch it intersects the Harper fault, which follows the southeastern base of the Davidson mesa, above the town of Louisville. It is quite possible that these constitute a single, curved fault, but this can not be determined.

The Sand Gulch fault belongs to the N. 30° E. series of fractures. Within 100 or 200 feet of it the strata on both sides are considerably crumpled, but beyond their dip is apparently away from the fault, from a gentle angle up to 20°. The evidence of the fault is the superficial existence of the lower Laramie sandstones and coal measures in the block on the west, opposed to the Fox Hills and to the basal sandstones A of the Laramie in the block on the east. The recognition of the Laramie is from an occasional characteristic outcrop, together with a sandy soil peculiar to areas immediately underlain by its lower members; the Fox Hills is recognized by its concretionary limestones and its fossils, the outcrop forming a narrow strip of land along the eastern side of the fault. The terminal points of the fault are invisible on account of the flat and covered condition of the region in which they lie, but observations were obtained within a short distance of either end, as given on the map, which prove an extent of at least the distance platted. Whether the fault is of the reverse type or not is undetermined. Its downthrow is on the west, the stratigraphic displacement being about 200 feet near its southern end, in the vicinity of the railroad, but probably decreasing somewhat to the northeast.

The Harper fault was discovered through boring for coal and water, no trace of it whatever being found at the surface. It has considerable economic importance, involving as it does the presence or absence of coal and the depth at which it may be found in the affected region. From the data furnished by the Messrs. Harper, the bore holes north of the fault afford satisfactory evidence of the presence of coal measures, while the hole to the south, put down but a short distance from the productive drillings across the line, is stated by them as showing no coal whatever at over double the depth. From the outcrops of the Fox Hills near the southern end of the Sand Gulch fault, it is probable that the surface immediately south of the Harper break is underlain by strata at least lower than the coal series. Farther out in the valley of Coal Creek, by reason of a southeasterly dip, higher measures succeed, until just north of the creek the coal itself is found in an old shaft, at a depth of 160 feet below the surface. North of the fault the strata are apparently crumpled, first dipping from the break, then turning up to the northwest, forming a shallow local syncline. The extent of the fault to the southwest is unknown. In its relation to the other faults of the Boulder Valley system, it belongs to the series of fractures having the trend of N. 50° to 60° E.

The North Boulder faults.—These appear in the low sandstone bluffs on the north side of Boulder Creek, midway between the towns of Valmont and Canfield. Erosion has brought the present surface of the country within the limits of the Fox Hills and Laramie formations and has cut in the bluffs of the channel the natural section given above. The series of faults is in effect repetitive. For four successive blocks the measures are reproduced within a few feet of the same stratigraphic and vertical range, and for as many times the coal horizon has been elevated and wholly or in part eroded from the region, until at the present time the first workable beds in passing eastward are found at the town of Canfield, on the western edge of the Erie Basin, several miles east of the area here described.

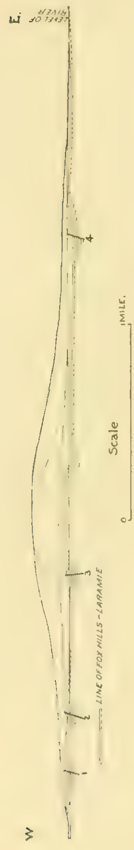


Fig. 17.—Section through North Boulder faults.

The inclination of the fault planes is unobservable for No. 1 and No. 4, the western and eastern, respectively; for No. 2 the inclination is to the westward 70°; for No. 3, apparently eastward.

In each of the faults the downthrow is on the west; the blocks are tilted to the east with a dip of from 5° to 25°; the displacement at the fractures is approximately 180 feet for the western or No. 1 fault, 60 feet for the second, 150 feet for the third, and 230 feet for the fourth or eastern fault. The northern extent of the several faults as platted on the map is entirely hypothetical, the fractures being lost in the clays of the Laramie in the hill beyond; their southern extent may carry them into some of the breaks already described in the field to the south of Boulder Creek, but it is impossible to so trace them.

Only the two central interfault blocks display any broad, general structure beyond the usual crushing or folding in immediate proximity to the fractures. The western of these, which forms a prominent part of the White Rocks outcrop, presents an indistinct turtle-back dipping into the hill in northwest, north, and northeast directions, and met in the body of the hill by a fold in the opposite direction, the dip being to the south. The strata forming this interfault block have a general fall of 2° downstream. The block to the east of this affords particular evidence of the compressive forces acting in an east-and-west direction over the prairie region, in the sharp fold which appears in the sandstones of the Fox Hills and Laramie. The beds have been thrown into a well-defined, unsymmetrical anticline. Its long slope of about 15° is to the west, the short one of 65° to the east. From the latter dip the strata again rapidly assume an approximately horizontal position, or one in which the dip is between 1° and 5° to the east. The center of this arch furnishes the finest collecting ground of upper Fox Hills fossils in the Denver field.

The lower Coal Creek fault.—By this is designated the prominent curved fault extending for the greater part of its length along the bluffs on the eastern side of Coal Creek from a point near the entrance of Rock Creek to the northern limits of the map. Though its recognized extent southward is as indicated by the solid line—to a point 1½ miles below the mouth of Rock Creek—it is probable that it reaches at least a mile or two farther up the valley of Coal Creek, as shown by the broken line. The northern end lies beyond the limits of the field mapped, and is also concealed beneath the surface deposits of the prairie, which here falls rapidly to the general level of the Coal Creek bottom. The fault probably belongs to the "normal" class, though the evidence is very meager.

Wherever the line of fracture is seen the shales of the upper Laramie are found upon the east, opposed by those of the Fox Hills on the west. The former hold all positions from horizontal to vertical, though usually the steeper, while the latter are always highly inclined, even to an occasional overturn. Within a short distance of the fault line the strata on either side regain their normal position, those on the west assuming a gentle westerly dip of 10°, prevalent for a narrow strip, those on the east settling to their natural position of shallow dip and gentle rolls. The particular horizons of the two formations opposed to each other at the outcrop are probably: for the Fox Hills, a stratum not over 50 or 75 feet below its summit; for the Laramie, one at least 250 feet above its base. This would give a general relative displacement of the two formations of about 300 or 325 feet, but this amount varies somewhat from point to point, especially toward the ends of the fault. From memoranda of borings for coal just east of the fault and 1¾ miles south of Erie, furnished by a Mr. Van Valkenberg, it is possible that the total displacement may be increased to between 350 and 425 feet.

The Baker fault.—This extends in a direction N. 61° 35′ E. from the bottoms of Rock Creek, near its confluence with Coal Creek, to a point within a short distance of the summit of the divide between Coal and Little Dry creeks, southeast of Erie, passing a few hundred feet southeast of the Baker mine. The fracture originated in one of the simple folds which are common upon this face of the divide, but whether it is of the normal or reverse type can not be determined. In a gulch a half mile northeast of the Baker mine it is reverse, the plane inclined 60° northwest, but this may be local. The stratigraphic displacement varies. For the entire length of the fault, upon its southeastern side, nothing lower than an undetermined horizon in the upper Laramie clays appears; on its northwestern, in the vicinity of the Baker mine, these beds are opposed by the coal measures; one-half mile northeast, for a distance of half a mile or more, by the Fox Hills and the basal sandstones of the Laramie; beyond this, still to the northeast, by upper Laramie. From this the greatest recognized displacement is in the apposition of the Fox Hills to upper Laramie, 250 feet, but it is doubtless more than this in places. The strata on either side of the fault line are locally somewhat fractured, but they rapidly regain their general, northwesterly dip of 5° to 25°, to be again folded, and perhaps faulted, at no very great distance beyond.

The economic effect of this fault has been to limit the southeastern extent of the small workable area of coal known as the Baker field by depressing the strata on this side of it to an unknown depth. No solution to the problem of depth is to be found on the surface, and there remains but one resource, boring.

The Baker cross-fault.—This is a short fault across the point of ground in the angle between the Baker and Coal Creek faults. Its trend is S. 65° to 70° E. The inclination of its plane is unknown. The downthrown side is the triangular piece cut off, showing Laramie clays and ironstones and, possibly, a portion of the coal measures, all greatly fractured; opposing the piece, on the north, are the Coal Measures, including their upper sandstones, also considerably fractured for some distance from the fault line.

The Louisville fault.—The single exposure of this fault is in the cut of the Colorado Central Railroad in the bluffs of Coal Creek immediately south of Louisville. (Fig. 9, p. 125.) Its course, N. 40° to 47° E., is not that of the bluffs, but forms an acute angle with them of about 15°. To the southwest it passes into the prairie and is obscured beneath surface deposits or by reason of the similarity of beds on either side; to the northeast it is lost in the bottom lands of Coal Creek, and no trace is found in the bluffs beyond.

At the railroad cut the fault is very pronounced, the downthrow being to the southeast, with upper Laramie of doubtful horizon opposed to sandstone B and a few feet of overlying beds on the northwest. The fault plane has an inclination of about 65° to the southeast, with the beds on both sides apparently bent down, though it is possible that those on the southeast, which are badly shattered, have been bent up.

The Rock Creek fault.—This is probably a simple dislocation of about 75 feet, with downthrow to the west, appearing in the bluffs east of Rock Creek opposite the point where it is crossed by the Colorado Central Railroad. The plane of the fault is not visible, but the evidence of fracture lies in two distinct benches of the basal conglomerates of the Arapahoe formation, horizontally disposed along the hill, and separated on its slopes by a zone of clays and ironstones belonging to the upper portion of the Laramie. Unconformity may be an alternative explanation of the conditions.

The Erie fault.—This fault crosses the Boulder Valley Railroad between 400 and 500 feet north of the Erie depot, having a trend about N. 64° E., and extending from the lower Coal Creek fault across Coal Creek for an unknown distance to the southwest. Along the line of fracture, east of Coal Creek, the maximum throw is at least 250 feet, the upper beds of the Fox Hills on the north being opposed to the coal measures of the Laramie on the south. The inclination of the fault plane is not shown at the surface, and though the fracture was followed for a distance of nearly 1,200 feet in the old Boulder Valley mine to the south of it, no reliable data concerning its features can now be obtained. The dip of the Fox Hills at the fracture is vertical; of the basal sandstones of the Laramie, 200 feet to the north, 45° northwest; of sandstone C, 100 feet still farther north 10° to 15°, beyond which an approximately horizontal position is assumed. South of the fracture the strata are much less disturbed, the dip being southeast, away from the break, 5° to 10°. The block north of the fault is badly fractured and has apparently suffered the greater amount of displacement.

Other possible faults to the north of the Erie fault.—About 700 feet north of the Erie fault there probably exists another, a parallel, fault, with downthrow to the north, making of the intervening portion an uplifted block of lower Laramie and Fox Hills between two masses of coal measures. There is no evidence of this second fault, however, beyond the rapid succession of the basal sandstones by the coal measures, and a report of its observance in now abandoned mines beneath its suspected locality.

Still farther north, at the northern edge of the northern block of workable coal, near the summit of the grade three-fourths of a mile east of Erie, there is said to exist a third fault, met with in mining though not appearing at the surface.

Besides the actual and possible faults of this region, the coal has been thrown into a number of very gentle parallel folds, the axes of which have approximately the same trend as the faults.

The relation of this series of faults and folds, especially of the principal or Erie fault, to the general system of the Boulder Valley is apparently that of cross-fractures, their trends all forming a wide angle with the predominant faults and folds. At the same time it is quite possible that their development may be due to a reappearance at this point of the forces which produced the similarly disposed fractures and folds in the southern and western parts of the field, notably the Baker and Harper faults and the southern and middle fractures of the Marshall subsystem.

The Jackson-Star fault.—This break appears only in the two mines from which it has received its designation, the surface of the ground between them affording no evidence of its presence.

The general trend is approximately N. 15° W., based on measurements furnished by the mine superintendents, made in the several cross entries of old workings not now accessible. A single point of observation was possible at the time of the survey, namely, in the Star mine, about 900 feet north of the shaft, where there appears to be a local variation of 8° in trend, to N. 23° W. The inclination of the fault plane was 30° to the east, or toward the downthrow, and though there was no possibility of estimating the amount of stratigraphic displacement, the superintendent of the mine, from former observations, regarded it as generally not over 30 feet.

The Canal fault.—This appears at a single point only—in the railroad cut rounding the eastern end of the Lake mesa. It is a fracture apparently independent of the general system of faults of the region. The fault plane is vertical; the downthrow north; the opposing beds, the upper and lower layers of sandstone B of the basal series of the Laramie. The stratigraphic throw is, therefore, about 50 feet. South of the fault, sandstones B and A, with the thin lignite band between, are crumpled into an anticline, which enters more or less into the structure of the mesa; north of the fault, the strata, though horizontal at the line of break, within a short distance acquire a northwest dip and form the eastern side of the Davidson syncline.

The Valmont fissure.—This is a fracture, apparently without dislocation, filled with eruptive material. Its discussion falls under the chapter on eruptive geology.

DISCUSSION OF THE GENERAL PLAINS STRUCTURE.

The six transverse sections of the Denver field (see Pl. IV) show the geological structure of the prairies, the structural connection of prairie with foothill and range, and the stratigraphical relations of the formations involved. They will be designated as follows:

I. The Boulder section.
II. The Davidson section.
III. The Ralston section.
IV. The Green Mountain section.
V. The Bear Creek section.
VI. The Plum Creek section.

THE BOULDER SECTION.

The structure of the western half of this section has been considered in the discussion of the geology of the Boulder Valley and the unconformity in the foothills near the town of Boulder. The eastern half will be described in the following.

The region east of Coal Creek Valley in the vicinity of this section is almost wholly occupied by the clays of the upper division of the Laramie formation; the eastern 2 or 3 miles only are underlain with Arapahoe beds, covered with considerable deposits of Quaternary sand. The homogeneity of the Laramie beds renders it quite impossible to determine the particular horizon outcropping in a designated locality, but observations of dip in connection with surface profile and the aid afforded by well borings have enabled the construction of a section sufficiently correct for the consideration of economic questions.

The section shows that in the high ridge east of Coal Creek the strata have a general easterly dip, although on the western slope of the ridge a number of rolls of minor importance occur. In the valley of Little Dry Creek slight local rolls also exist, but for long distances the strata lie horizontal or with a maximum dip of from 0° 30′ to 1° 0′ to the east. In the valley of the Platte the Quaternary deposits are so widely distributed that only occasional outcrops of the underlying formations occur; these outcrops, however, with the wells and borings to the south of the section, indicate for the strata a horizontal position, or one of slight easterly dip. For the country east of Coal Creek, therefore, the strata have a general easterly dip, with longer or shorter horizontal reaches and occasional gentle rolls. The thickness of the Laramie measures beneath the Platte, on the line of Section I, is probably about 900 feet. This estimate is based on artesian borings in the Platte Valley less than 1 mile south of the section, which reach depths of 300 and 530 feet without striking coal or the heavy sandstones at the base of the formation, or even encountering a change in the composition of the strata. Increasing the greater depth, as that nearest the line of section, by 220 feet—the thickness of the lower division of the Laramie—the accounted thickness of the formation becomes 750 feet. It is believed, however, from considerations of dip and the position which the strata hold between Coal Creek and the Platte River, that to this may be added at least 150 feet more, affording thus the thickness of 900 feet given. The maximum thickness of the Laramie at the line of section is probably about 1,100 feet. This, however, does not represent the original depth of Laramie deposits in this vicinity, for on the western face of the ridge east of the Platte River a considerable degree of erosion prior to the deposition of the Arapahoe is clearly discernible in the gradual rise to the north of the line of union between the two formations.

The deposits of Quaternary crossed by Section I are chiefly river gravels and sands, with some loess. In the valley of the Platte the gravels underlie both the present bottom and the broad benches to the east—the loci of the river's early channels—attaining a depth beneath the latter of 30 to 40 feet. Heavy sand deposits occur in the highlands east of the Platte, and in the valley east of these they show considerable irregularity of outline and position, having locally the appearance of dunes.

THE DAVIDSON SECTION.

The western half of this section also involves the geology of the Boulder Valley and the foothills to the west, and has been discussed in the preceding pages. The eastern half closely resembles in structure the eastern half of the Boulder section (I). There is a general easterly dip of about 1° for the greater part of its length, steepening to 2° or 3° in the ridge dividing the valleys of Coal and Dry creeks. The main body of the Arapahoe formation extends much farther west than in the Boulder section, and there is, besides, a prominent outlier of this formation on the divide between the creeks just mentioned. An especial feature of the section and the region adjoining is the illustration afforded of the unconformity by erosion between the Arapahoe and Laramie formations. In the area immediately west of the Platte River the Arapahoe forms the merest cover upon the subjacent Laramie, and in almost any of the shallow yet sharply-cut ravines the uneven line of contact between the two formations clearly appears; within a distance of 200 yards the difference in the level of this line sometimes amounts to 50 feet. A still more pronounced difference in level occurs midway between Sections I and II, at the head of a short gulch entering Dry Creek from the west, where, at a contour considerably below that marking the base of the Arapahoe on either side of the creek, there is an isolated remnant of the gritty sandstone belonging in the lower portion of the later formation.

The difference in level between the lower limit of the Arapahoe in the outlier to the west of Dry Creek and the main body of the formation to the east is attributable in part to difference in level of the lake floor and in part to the general southeasterly dip of 1° to 3°, which the strata west of the creek have.

The base of the Arapahoe formation in the region east of the Platte River probably nowhere attains a depth of over 150 feet. West of the Platte, however, and particularly as distance south of the Davidson section increases, there is a constant and rapid gain in thickness to the maximum.

The depth attained by the base of the Laramie along the line of Section II is estimated at a minimum of between 900 and 1,000 feet—a slight increase over that of Section I. This is based upon a boring on the line of the section in the bluffs on the west side of the Platte directly west of Brighton; here a depth of a little over 600 feet was reached, in which nothing but clays and ironstones of the upper Laramie were encountered. No water was struck and nothing having the appearance of the basal sandstones of the Laramie was observed. This, with the same allowances as were made for Section I, would place the base of the formation in this locality at a depth of at least 970 feet. Another hole, about 5 miles south of Section II, at a depth of 1,200 feet, showed clays, with a few interbedded sandstones and several narrow seams of coal at about 800 feet; the records do not definitely indicate, however, whether or not the base of the Laramie was passed.

THE RALSTON SECTION.

The important structural features are the Ralston dike and the accompanying disturbed conditions of the strata near the western end of the section; the unconformity between the Arapahoe and Denver formations, especially well shown in the hills west of the Platte; and the occurrence of the large area of Laramie in the eastern part of the field and the relations of this formation to those surrounding it. Besides these, there are the usual considerations regarding the depth of the strata, bearing upon the economic questions involved.

The Ralston dike and immediate vicinity have been described in connection with the foothills, and will not be discussed further.

The Arapahoe-Denver nonconformity, like that between the Laramie and Arapahoe, is one of erosion. It is conspicuously shown in the many gulches entering the Platte Valley from the west, north of Clear Creek. Over this region the Denver either forms the merest coating upon the Arapahoe or occurs in isolated outcrops which lie at various heights upon the gentle slopes formed of the older formation. The northern limit of the main body of the Denver formation lies to the south of the line of the present section and has an irregular trend in a west-southwest direction.

SECTIONS III, IV, AND V.

To more clearly understand the geological structure of the area of Laramie strata within the map limits east of Denver and the relations that exist between this formation and the several of younger age surrounding it, it is necessary to consider jointly the eastern portions of Sections III, IV, and V.

The Laramie here, as elsewhere, suffered considerable erosion prior to the deposition upon it of the younger sediments; this is evident at many points on the periphery of its outcrop, in the wavy line of union between it and the younger formations. Moreover, the area of exposed Laramie is part of the locus of an early hill of which the northern, western, and southern slopes are clearly shown, first, by the occurrence of the Denver and Arapahoe formations on these sides, practically at the same level with the Laramie, the edges of the overlying formations being beveled upon that beneath; secondly, by the perceptible increase in depth at which the lower beds of the adjacent formations are found in bored wells as distance is gained from the periphery of the Laramie exposure; and thirdly, by the fact that to the east the Monument Creek beds, at a still higher topographic level than any of the other formations, overlie the Laramie, a wavy line of separation also occurring between the two.

Within the area of Laramie its clays and associated ironstones are frequently encountered in creek bluffs, wells, and borings, and south of a line west-southwest through Scranton is a bed of lignite, probably of much higher horizon than that of the coals in the western half of the field. Northward the lignite disappears, and in the deeper borings, 800 to 900 feet, only shales, ironstones, and occasional streaks of coal are met with. Neither the base of the Laramie nor, indeed, any of the lower sandstones are reached within this eastern area. Water-bearing, sandy layers occasionally occur, notably in the Gilbert well, 800 feet deep, midway between First and Second creeks and the meridians of 104° 45′ and 104° 50′, but these are probably local developments in the upper series of the formation.

The line of the Arapahoe bordering the Laramie area on the north is only approximately determined, on account of overlying deposits of gravel, sand, and loess, but it is shown on the map probably within 1 mile of its proper location. The most important outcrops of the Arapahoe occur on Third Creek, near the eastern edge of the field. The sandstones are here characteristically, and, for the prairie region, rather exceptionally developed, the looseness of texture, the bright yellow to white appearance, the coarseness, the siliceous composition, and the flinty character of the pebbles, all being present. The thickness of the sandstones is here between 15 and 30 feet.

The line between the Denver and Laramie formations is distinct, following for several miles the southern bluffs of Coal or Sand Creek and crossing thence to the north on the lower part of the stream. The conglomerates and clays of the Denver form an almost continuous outcrop from the eastern limit of the field to the creek crossing of the narrow-gauge railroad leading to the Scranton coal mines, displaying local dips in one direction or another, but in general approximately horizontal. Exposures are also frequent in the ditches to the south of Coal Creek, particularly in the large High-Line Canal and in the gulches below it.

The line between the Monument Creek and older formations is very irregular, being influenced both by contours and by the uneven surface of the beds upon which it rests. The formation lies in a horizontal position, so far as can be determined, and weathers into bold mesas with sharp bluffs.

The detailed relations of the Laramie, Arapahoe, and Denver, at the western end of the Laramie area, can not be determined, owing to the

Quaternary deposits of the Platte Valley. Probably, however, the western slope of the Laramie hill continues to sink, while the Arapahoe and Denver meet around its spur, the latter covering the former in the same irregular manner as it does in resting elsewhere upon the formations beneath.

The depth of the Laramie beneath the area under discussion probably varies, but to what extent and in what direction is indefinite. It is believed, however, from artesian flows in the valley of the Platte and from a general examination for dips over the entire region, that there is a basining up of the strata east of the river by which the depth that would otherwise be attained by the formation is considerably lessened. Without this the Laramie would, in the vicinity of Section V, reach a development of 2,400 feet—a thickness perfectly possible, indeed, and even admissible, but nevertheless abnormally great in comparison with its known thickness in every other part of the Denver field and in much of the country beyond. The thickness assigned the Laramie at the eastern end of Section V is 1,500 feet.

Along the line of Section III, the Laramie strata have been taken as horizontal, the base of the formation at the eastern end of the section being thus placed at a depth of 1,450 feet. This may be regarded as the extreme limit at which the coal series may here be found, and it is quite possible that unrecognized upward flexures may make it less. The depth of the Arapahoe on the western slope of the Laramie rise in Section III is determined chiefly by its depth beneath the Platte River, the wells along here indicating for it a thickness of between 300 and 400 feet, and the line of division being drawn accordingly. Northeast of the Laramie the deposit of Arapahoe sediment is but slight, the underlying formation apparently sloping off very gradually.

At the eastern end of Section IV, without flexure in the strata, the base of the Laramie probably lies about 1,584 feet beneath the surface. This gives it approximately the same level as at Denver. A slight upward flexure might, however, be allowed the strata by way of connecting Sections III and V, along the latter of which an upward flexure is highly probable. The artesian wells on the line of Section IV afford no data in regard to the question, unless it be in favor of a horizontal position or of a flexure affording a very slight rise to the east, in which case the depth of the lowest Laramie beneath the surface might possibly be reduced to 1,200 feet.

The Arapahoe on the line of Section IV appears only among the highly inclined series of beds adjoining the foothills. It there sinks a considerable distance beneath the surface of the prairie, to be again brought by erosion of the overlying beds within easy reach in artesian boring in the valley of the Platte and its immediate tributaries. At the mouth of Cherry Creek the formation is approximately horizontal, its base lying between 700 and 800 feet beneath the river. The formation has a general easterly dip of about 2° between the foothills and the Platte, and at its eastern limit may or may not again be bent slightly upward as the eastern rim of a synclinal basin. The flexure suggested here is in no way necessary to the success of artesian flows in the Platte Valley, since from lying upon and against the west-sloping surface of the Laramie clays it there meets with a most effective confining medium. The precise eastern limit of the Arapahoe on the line of Section IV is conjectural, but its position in the section is at least as far to the east as drawn, its presence west of this being everywhere recognized in the deep artesian borings.

In the eastern half of Section V a pronounced flexure has been given the strata for reasons already stated. The depth at which the base of the Laramie has been drawn at the eastern end of the section is 1,500 feet, or about that of the other sections, indicating that the rise figured has taken place chiefly between Sections IV and V, with its incipient point, perhaps, slightly north of the line of Section IV. Conjectures as to underground stratigraphy and structure are always unsatisfactory; it is necessary to recollect that for the Denver field the base of the Laramie is probably rolling and that the foregoing figures are only approximate, and may vary even 200 or 300 feet, according to locality.

The subterranean limits of the Arapahoe and its relations to the other formations are indeterminable, except through the aid of numerous and systematic borings. From Sand Creek southward the eastern edge of the formation is totally obscured, and in the sections it has been drawn from its recognized presence in deep wells in the Platte Valley, in the southeastern portion of the city of Denver, and at an occasional point on the plains east of Denver.

Along the western portion of Section V, the Arapahoe, on account of gentle dip and the removal of the overlying Denver beds, occupies a broader superficial area than at any point along that outcrop to the north.

The area covered by the western portions of Sections III, IV, and V is discussed in the geology of the region about Golden.

THE PLUM CREEK SECTION.

The line of this section lies within a short distance of the northern face of the extensive table-land which forms the divide between the Arkansas and Platte rivers. The western portion of the section presents nothing unusual either in stratigraphy or structure; the formations succeed one another with regularity, although the Montana has decreased somewhat in thickness; the great fold at the foot of the mountains still appears in the lower beds of the Arapahoe, the strata presenting the customary change from steep to gentle dip and thence to horizontal well out beneath the prairies. A little south of the section, the broad zone of the Arapahoe, occasioned by the recession of the Denver formation north of Section V, is again contracted by overlying Monument Creek beds, but along this portion of their outcrops the line of separation between the two formations is of doubtful position, their materials being conspicuously alike. The Denver in this portion of the field maintains its recession to the eastward, and is in turn overlain by the Monument Creek. The broad area of exposure of the Arapahoe beds possibly represents an old elevation in the floor of the Denver sea, either isolated or a portion of the confining rim of the sea on the southwest.

The relation between the Denver and Monument Creek formations is distinguishable at several points along the line of section and in the bluffs and high, rolling prairie to the south of it. In the bluffs the uneven surface of erosion presented for the deposition of the younger formation appears in a waving line, varying in the amplitude of its flexures from 50 to 150 or 200 feet, while in the southeastern part of the field and beyond there frequently occur in the stream bottoms, and along their adjoining slopes, local bosses of the Denver formation projecting through the overlying beds of characteristic Monument Creek material. This is notably the case at the head of Coal Creek and on its tributary, Dutchman Creek. Between streams the Monument Creek formation projects in extended promontories from the mesa to the south, often covering the Denver beds for several miles beyond their points of outcrop in the gulches. On the upper part of Cherry Creek erosion has carried the outcrops of the Denver beds in the bluffs of the mesa a distance of nearly 8 miles up the valley, the most southern exposure occurring a little south of Parkers Station, on the Union Pacific, Denver and Gulf Railroad. On the west side of the valley, in the broad, low flat which extends back from the stream for a considerable distance, only the younger formation appears, indicating, in conjunction with the beds east of the creek, a marked and rapid change in the level of the old lake bottom of Monument Creek times. Over this latter region the Monument Creek probably forms but a thin covering, for in one or two localities, notably in Happy Canyon Gulch, the Denver is found projecting through the overlying formation in the same manner as at the head of Coal Creek.

The eastward extent of the Arapahoe along the present section is altogether conjectural. The depth of its base beneath the channel of Plum Creek is probably about 800 feet.

CHAPTER III.

POST-LARAMIE AND TERTIARY GEOLOGY.

SECTION I.—THE ARAPAHOE FORMATION.

By George H. Eldridge.

INTRODUCTION.

The Arapahoe[1] is the oldest of the post-Laramie formations of the Denver field. It has only recently been ranked as a formation, notwithstanding the distinct features of its component materials and the nature of its sedimentation. With the overlying Denver formation it has been regarded by previous observers as part of the Laramie, without discrimination either as regards constitution, stratigraphical relations, or forms of life.

Like many other post-Laramie formations, the Arapahoe occupies the site of an ancient lake, the area of which probably extended considerably beyond the present confines of the formation, at least to the north, northwest, and west. Along the northern and northwestern edges the formation now appears only as a thin horizontal sheet, or in scattered outliers upon the uneven surface of the underlying Laramie. Along the western outcrop, where the strata are highly inclined and confined between underlying and overlying terranes, the formation is 600 to 800 feet thick, the size of material and the position relative to the mountains indicating still a distance of at least several miles from the original shore-line. To the south and east the younger formations have not yet been removed from the Arapahoe, and the extent and nature of its shore-lines can not be

[1] The name Willow Creek was at first employed to designate this formation, but was changed to Arapahoe in a footnote to the original paper. Proc. Colo. Sci. Soc., Vol. III, p. 86, Denver, 1889.

determined. The position of the formation beneath the plains, east of its upturned western edge, is either horizontal or slightly undulatory. The total thickness of the Arapahoe as originally laid down is indeterminable, either because of recent erosion or by reason of the removal of much of its material prior to the deposition of the overlying formations, or from the uneven floor presented by the Laramie.

STRATIGRAPHY.

The Arapahoe is divisible into two well-marked series of beds; a lower, of sandstones and conglomerates, 50 to 200 feet thick, and an upper, of clay, 400 to 600 feet thick.

THE LOWER DIVISION.

The sandstones and conglomerates constituting the lower division of the formation are especially well developed along the upturned portion next to the foothills. They are here generally about 150 feet thick and appear at intervals either as low projecting combs of rock or as streaks of weathered-out, pebbly débris upon the surface along their line of outcrop.

The lower 40 feet is prevailingly a coarse conglomerate, consisting of material derived not only from every formation of lower horizon in the Denver field, but also from other formations beyond. In this material are white sandstones belonging to the Laramie and to the Dakota; fragments of coal and pebbles of silicified wood from the Laramie; clay-ironstones, which might have come from the Laramie or from lower divisions of the Cretaceous; limestone pebbles from both Niobrara and Jura; numerous and most characteristic pebbles of the hard, cherty conglomerate at the base of the Dakota; red sandstones, which might have come from the Jura, and others that certainly represent the Triassic Red Beds; and, lastly, silicified limestone pebbles from the Carboniferous, some containing excellent specimens of Beaumontia. Besides the débris of recognized sedimentary origin, vari-colored jaspers, flints, agates, and silicified woods exist in profusion. Silicification is, indeed, a marked peculiarity of the coarser material of the Arapahoe conglomerates; this process seems, however, to have affected only the pebbles, the sandy matrix of the conglomerate and the sandstones proper showing no evidences of it. The conglomerate is somewhat unevenly developed, locally assuming the nature of a grit or even a coarse sandstone. Rarely, however, are the pebbles wanting to such an extent that they cease to be a means of distinguishing the horizon.

The remaining portion of the lower division consists of alternating bands of coarse sandstones, conglomerates similar to the one just described, and a few thin, local bands of clay. The prevailing color of this division within the Denver field is gray or white, but south of the field reds and yellows also appear. There is also present in the south a higher percentage of material derived from formations outside the Denver field, notably limestone fragments of Carboniferous age.

The type locality for the foregoing series of beds is along the bluffs of Willow Creek, 3 or 4 miles southeast of the entrance to the Platte Canyon. In passing eastward to the prairie region, however, the conglomerates are gradually replaced by sandstones, which still carry a few pebbles, here unaltered and derived chiefly from the clays and ironstones of the Laramie. In most cases such pebbles have doubtless been transported but comparatively short distances, though the materials of the matrix in which they are embedded may have been brought from far distant and widely separated sources. The sandstones of the prairies are generally irregular in thickness, but rarely exceed 40 feet.

The changes in sedimentation are clearly shown along the northern edge of the formation. The coarse materials of the western side of the deposit, derived from the Cretaceous and older formations along the neighboring lake border, gradually give way, to the east, to the fine sediments of deeper waters, in which there are but few pebbles except those derived from the Laramie floor itself. Along this edge, too, the unconformity between the Arapahoe and Laramie is clearly shown in the disappearance of successive beds of clay and sand and in the outliers of Arapahoe sandstone, which rests upon and against the slopes of the Laramie floor.

THE UPPER DIVISION.

The shales which constitute this portion of the Arapahoe are distinctly arenaceous, are of light-gray color, and have a maximum thickness of about 600 feet. They contain a few ironstones somewhat similar to those of the Laramie. South of the Denver field the gray color is varied by bright reds and yellows, in this respect a resemblance to the Monument Creek formation arising.

LIFE.

The only animal remains yet found in the Arapahoe beds are the bones of vertebrates of new and remarkable types. These occur in the conglomerate along the foothills and in the basal sandstones and overlying clays beneath the prairies. In the conglomerate but few have been found, and these are more or less worn; in the clays they are abundant and their articulations, edges, and muscular insertions are sharp and clearly defined, and their cancellous tissue is in complete preservation. Their chemical composition differs but little from that of bone in general, excepting in the foreign matters washed into their hollows and interstices. They are found at all horizons in the formation, and occur buried in the clays or sandstones or partially weathered out upon the surface of the prairies. The detailed description will be found in another chapter.

Plant remains occur in considerable abundance and are discussed by both Messrs. Cross and Knowlton in Section III of this chapter and in Chapter VII.

DISTINGUISHING CHARACTERISTICS.

The Arapahoe formation is distinguished from the Laramie by the sandy nature of its clays, by the comparative paucity of ironstones, by the generally brighter colors, and by the vertebrate remains. From the overlying Denver the Arapahoe is readily distinguished by the eruptive nature of the material composing the former. From the Monument Creek, owing to the similarity of their materials, it is indistinguishable—unless by its fossils—when, through the absence of the Denver formation, the two come in contact.

STRATIGRAPHICAL RELATIONS.

Within the area of the Denver Basin the Arapahoe formation rests unconformably upon the Laramie, although along its upturned western edge the break is recognized only through change in sedimentation. Upon the Arapahoe rests unconformably the Denver; upon the Denver formation, the Monument Creek. Interruptions to this succession are due to topographical causes and to the lacustrine character of the bodies of water in which the sediments were laid down.

SECTION II.—THE DENVER FORMATION.

By Whitman Cross.

INTRODUCTION.

The Denver formation is the most recent one now remaining in the greater part of the district, and its strata form the surface, except when covered by drift or Pleistocene deposits. Owing to their soft and friable nature this fact does not insure the existence of outcrops suitable for the study of the formation, and this superficial position of the strata has, moreover, caused them to be especially subject to erosion, and the greater part of the formation affected by the fold along the foothills has been removed, so that no complete section across the upturned edges now remains, while such profiles are available for nearly all the underlying formations. Except for the protection afforded to a part of the strata by the basaltic sheets of Table Mountain, and for the fortunate preservation of other strata in the mass of Green Mountain, we should now be wholly without data concerning the greater part of this most interesting formation.

Geographical extent of the formation.—Almost the entire known area of the Denver formation is included within the limits of the accompanying map. It now covers an area of about 400 square miles. Roughly stated, the formation extends from a line along the western bases of Green and Table mountains eastward, embracing the entire block between Clear and Bear creeks and continuing to the east line of the map, with Coal Creek as the northern boundary, and the high lands of the overlying Monument Creek beds as the southern limit of the exposed strata. Small areas north of Clear Creek and south of Bear Creek are also of Denver beds.

Concise characterization.—The Denver formation is characterized by the nature of the material composing its sediments. While its strata are texturally very similar to those of the underlying Arapahoe formation, they are essentially different in composition. The Arapahoe beds contain little which is not derived from the crystalline rocks of the mountains, though a portion comes through the medium of older sedimentary formations. The Denver sandstones and conglomerates, on the other hand, consist chiefly of débris of eruptive rocks of the andesite family, with which material of other origin is prominently associated only in the upper horizons. For several hundred feet at the base of the series the strata contain almost nothing derived from granite or gneiss. Upward in the series the latter material reappears and finally predominates very largely, although no horizon is free from andesitic débris.

Historical.—Before the identification and description of the Denver formation by the writer in 1888, the strata in question had been uniformly treated as a part of the Laramie. The strata of Table Mountain—the most typical of the series—had been examined and described by various geologists, and, as the matrix for well-preserved plant remains, were extensively represented in large collections of the country. The strata have been referred to as simple "sandstones" or "clays," and the material composing the sandstones seems in no instance to have attracted attention, though conglomeritic layers everywhere alternate with simple sand and clay strata.

As far as the writer is aware, the first geologist to study strata belonging to the Denver beds was J. L. Le Conte,[1] who examined the vicinity of Golden in 1867. He refers to Table Mountain as follows:

> East of Golden City is a plateau nearly 600 feet high, composed of horizontal sandy and clayey strata, containing badly preserved vegetable remains; it is capped by a thick sheet of basalt, which has been poured out from craters, the remnants of which exist on the grassy plains of the mesa as elliptical ponds.

F. V. Hayden[2] personally visited South Table Mountain in 1869, and in his report speaks of the mesas and of the sandstones and clays bearing plant remains, classifying the latter as belonging to the "Lignitic group." Green Mountain is spoken of as "entirely composed of the coal strata."

In a later publication[3] Hayden repeats the statement that "under the basaltic caps of Table Mountain there is a great thickness of Lignitic beds."

[1] Notes on the Geology of the Survey for the Extension of the Union Pacific Railway from Smoky Hill River, Kansas, to the Rio Grande. Philadelphia, 8°, 1868, p. 76.

[2] Preliminary Field Report of the U. S. Geol. Survey of Colorado and New Mexico, 1869, p. 35.

[3] U. S. Geol. Survey of the Territories, Bulletin 4, second series, p. 215.

He also remarks that 1,500 feet or more of Lignitic strata are present in the gap west of Table Mountain. The city of Denver is said to be built on the "Lignitic" beds.

In 1872, L. Lesquereux[1] examined the locality about Golden, collecting large numbers of fossil plant-remains, chiefly from South Table Mountain. In his report the capping sheet of Table Mountain is called a "basaltic dike" against which leaf-bearing sandstones and clays are "upheaved." In his monograph upon the Tertiary flora of the Western Territories[2] Professor Lesquereux gives Golden as the habitat of 95 species of fossil plants, all assigned to the "Lignitic group." In no case is the essential difference in composition noticed which exists between the highly quartzose sandstone of the coal horizon and the Table Mountain rock which is entirely made up of andesitic débris.

In 1873, A. R. Marvine[3] gave a section of the exposure at the northeastern extremity of North Table Mountain. It is as follows:

	Feet.
Cliff at top, dark columnar basalt	40
Slope, scoriaceous basalt and amygdaloidal dolerite	30
Palisade, columnar basalt	60
Slope, débris of scoria and volcanic sand	100
Palisade, columnar basalt	30
Slope—covered to the base.	

The 100 feet of "scoria and volcanic sand" represent the upper semi-tuffaceous strata of the Table Mountain sections to be given later. No further mention of this volcanic sand is made, and Marvine evidently thought it local and connected directly with the basalt. Marvine also quotes[4] a "section of the Lignitic strata at Golden City," by Capt. E. L. Berthoud, of Golden. In this section the horizontal strata of Table Mountain are called "conglomerates" and "sands" and "clays," with no reference to the character of the material.

[1] Sixth Annual Report of the U. S. Geol. Survey of the Territories, by F. V. Hayden, 1872, p. 329.

[2] Monographs of the Hayden Survey, Vol. VII, Contributions to the Fossil Flora of the Western Territories, Part II. The Tertiary Flora. 1878.

[3] Annual Report of the Geol. and Geog. Survey of the Territories for the year 1873, by F. V. Hayden, p. 130.

[4] Loc. cit., p. 109.

Of Green Mountain, Marvine simply says:

Below it is also made up of Lignitic strata, while above occur large bowlder beds of rolled volcanic rocks, showing in its northeastern side that it is apparently an extension of the same lava that caps the South Table Mountain.

Marvine apparently ascended Green Mountain from the north and correctly interpreted the angular basaltic blocks of a certain exposure as a remnant of the Table Mountain flow. He erred in considering the worn bowlders of dark andesite as derived from the same source, but had he passed down the western slope of the mountain the key to the problem would probably have been found.

In 1877 Dr. C. A. White visited the region and in his report[1] remarks:

Search for fossils was prosecuted in the strata of the Table Mountains of this district, which are mainly composed of strata of the Laramie group, and are capped by a trap outflow. In this search I was not successful, although the strata are no doubt equivalent with those [of the Laramie] that were found so fossiliferous in the valleys of Crow and Bijou creeks.

Prof. Lester F. Ward, paleobotanist of the Geological Survey, spent several days at Golden in August, 1881, studying the geology and collecting plants from South Table Mountain.[2] He was accompanied by Dr. C. A. White during a portion of the time.

The result of Professor Ward's study is given in his "Synopsis of the Laramie Flora."[3]

The first published reference to these beds as distinct from the Laramie is contained in a pamphlet upon the artesian wells of Denver, issued by the Colorado Scientific Society in June, 1884.[4] In this pamphlet, while discussing the geological relations of the wells, the present writer referred briefly to the "Tertiary andesitic pebble beds" of the country adjacent to Denver on the west, and shown in Table Mountain, which had previously been classified through their plant remains as Laramie.

The formation was first described and named by the writer in a paper read before the Colorado Scientific Society in Denver, July 2, 1888. This

[1] Annual Report of the U. S. Geol. and Geog. Survey of the Territories for 1877, p. 192.

[2] Third Ann. Rept. U. S. Geol. Survey, 1883, pp. 26–27.

[3] Sixth Ann. Rept. U. S. Geol. Survey, 1885, pp. 405–557.

[4] The Artesian Wells of Denver—a report by a special committee of the Colorado Scientific Society, p. 8. This report was reprinted in Vol. 1 of the Proceedings of the Society, issued in 1885, p. 79.

was published in the society's "Proceedings,"[1] in association with a paper by Mr. Eldridge in which the Arapahoe formation was first described and named. In revised form the same communication was later published in the American Journal of Science.[2]

Since the first published descriptions of the Arapahoe and Denver formations a number of articles have appeared in discussion of their age or describing fossils found in them. Reference will be made to these publications in the following chapter.

From the foregoing historical sketch it appears that Golden has been visited by a goodly number of geologists and paleontologists who have paid more or less attention to Table Mountain and its strata. It is true that no very detailed work was attempted by any one of the gentlemen cited, yet several of them made extensive collections of fossil plants in the strata of the coal measures and of Table Mountain, and from the weight that has been attached to the determinations of these plant remains it would seem that the collectors must have had full confidence in the accuracy of their knowledge concerning the relations of the various horizons from which the fossils were obtained.

DESCRIPTION OF THE FORMATION.

THE BASE OF THE SERIES.

Character of the first sediments.—The following description of the lowest deposits has special reference to the section more or less plainly seen along the western line, at the bases of Green and Table mountains, for here the sediments are more clearly typical than in the exposures apparently at the base of the series which are found north of Clear Creek. Here, too, the transition into higher horizons can be followed more connectedly, and thus a characteristic section established with which other outcrops may be compared. The actual contact of Denver and Arapahoe beds is seldom well exposed, hence a complete description of the change from one to the other can not be given. The boundary line of the Denver formation as drawn upon the map is approximate, being clearly established at but few points. The explanation of this inability to definitely locate

[1] Proc. Colorado Sci. Soc., Vol. III, pp. 119-133.

[2] The Denver Tertiary formation: Am. Jour. Sci., Vol. XXXVII, 1889, pp. 261-282.

what is probably in reality a very sharp line, lies in the soft and easily destructible character of the clays and friable sandstones constituting the strata of both formations near their contact. Even along the western border, where the edges of the strata are upturned, it is difficult to find good outcrops at this horizon.

The lowest beds seen which have been referred to the Denver series are sandy layers consisting of a mixture of quartz and feldspar plainly derived from Archean rocks, with other minerals, such as augite, hornblende, biotite, and feldspar, which exhibit properties belonging to the constituents of eruptive rocks. Except, however, occasional pebbles of distinct andesite, which sometimes occur in these layers, there may be nothing to suggest the character of these mineral particles until they are subjected to microscopical examination. It is then found that at least a portion of the feldspar contains ore grains or microlites of zircon, apatite, and augite, with more or less typical glass inclusions, all these indicating an eruptive origin. As to the hornblende and biotite, it is not always possible to determine their source so clearly, but the augite is, like the feldspar, plainly to be considered as a former component of some eruptive rock.

Although much of the lower part of the Denver series is almost if not entirely free from Archean débris, the actual base contains a mixture of materials. A consideration of the facts leads to the belief that all mineral particles of noneruptive origin contained in the lower layers of the series belong to the movable sands of the sea-bottom upon which the new formation began. The base of the Denver series is thus determined by the first appearance of eruptive material among the particles derived from the crystalline or older sedimentary rocks. This line could be determined with accuracy were there sufficient outcrops along its course.

Strata of Section Ravine.—The single exposure along the western line which shows clearly and sharply the transition from the beds of the Arapahoe to those of the Denver formation is that in Section Ravine, upon the southwestern slope of Green Mountain. The Arapahoe formation ends with a series of clays, which are succeeded at a certain point by a hard, coarse-grained sandstone or grit layer, in which quartz grains are very prominent, but which contains in addition some augite and some clear plagioclase particles with glass inclusions. The strata are here vertical, with a strike N. 4° to 5° 30′ W., and the contact plane of sandstone and clay is wavy and irregular. At some 10 feet above the contact the sandstone is finer-grained, softer, and contains abundant glassy plagioclase grains, with hornblende, augite, biotite, and some rounded quartz particles. Above this horizon the section is incomplete, but sandy beds or fine conglomerates appear at intervals, with a rapidly decreasing dip, and in these the particles are all derived from andesites. It is probable, then, that we have here exposed the actual contact line of the Denver and Arapahoe formations.

Outcrops in Kinner Run.—The small water course called Kinner Run, which enters Golden from the southeast, near the base of Table Mountain, has cut down into the lower strata of the Denver formation at several points, though it may not have penetrated to the very base. The banks of the ravine east of the court-house show horizontal, crumbling gravel and sand strata in which minute pebbles of andesite are more abundant than quartz grains. Below these layers are clays. Also near the forks of the run, a little south of town, there is a similar contact between sandy beds containing small andesitic pebbles and pure clays below.

THE STRATA OF SOUTH TABLE MOUNTAIN.

General statement.—For a distance of 300 or 400 feet above its base the Denver formation is prevailingly made up of fine-grained, friable sand rocks, of clays, and of intermediate mixtures, which are not sufficiently coherent to form good outcrops except under the most favorable circumstances. In consequence of this character no complete section can be given of this part of the series.

The basaltic sheet of Table Mountain which was poured out upon the floor of the shallow Denver sea has preserved the underlying strata from complete destruction, and it is upon the steep slopes below this lava flow that all the best exposures in this part of the series are now to be found. While continuous sections are of very limited extent, a good idea of the character of the entire thickness of the strata represented may be obtained by correlating, as far as possible, the scattered outcrops of Table

Mountain, and while the slopes of North Mountain are steeper and higher the most instructive exposures are all upon South Mountain, or adjacent to it.

Exposures upon the western slopes.—Were the rocks under discussion a little better adapted to resist the disintegrating tendencies of ordinary weathering, there would probably be continuous sections at many points. For instance, on the ridge running west from Castle Rock toward Golden, the coating of débris upon the slopes is very thin and the presence of Denver strata can be demonstrated at almost any spot, although the character of the stratum may not be well shown. As it is, the study of the footpath leading from Golden to Castle Rock, following in the main the ridge just mentioned, will give a very good idea of the essential characteristics of the formation.

The lowest stratum clearly shown is that exposed by the ditch at the end of the ridge nearest town. This is perhaps 75 feet above the outcrop in Kinner Run which has been mentioned as the possible base of the formation. The rock is yellowish in color, consisting of small pebbles, gravel, and sand with some clay as matrix, and crumbles easily. Some pebbles reach an inch in diameter and prove to be hornblende-andesites of fresh condition and typical structure. One of these contains 61.25 per cent SiO_2, and in this rock tridymite is very abundant. With a hand lens one can recognize glassy feldspar, augite, biotite, and hornblende particles, and a few rounded quartz grains in the finer material.

About 300 yards south of the footpath and 75 to 150 feet above the ditch level there is a succession of conglomeritic and sandy beds exposed by a small gully. The greater part of this exposure consists of more or less friable sandstone or tuff composed entirely of débris of andesites. The microscope shows glassy feldspar, biotite, augite, hornblende, ore, and small, worn particles of corresponding andesites. The cement is partly fibrous and partly isotropic, and is described in detail in another place. Pebbles of typical andesite are scattered through nearly all layers, but are most abundant near the top of the section here exposed, there forming a normal conglomerate. Nearly all the pebbles are small and there is a great variety of types represented, all belonging in the andesitic group.

At horizons corresponding to this outcrop there are in many places indications of the presence of similar strata, through small exposures or surfaces strewn with pebbles.

On following the footpath up the ridge a number of outcrops of sandy strata may be found, though seldom of an extent deserving special mention. The beds shown are often so fine-grained that their composition may not attract attention. At the northern base of Castle Rock the contact of basalt and sandy strata is shown at several points near the path, and other outcrops reveal the character of the adjacent beds very well.

About 250 yards southeast of Castle Rock there is a fine outcrop of one of the most persistent beds shown in Table Mountain, and one that conveys most readily and clearly an idea of the characteristic composition of the strata of the formation. It is a dark conglomerate, 15 to 20 feet in thickness, which here forms a small cliff at about 20 feet below the basalt sheet. It is chiefly made up of dark andesitic pebbles of many types, varying in diameter from 5 inches downward. The matrix is a coarse sand of eruptive origin, prominent among the particles being augite in isolated prisms with terminations, the edges not having been sufficiently rounded to obliterate the form. The sandy parts of the bed develop in places to wedge-shaped masses exhibiting in their relations to each other and to the conglomerate a very marked cross-bedding. Above this conglomerate are dark sandstones continuing upward to the basalt, which are characterized by the abundance of distinct augite crystals. Below are similar sandy strata.

The variety of andesites represented in the conglomerate is great, as will be seen by a reference to the petrographical chapter. Most of them are augite-andesites with varying amounts of hornblende and biotite, but no type here found contains hypersthene, while such rocks are common in the higher strata shown in Green Mountain. One variety is very light colored, aside from the sparsely distributed augite prisms which correspond closely to those mentioned as occurring free in the sandy matrix of the conglomerate, and in the sandstones above. The variation in silica is great, some being very basic, while others contain free silica in the form of tridymite. Compact porphyritic structural types prevail, although even-grained and porous rocks are also abundant.

This stratum, while the most persistent known in Table Mountain, may, nevertheless, be also used as an excellent illustration of the lateral variation in composition common to all or nearly all the conglomeratic and sandy beds of the formation. On following this conglomerate toward Castle Rock, it is found to decrease rapidly in thickness, and at the same time the size of the pebbles becomes less. The horizon can be traced for some distance uninterruptedly, is then covered for an interval, and it can scarcely be identified with the equivalent sandy layers shown on the south face of Castle Rock. There are in the latter outcrops some sandy beds containing small pebbles, but not in sufficient quantity to constitute a conglomerate, nor in so great a quantity as may be found in many other horizons where no conglomerate proper is ever developed so far as known. In spite of this described variation the horizon is exceptionally well marked as a conglomerate, and at many points on both Table Mountains, and on all sides, the clear equivalent of this stratum is to be found at or within a few feet of the contact with the basalt sheet.

Section at the northeastern point of South Table Mountain.—While the exposures already described give a clear idea of much that is characteristic in the series under discussion, the lack of continuity in outcrops fails to bring out other important peculiarities of the formation. This lack is in a measure supplied by the succession of strata shown on the eastern slope of the northeastern extremity of the mountain. There is here a continuous section of 170 feet of strata, from the basalt downward. No other outcrop exhibits so great a thickness of the lower beds of the formation.

The succession of beds here seen gives a very good idea of the constitution of all the Denver beds, except the heavier conglomerates. Below this section there are several small outcrops at points down to the ditch level. They are either of clayey beds, with but little sand, or they represent layers corresponding to 1 or 2 of the section. In the sand rock included under 1 of the section, black biotite leaves are very prominent; pebbles are very rare here, and most of the mineral grains are angular. The section is as follows:

		Feet.
	Basalt, at top.	
0.	Dark-brown clays and fine gravel in alternating layers	11
9.	Coarse gravel and pebble-bearing bed	5
8.	Gravel layer at bottom, passing gradually into a dark, reddish-brown clay at top	18
7.	Conglomerate of small, dark andesite pebbles	2
6.	Fine-grained, light-colored sand rock or tuff	5
5.	Fine-grained rock, like 6 at base, passing into clay at top	20
4.	Dark clays, often mottled, containing small pebbles of light-colored andesite and tuff	34
3.	A series of alternating light-colored clays and semiconglomeritic or tuffaceous layers	52
2.	Friable sand rock and sandy clays	18
1.	Sand rock, more compact than 2	6
	Total	171

In division 2 of the section there is a general distinction to be made between the lower 8 feet, which are dark-colored through the abundant admixture of vegetable matter, and the upper 10 feet, which are firmer and contain less carbonaceous substance, though stems and imperfect leaves of plants are common. Some of the lower layers are chiefly made up of plant remains.

Under division 3 are included strata of peculiar constitution which are well developed in some places not far from this exposure, but do not appear at many other points where it seems likely they would be distinguishable if of the character here presented. In the section the division begins with some almost conglomeritic pebbles of a light-yellow or straw-colored andesite, and others of reddish or brownish colors. The latter are merely decomposed rocks similar in kind to the darker ones of other horizons, while the light andesite is of a variety found only in 3, 5, and 6 of the section. Passing upward in the series there is an alternation of clay, or what may be more expressively termed mud layers, with gravel or sand rock. The strata of this complex vary in thickness from a few inches to 6 feet or more and are laterally variable in this respect. The coarser-grained beds show cross-bedding. The mud layers are easily removed by water on any exposed surface, and so leave projecting shelves of the intermediate strata, producing very jagged outcrops. Short tree stumps are common in the gravel layers, their roots penetrating the mud beds below. The repetition of this feature shows the conditions of deposition of these beds. The gravel layers ordinarily contain many small pebbles of the light andesite, while darker varieties are in some places almost excluded. The lighter-colored rock is augite-andesite with a very small amount of augite, carrying some hornblende and biotite; the groundmass is often largely cryptocrystalline. The upper layer of 3 is more nearly a sandstone in composition than the lower beds. It contains very many small pebbles, but the main substance is ash-like and the rock is thus similar to that of higher layers, designated tuff.

The strata included under 4 are chiefly clayey in character, but there is really no sharp line at the base, for the upper stratum of 3 differs from the lowest of 4 in being firm and coarse-grained, and the latter passes through admixture of clay and increasing fineness of grain into the beds which are more properly called sandy clays, and so on to quite pure clay. Upward there is a change in color, the upper clay being dark reddish-brown with spots of lighter color. Pebbles of andesite occur sparingly all through, and a few angular fragments have been found. Tree stumps occur near the middle of this division. The darker clays are full of sand, as is shown by washing them, and if the sand thus purified be examined under the microscope it will be found to consist of augite, hornblende, biotite, and feldspar. With these minerals are small, round grains representing pebbles and fragments of andesite now almost completely destroyed. A sand of similar composition will be obtained on washing any clayey stratum in the Denver formation. Plant remains are abundant in the division 4, though seldom well preserved.

The beds of No. 5 of the section are most typical. Deposited upon the hard, brown mottled clay of 4 is a stratum of quite compact sand rock of light-yellow or gray color. This is even-grained and uniform except for pebble-like masses or concretions of a material extremely like the matrix in which they lie, but as a rule somewhat coarser in grain. These masses are sometimes 3 or 4 inches in diameter and in certain layers are thickly crowded together like the pebbles in a conglomerate. By the aid of the microscope it appears that both matrix and pebble-like masses are made up of angular mineral particles, chiefly glassy feldspar, with some hornblende, biotite, and augite, and also of particles representing the dense groundmass of corresponding andesite. But few true pebbles are present, and these are of the general type mentioned as occurring in the beds of 3. The rock is then made up chiefly of particles which are not extreme results of abrasion, and they are plainly derived from a certain type of rock. It is thought entirely appropriate to call it a tuff. The pebble-like masses are to be considered as masses of a tuff probably rounded up by wave action while yet semiplastic. In proof of the correctness of this deduction from their mineral constitution and structure it is to be mentioned that plant stems have been seen in the pebbles, but they are never found extending outward into the surrounding matrix. The lower 8 feet of division 5 are of the character above described, while in the upper 10 feet there is a gradual transition through sandy clays to a pure clay at top.

In division 6 there is almost a repetition of the preceding beds with a development of friable sand rock or tuff in some layers, of about the composition described.

Number 7 of the series represents a decided and sudden change in the character of the materials deposited. It is practically a fine conglomerate in which dark and comparatively basic andesites prevail, the lighter ones of the lower horizon being very subordinate in quantity. No pebbles seen in this stratum are over 5 cm. in diameter. This conglomerate may be the representative of the thick, dark bed near Castle Rock, but that is hardly probable, as it is here too far below the basalt, and such local development of sandy or gravelly layers is entirely possible at almost any horizon.

The beds included under 8, 9, and 10 of the section are really not separable except for this particular section. Their differences are such as may arise in any complex of strata at about this general horizon, in different order and manner from that here found. The specially marked conglomerate (7) may also be included in this statement, but the change from 6 to 7 is probably always marked by the development of a coarse-grained bed which may or may not be easily separated from the stratum next succeeding. In the section there is merely a marked line between the conglomerate (7) and a sandy or gravelly bed of practically the same composition but of finer grain. This is followed upward by sands and then by sandy clays, and these by darker, purer clays, to which succeeds again a coarse gravel layer (9), followed once more by transition beds. The bed at 9 is more probably the equivalent of the darker conglomerate usually found at about this horizon than is the better-defined conglomerate below (7).

The detailed description of the foregoing section is intended to show the peculiar composition normal for the strata of the Denver series in those horizons and also to bring out clearly the conditions which must have attended the deposition of such fine-grained sediments. It is clear that the small pebbles so universally found have been greatly reduced in size through continued abrasion; that the transition from the coarse layers at the base of a certain series upward through the finer and finer sediments to clays, which are as a rule succeeded by a sudden change to coarse materials, must indicate the periods of comparative rest or disturbance of the waters of these seas. Furthermore, the presence of considerable tree stumps in erect position with roots in mud layers and broken trunks in sand or gravel, shows that the water was shallow or even that low-land masses alternated with shallow seas. Probably the latter was the case. The accumulation of these strata was slow and they represent a long epoch of sedimentation.

Outcrops at the southeastern point of South Table Mountain.—Opposite the middle of the foot-like extremity of South Table Mountain is a knoll connected with the slope of the mountain by a ridge, and on the south side of this knoll is a little basin. From the basalt contact down to the bottom of this basin and on the ridge and knoll are good outcrops of horizontal strata which again illustrate the occurrence of the beds found in the preceding section within 100 feet of the basalt. Here the section is not quite continuous, and the fine grain of most of the gravelly layers makes a direct comparison difficult, but it is still plain that the sections are equivalent so far as they go. At 60 feet below the basalt appears a light-colored layer, with pebbles of straw-colored andesite. This represents the base of 5 of the section given. All below this point can be brought in comparison with the beds of 3 and 4, but erosion has not yet cut down enough to show the characteristics of bed 3. Fossil wood, leaves, and stems are abundant. Irregular fragments of andesite were found in layers at about 100 feet below the basalt. At this point the basalt capping is scarcely more than 10 feet in thickness; below it the contact with strata is plainly shown. As a whole it seems plain that the strata of this section are finer grained than those of any corresponding outcrops farther west. Cross-bedding is very beautifully shown in the sandy and gravelly rocks on the knoll and connecting ridge.

Outcrops on the northern slopes of South Table Mountain.—On the north slope of South Table Mountain there are prominent outcrops caused by the appearance of beds shown in division 3 of the section. One of these exposures is on the north side of the northeastern point. This shows nothing of special note. The other outcrop is below the indentation in the center of the northern face.

Other outcrops on South Table Mountain.—Beyond the chief outcrops mentioned there are none of special importance in determining the succession of strata present. All over the slopes are scattered croppings of minor extent which can not be directly correlated with definite strata of the large sections, but none is found which does not have its equivalent.

The leaf-bearing beds which have been visited by those in search of fossil plants are situated chiefly on the southern and southwestern slopes of the mountain and are in minor outcrops. Possibly none of them have been associated in consecutive outcrops with the darker conglomerate beds. As a rule the best-preserved leaves occur in fine, yellowish-brown sandstones or clayey strata in which the nature of the constituent mineral particles is not always plain to the unaided eye.

One of the horizons which has furnished many of the fossil leaves both of the earlier and of the most recent collections is on the south slope of the southwest point of the mountain, opposite the Reform School. These strata, at about 100 feet below the basalt, are water-bearing, and the Reform School authorities have dug into them, making an artificial spring which furnishes a water supply for the school. The rock taken out here is full of leaves and stems of plants. A collection was made at this place in 1883 and the specimens were placed in the hands of Prof. Lester F. Ward for identification.

EXPOSURES ON NORTH TABLE MOUNTAIN.

The slopes of North Table Mountain are both higher and steeper than the average slopes of South Table Mountain, but there are no outcrops of Denver strata here that are of special importance. Near the basalt there are frequent exposures of a dark conglomerate bed of very variable thickness. On the west side of the southeast gulch an outcrop at the contact with the main basalt sheet shows the contact surface cutting down obliquely from the north across about 10 feet of strata, but whether this is due to a plowing action of the basalt or to earlier causes can not be determined. The horizon of the lower basalt streams is situated quite uniformly at 100 feet below the capping sheet, and is at the top of the beds included under 3 of the section already given. These basaltic streams, which are described in detail in the chapter on eruptive rocks, must have been poured out upon a sea bottom and quickly covered by sediments, as is plain from their texture and the fact that they are overlain by sandy beds of material similar to those upon which they rest. The best locality for examining the relations of these streams to the Denver strata is on the southern slope of the mountain, midway between the two large gulches. Here the upper and lower contacts of a small basalt stream, as well as those of the upper sheet, may be clearly seen, and also a number of characteristic beds of the Denver series.

In the sandy strata of a horizon slightly above the basalt streams are found isolated angular specimens of pale bluish-gray augite-andesite, in structures varying from the massive to the very porous forms. The same rock is also occasionally found on South Mountain and on Green Mountain. It is not demonstrable that all loose pieces come from a single horizon, but it is quite probable that the one above referred to contains nearly all of them. In the cavities of the porous variety are found chalcedony, quartz, and heulandite, and in some fragments the new zeolite species, ptilolite.

A distinct spherical sundering was noticed in certain sandy beds not far below the basalt on the northwestern slopes of North Table Mountain.

GREEN MOUNTAIN.

Position and form.—Green Mountain lies upon the plains between Golden and Morrison and 9 miles south of west from Denver. It is a bald, massive hill of smooth and gentle slopes, rising 1,200 feet above Bear Creek at its southern base, and nearly as much above the western and northern bases. Seen from Denver and corresponding points upon the plains it appears to be a part of the foothills of the main range, but it is actually separated from them by the zone, about 1 mile in width, in which the upturned edges of all the sedimentary formations below the Denver are exposed. The approaches on the north, east, and south are gradual up to the base of the mountain proper, where there is a rather sudden change to an angle of 15° to 20°. The massive appearance, as seen from a distance, is somewhat deceptive, for the mountain is deeply scarred on all sides by ravines which penetrate to its core, so that there is a system of smooth, narrow, branching ridges. These deep indentations are the heads of as many water courses, few of which are more than shallow drains when beyond the base of the steeper slopes.

The surface of the mountain is thickly strewn with round bowlders, which have weathered out of the underlying strata. As will be seen by reference to the map, the entire mountain mass, with the exception of a narrow band at its western base, is made up of strata belonging to the Denver formation. Nowhere else is the thickness of these deposits approximately indicated, and even here it is evident that an unknown amount has been removed. The reason for the special preservation of Green Mountain is not apparent.

The Green Mountain profile.—The smooth slopes characteristic of the mass present few actual rock outcrops, and the deep ravines afford only limited exposures, but upon the western side of the mountain there is a hollowing out of the usually even surface, bounded on the north and south by minor ridges, and drained at the bottom by a little ravine. The steep face at the back of this hollow, the ridges on either side, and the ravine below, combine to give a practically continuous section of strata extending from near the summit down to the base of the steeper slopes, a vertical distance of about 500 feet. In consequence of the near approach of Green Mountain to the line of the great fold, this exposure on its western face exhibits very clearly the extent to which its strata have taken part in that folding. At the top of the section the heavy conglomerates have a slight eastern dip; at its base a dip of 45° is shown, and at a distance to the westward but little greater than the known thickness of the intervening strata the beds are found in vertical position.

In order to determine the total thickness of the Denver beds and the relative positions of prominent horizons, a straight profile line was surveyed across the mountain, passing up the outcrop described, as nearly parallel to the direction of dip as possible. The course of the section is N. 42° 30′ E. and the direction of the dip is N. 74° 30′ E., hence there is a divergence of 32° between them. By projecting the outcrops of distinct horizons from the section line upon the line of dip, and by estimated average dips for certain subdivisions of the sections, an approximate determination of the total thickness of the section has been made.

Estimated thickness of Denver formation.

Subdivision.	Average dip within subdivision.	Length of outcrop on line of dip.	Equivalent thickness of strata.
		Feet.	*Feet.*
a	Vertical	250	250
b	75°	180	175
c	55°	250	205
d	42°	205	137
e	35°	170	98
f	25°	275	116
g	15°	465	120
h	5°	2,745	239
i	Horizontal	....	100
	Total		1,440

In regard to the average dips assumed in the above table it should be explained that at various places on the line of the profile the dip can be determined approximately, though seldom very accurately. The strata of the Arapahoe conglomerate horizon are found to be vertical. Above this to the dark andesitic conglomerate at the base of the section no dip can be measured, but as the latter has a dip of 45° and as it is shown by adjacent outcrops that the fold is here sharp and that the transition from vertical beds to those having a dip of 45° is sudden, it seems highly probable that some of the lower beds of the Denver series are vertical on the section line. From the dark conglomerate the exposure is almost continuous, and although sharp bedding planes are so rare as to make accurate dip measurement difficult, still the gradual changes are visible and they agree closely with the drawn section. Dip measurements were made as follows: 42° between *d* and *e*; 18° in *g*; 10° in *h*.

For convenience in discussing the section, four divisions are made—A, B, C, and D.

Division A, 580 feet.—This embraces all up to the dark conglomerate. No outcrops of importance occur on or near the profile line of division. Its base, which is also the base of the formation, is an assumed point deduced from the known thickness of the Arapahoe beds in the vicinity, their known strike, and vertical position. A few yards south of the line of profile is a smooth ridge showing here and there crumbling, sandy strata of the Denver formation, and also farther west the upper Arapahoe clays. The outcrops here are not numerous enough to permit a determination of the line between the formations with accuracy.

This division must include strata corresponding to those described in Table Mountain, but the detailed constitution can hardly be the same here, or else more distinct outcrops would have resulted. The strata occurring about 100 feet below the basalt forming an alternating series of tuff, gravel, and clay layers of light color, are apparently not represented here, as such material would surely have been discoverable in the ridge mentioned near the profile line, or in some others on the western slope of the mountain. The few exposures in Section Ravine to the southward, which have already been mentioned (p. 160), show that the lower horizons are composed of very loose and friable clays and sand rocks, and the absence of firm outcrops on the section line is not at all remarkable.

Division B, 50 feet.—This division embraces the dark conglomerate and the gravelly transition beds immediately above and below it. Without being able to trace the actual connection on the surface this conglomerate is thought to be the equivalent of that found just below the basalt of Table Mountain. The reasons for this are the apparent correspondence as to horizon and the great similarity of composition, although it is recognized that the latter fact would prove little in the light of the known variability of the strata of such constitution. If this conglomerate is the equivalent of the Table Mountain bed we have a nearly complete section of the formation by combining the two exposures.

The stratum on the line of profile has a strike N. 15° 30′ W., with an easterly dip of 45°. It occurs along the entire western base of the mountain at or a little below the steeper slopes, and it can be traced continuously in either direction until the low approaches to the mountain are reached.

At its base this division is composed of dark sand with a few small andesite pebbles. In the central and upper parts it shows pure conglomerates with sandy layers interstratified. The latter are seldom continuous in the body of the conglomerate, their form being that of wedge-shaped masses with marked cross-bedding, shown both by their stratification and by their relation to the conglomerate proper. A similar cross-bedding is also apparent in the conglomerate itself, so that determinations of dip and strike can be made only by observing the course of the bed as a whole. The pebbles are mostly small, but few reaching a diameter of 4 to 5 inches, the majority being less than 2 inches. The rocks represented by the pebbles are nearly all dark, and there does not seem to be as much variety here as in Table Mountain. Few of them are porous. They lie in a scanty matrix of sand composed entirely of débris of andesitic rocks, while the actual cementing material is chiefly zeolitic in nature. In the small, irregular spaces between larger pebbles may occasionally be found cavities lined by small crystals of chabazite or stilbite, or in other cases filled by yellow calcite. Isolated augite crystals are abundant in the sandy matrix, but they are less perfect in form than those of the Table Mountain conglomerate. A few Archean pebbles were found in this conglomerate after careful examination of a considerable area.

The distinctly conglomeritic portion of Division B is actually 25 feet in thickness. The remainder of the 50 feet assigned to it is chiefly at the base and represents the change from the friable semi-clayey rocks of A to the distinct conglomerate. Veinlets in this sand rock are usually filled by zeolite or calcite and the actual cement is doubtless of the same substances.

Division C, 285 feet.—The strata included under C are probably very much like those of Division A, but they are much better exposed than the former on the line of profile. The three divisions (A, B, and C) really constitute a single division standing in contrast to the strata above.

Nearly the entire thickness of C is made up of yellowish-brown sands and clays with intermediate members. The little ravine coming from the hollow in the face of the mountain above exposes nearly the entire thickness in a most excellent manner. Few horizons stand out so plainly that they can be specially designated. Immediately above the conglomerate of B come about 30 feet of pure sandy strata; there is then a layer of pebbles 4 inches thick, succeeded by yellowish-brown clays containing varying amount of sand. The small conglomerate layer is frequently broken up into a series of lenticular masses arranged one after another. At about 100 feet above B is a development of 6 to 8 feet of dark, sandy clays with light spots very similar to certain layers noticed in the section at the northeast point of South Table Mountain. Above this comes a crumbling semiconglomerate or gravel layer 3 feet thick. This stratum has a strike N. 15° 30′ W. and a dip of 42° easterly. Only eruptive material was noticed in this conglomerate. This bed is followed by fine, yellowish, sandy beds, soon passing into clays of buff, lavender, and dark-brown colors, also somewhat arenaceous. Some of the dark-brown clays are mottled by light spots, as in the stratum already mentioned. In such clays occur concretionary masses of hardened, light-colored clay with an outer zone of darker material in which a rude cone-in-cone structure is visible, the apices pointing inward. These masses are ellipsoidal and up to 2 feet in diameter. Search for fossils in them proved fruitless. These concretions are apparently not confined to particular layers, but may be found anywhere in clay beds of the character mentioned.

The upper portion of Division C is composed chiefly of friable sand rock with clay, and it is not so continuously exposed as are the lower portions.

Division D, 525 feet.—This stands in contrast to lower divisions both in structure, being composed of coarse conglomerate beds, and in material, through the appearance and general increase in importance of Archean débris with the eruptives.

The actual base of D is not shown by the outcrops, although it is approximately indicated by the exposures in the small ravine just south of the section. It is in all probability a sharp line. The series begins with a conglomerate which is less compact and firm than that of B. At the base the pebbles are not very large, but they vary in character, showing for the first time a decided admixture of Archean with the andesite. There are also distinct clay bowlders mingled with the others in these lower horizons. Above the first 25 feet of conglomerate there comes a gap which evidently represents a return to clay or fine, sandy deposits. Above this gap come still coarser conglomerates with a greater admixture of Archean than before. Bowlders here vary from 1 to 2 feet in diameter for the large ones, and from that limit downward. The bowlders lie in a matrix of coarse, crumbling sand in which angular Archean particles are predominant. Cohering outcrops are naturally rare, and smooth, steep slopes covered with round pebbles and bowlders are usually presented, but a few strokes of the pick reveal beneath the surface a mass of varying-sized bowlders embedded in crumbling gravel. The relative proportion of Archean and eruptive materials in these strata is hard to determine without close scrutiny. The andesites are much decomposed as a rule, and on exposed surfaces crumble away quickly, while the Archean remains comparatively fresh, and is thus more prominent. In the lower 100 feet of D the eruptive material is nearly equal to the Archean in quantity. Large bowlders increase in number upward in the series.

At about 100 feet above the base of D there appears on the line of this section a stratum with an easterly dip of 18° which contains so much iron oxide as its cement that it is hard and forms a projecting outcrop. At about the same horizon, too, there is a decided gain in the amount of Archean relative to the eruptive bowlders. The iron is noticeable through about 10 feet of strata, though present in large quantities only in the stratum at the base, about 1 foot in thickness.

About some pebbles in this heavily iron-bearing stratum there is a shell of limonite nearly an inch in thickness, in which an imperfect radiate structure can be seen. Archean strongly predominates over eruptive material in all the strata from this horizon upward. Dakota conglomerate bowlders were noticed at and near the iron-bearing horizon. One of them was 2 feet in diameter.

The sandy matrix of the crumbling conglomerates is chiefly composed of quartz and red feldspar. Besides the stratum especially mentioned there is a slight appearance of iron oxide in the cement at many places, the result being a firmer rock in all instances. Large bowlders, with an average diameter of from 1 to 2 feet, are thickly piled in together in some layers, with smaller ones in the interstices.

While conglomerate rocks strongly predominate in all of Section D, fine-grained beds appear in places, though perhaps with but limited lateral development, much as the conglomerates appear in the fine-grained beds of the lower portion of the formation. Thus, a few feet below the point *h* on the profile, there appears a dark, arenaceous clay stratum, containing much vegetable matter. Seen on the line of profile it appears to be a well-defined horizon occurring as a break in the conglomerate series, but this stratum can not be identified as such at a distance of but a few yards to the north on a ridge where there are good croppings. Probably the conglomerate succeeding it was deposited in turbulent waters, which locally or perhaps generally destroyed the fine deposit of a period of quiet. The study of the conglomerate series made it evident that fine-grained beds of local development might occur at almost any horizon, probably representing in all cases remnants of a layer of former continuity. In subdivision *h* no continuous bed of fine grain was found, but one noticeable local stratum was observed a few yards north of the line of section on the northern ridge. Here is a dark clay stratum, 18 feet thick, with coarse sandstone above it. The clay is dull-purplish in color and has a few gravel stones mixed in with it. One foot more or less below the sandstone is a local layer of lignitic material, a part of which is changed into true jet of great brilliancy. In part of this layer the woody fiber and toughness are still preserved. Tracing these beds southward they wedge out rapidly, and on the line of profile are represented by almost normal conglomerate, vertically and laterally, with the appearance of bowlders in increasing quantity. The dip of the sandstone above the jet layer is 18°. Approaching the summit, the bowlders are larger and the conglomerate of which they are a part becomes looser and looser, until it is difficult in places to see that regularly stratified deposits are to be recognized in the heap of bowlders. On a glance at a considerable face of the exposure, however, the stratification is always plain.

Andesite continues to be a marked element of the conglomerate to the very top of the series, but the variety formerly noticeable is now no longer a feature. The rock prevailingly represented here is a dense pyroxene-andesite in which the microscope shows both augite and hypersthene. The amount of Dakota conglomerate pebbles and bowlders is larger than below, while red and white sandstones are also present in considerable number. Just on the edge of the exposure is a large, white bowlder, 6 feet in diameter, of a felsitic eruptive rock not identified in any lower horizon. This may be an erratic, and it is also possible that glacial bowlders may be mingled with those of the coarse conglomerate on the upper slopes of the mountain.

Distribution of particular beds.—In speaking of the form of the mountain it was said that at a certain level the low, gentle slopes or approaches gave way to steeper ones. This line is approximately the base of the heavy conglomerate series. On following up almost any one of the ravines penetrating the mountain, outcrops representing the lower 100 feet of this conglomerate may be found in the stream bed or on the adjacent slopes, and the larger ridges practically terminate at the same horizon. Those ravines leading south into Bear Creek usually show the dark conglomerate of B as soon as they have cut down sufficiently to bring it to the surface, and this occurs half way or more down to the creek. The gentle slopes about the mountain are then, for the most part, in the series of fine-grained sandstones or clays of the Division C, above described, and, except for the local development of a conglomeritic layer, there are few conspicuous outcrops, although the beds of almost all water courses reveal clayey strata or sands here and there, whose characters, as members of the formation, would not be at all clear were it not for the continuous section which has been described.

THE STRATA OF THE PLAINS.

The horizons represented.—The bed of the Platte at Denver is vertically 500 feet below the horizontal strata thought to be at or near the base of the formation in Kinner Run at Golden, and 600 to 800 feet below the more or less uneven horizon at which the Denver beds disappear under the Monument Creek to the south and southeast. From Table Mountain toward Denver there must, then, be a slight dip, enough at least to carry the bottom of the formation under the city, and from the known limit of the strata along the northern line, and from the data of the artesian wells, it seems that the base of the series is, in fact, but little below the river level This slight dip is not recognizable in outcrops, for the frequent local variations in planes of sedimentation are greater than the dip in question.

For the same reason one can not determine accurately the thickness of strata actually exposed between Denver and the southeastern limit of the formation, but here, too, it seems most likely that it is much less than the vertical interval above mentioned, owing to a slight northerly dip.

All the strata of the plains are considered to be equivalents of the lower 400 feet of the series represented in Table Mountain.

General characteristics.—Although the strata of Green and Table mountains have been described as very fine-grained in the horizons corresponding to these deposits of the plains, the latter are as a rule still finer. This is shown chiefly in the small size of the andesitic pebbles found in the grit or conglomerate layers. Near the western line it is common to find some few larger pebbles, 2 inches or more in diameter, in almost any bed containing pebbles, but beyond the Platte such pebbles are very rare. Coarse-grained beds may be searched in vain for any worn fragment a quarter of an inch in diameter, while smaller ones may be abundant. This fact is of course a natural sequence of the conclusion adopted that the source of the eruptive material was entirely on the western shore.

A feature of the strata found on the plains is the abundance of nodules in certain sandy layers. These are often 3 feet or more in diameter, dark in color, and very hard, while lying in a soft, friable sand rock, easily disintegrating and of yellowish-brown color. In form the nodules are more frequently lenticular than round, but almost perfect spheres have been seen in some cases. As a rule certain layers carry many nodules, and occasionally they adjoin each other so closely as to make up the greater part of a given stratum, or they may be united, and as an extreme of this development a given layer may be found to possess the color and hardness of a nodule for several yards with quite uniform thickness, though always ending with round outlines showing the real formal relation.

A complex of layers in which such lenticular masses are abundant rarely fails to make itself known by good outcrops. On Murphy Creek are several particularly fine exposures of such strata, and on the High Line ditch, between Cherry Creek and the Platte, such outcrops are numerous. In the latter case, the bed of the ditch for a short distance below an exposure of nodular masses is covered by the nodules washed out. Similarly, on the dry creeks of the region south and southeast of Denver, the appearance of dark nodular fragments in the stream bed surely indicates good exposures not far upstream, cut out by the floods of the rainy season. Good examples of the nodular masses may also be seen on the west bank of the Platte opposite Overland Park.

One feature of many outcrops of the Denver strata seen upon the plains is likely to be at least temporarily misunderstood by anyone not thoroughly acquainted with the developments in Table Mountain. This feature is the irregular, unconformable contact so frequently seen to exist between a conglomerate or grit layer above and a clay or shale below. Often the distinctive eruptive character of some of the pebbles and fragments of the coarser bed may be seen at a glance, while in the clay below nothing showing its true position is visible, and one is inclined to wonder if the actual base of the Denver may not be exposed, the clay belonging to the Arapahoe or Laramie. Often the unconformability is very marked, and unless adjacent exposures show similar relations at other levels, or reveal characteristic Denver sandstones below the clay, the true relationship may not be clear. The changes in conditions of sedimentation which give rise to such stratigraphical relations of consecutive beds were, however, common in both Denver and Arapahoe epochs. Fine sediments were often disturbed and locally removed at the beginning of periods of rapid deposition of coarser materials. Such alternations of sediments were especially mentioned while discussing the exposures of South Table Mountain

While the sediments of the plains are usually finer grained than those of the western border, and hence are distinguishable with less readiness, there is another element at first contributing to the difficulty in the appearance of quartz and feldspathic grains plainly not of eruptive origin. This feature will be discussed more fully in a following section, and it is only necessary here to mention the conclusion reached that such materials came from the Arapahoe shores on the north and south.

Hints from topography.—While the area of the map east of the line of Green and Table mountains is essentially plain, there are many diversities found to bear more or less direct relation to the underlying solid rock formation in spite of the numerous Pleistocene divisions which play the chief rôles. A thorough acquaintance with the region immediately underlain by the Denver beds shows several peculiarities to be named.

The strata have been described as prevailingly loose and friable, yet they resist erosion in a way of their own. A clay matrix for many beds causes the disintegration to proceed slowly and only on the very surface. Water may remove the outside layer easily, but the wet clay below holds the loose grains together for some little time. In many strata, too, a still more powerful agent exists in the secondary cementing substance of zeolitic character which has formed sometimes very abundantly. The dark, friable sandstone exposed in a surface quarry on the south side of Bear Creek contains 54.59 per cent of substance soluble in hydrochloric acid, and a fine-grained, brownish bed shown in the ravine near the old St. Luke's Hospital, Highlands, was found to contain 38.22 per cent of soluble matter, a large amount of gelatinous silica being formed in each case.

The result of this resistance to erosion is to produce rounded bluffs on all considerable streams, as Bear, Clear, Van Bibber, and Coal creeks, and along the Platte. Such lines of bluffs generally represent practically continuous outcrops, while solid rock appears only in gullies or on actual stream banks. The Arapahoe and Laramie do not produce such forms, though the differences are perhaps not very pronounced to the unaccustomed eye.

Fossil remains.—As far as present experience goes the strata of the plains are richer in animal remains than the better-exposed strata of Table Mountain, and this conclusion does not rest solely on the experience of the writer and of the earlier explorers of the flora at Golden. The exposures of Table Mountain have been studied for years by students from the School of Mines at Golden, alone and under the guidance of Prof. A. Lakes, who has collected so many fossil plants from this locality, and in all this time but a single vertebrate fossil has been found (a tooth of a dinosaur) and no invertebrate remains whatever.

In the vicinity of Denver, however, mainly through the careful searchings of Messrs. G. L. Cannon, jr., and T. W. Stanton, a considerable number of vertebrate fossils and some shells have been found in place in typical Denver sandstones and clays.

THE SHORE-LINE DEPOSITS.

Besides the present limited extent of the Denver beds there are certain indications that the sea in which the beds were deposited was quite circumscribed, at least in its earlier stages. On the west the continental land mass could not have been far away from the present foothill line, though as a matter of fact there is no known evidence to show how far back any of the sedimentary formations of the district may have gone. But on the north and south there is evidence indicating that during the first deposits of the Denver period the shore-lines were not far distant from the present boundaries. The evidence in the one case lies in the stratigraphic relation to the Arapahoe and in the other in a combination of lithologic and stratigraphic relations.

Within the Denver period, however, there may have been considerable changes of level and correspondingly of extent covered by the sea, so that the observations to be mentioned do not apply with any certainty to the later stages in the history of the sea.

The northern shore-line.—From North Table Mountain eastward to the hills north of Arvada, erosion has removed everything which might have indicated the shore-line; but in the angle between Clear Creek and the Platte River, in the low hills a mile or more back from these streams, remnants of the Denver are found resting on the Arapahoe in positions showing a very uneven sea-bottom, and suggesting the proximity of the northern shore-line of Arapahoe land. The details of this region are derived chiefly from Mr. Eldridge's notes, for these Denver exposures were discovered by him while studying the Arapahoe.

It is impossible to indicate upon the map the details of the relation between the two formations as it is here known. The generalization of the map may be explained in words by saying that these hills are capped by thin remnants of the Denver beds at varying altitudes, through which many of the small drains have cut into the underlying Arapahoe; and that, as practical horizontality exists for both formations as a whole, the elevation of the Arapahoe floor at this point, being some 200 feet above the known Denver beds on Clear Creek near its mouth, necessitates the conclusion that the north shore of the Denver Basin was rapidly ascending in the area in question. Moreover, the still higher ground occupied by the Arapahoe to the northward seems to show the form of the Denver sea-bottom in this direction.

The southern shore-line deposits.—East of the Platte River and near the ascending line of the Arapahoe as it approaches the Monument Creek there are some exposures of Denver strata which clearly show the immediate proximity of the old shore-line. On one of the creeks, just about the High-Line Canal crossing, are several good outcrops on sloping gulch banks, of very light-colored sandstones or grits, coarse and crumbling, in which no eruptive material can be found. These light-colored beds lie in isolated patches, while above, below, and, in some cases, between them, are typical Denver beds, rich in dark, eruptive-rock pebbles. Taken by itself this group of outcrops would be accounted for with difficulty, but a short distance up the same creek on the north bank is a bluff outcrop in which the explanation for this occurrence is well shown. Here are seen grits composed of quartz and feldspar, overlain and underlain by normal Denver beds, and these grits are seen to pass laterally in continuous outcrops into beds of nearly the same grain in which andesitic pebbles are abundant and soon predominate. Such a change takes place within a distance of 50 feet, there being continuous stratification from one end to the other of the variable beds.

The Denver strata in this place are therefore capable of being locally developed as nearly pure sandstones of Archean débris, and this possibility indicates most plausibly that a local source for such material is near at hand. The loose sandstones and grits of the Arapahoe are distant but a few hundred yards from this spot, where they seem to have constituted the shore, although actual exposures of the shore-line could not be found.

Such local variations of the Denver sandstones were found in less marked degree throughout the southern part of the area represented as Denver, from the Platte to Coal Creek, and it seems probable from this fact that the early Denver sea was quite circumscribed in this direction, where the boundary of present exposures is set by the overlapping of the Monument Creek.

OCCURRENCE OF THE FORMATION.

As the strata of the Denver formation are, almost without exception, soft and friable and thus easily disintegrated, and as they have been especially exposed to erosive agencies, their identification as a distinct formation would have been very difficult were it not for the protected outcrops of Table Mountain and the section shown in the mass of Green Mountain. Without these it would have been almost impossible to correlate the scattered outcrops in obscure ravines and drains upon the plains, and many exposures of clay or fine-grained sandstones would have long gone unrecognized. Now that the relations are clear it is seen that characteristic outcrops are really quite common over the greater part of the field.

It is the aim of this section to describe the localities and special features of the principal exposures known, that it may be easy for others to test the conclusions reached in regard to this interesting series of rocks, the identification of which bears upon several questions of Rocky Mountain geology and raises, on the other hand, so many new problems for future solution.

Table Mountain.—The lower portion of the Denver strata is much better exposed on Table Mountain, near Golden, than at any other place. Here, at the northwestern extremity of the present area of these rocks, the lower 450 to 500 feet of the formation is now protected by the basalt sheets which were poured out upon them during the Denver epoch. North Table Mountain possesses an average elevation above the adjacent country of 650 to 800 feet; its basalt capping presents cliffs varying in height from 100 to 200 feet, and below them are rather steep slopes upon which here and there over the entire extent of the mountain are outcrops of Denver strata. So far as known they are horizontal or have possibly a very slight dip to the southeast. The soft, easily disintegrated sandstones and clays afford projecting outcrops only under the most favorable circumstances, hence the slopes are unusually débris-covered, but where smooth, a blow of the pick will commonly expose the sandy or clayey strata.

The contact of the main basaltic sheet with the Denver strata is exposed in many places at the base of the cliffs, and the relation of the smaller, earlier basalt streams to the inclosing sandstones is clearly shown. The former contact is particularly well exhibited at the head of the southern gulch which cuts into the mountain; also on the southern face between the large gulches, on the western side of the larger gulch, and on the northwestern face above the eastern end of the lower basalt flow. Below the last contact and at several places upon the southern slopes are outcrops of strata at various horizons.

The actual line between the Denver and the underlying Arapahoe beds is nowhere visible. From the data soon to be given it is estimated that the thickness of the Denver strata present below the basalt can not be far from 450 to 475 feet. The base of the formation along the northern foot of Table Mountain is drawn according to the estimate, with the assumption that there is a slight easterly dip to the strata. Directly west of North Table Mountain the rising ground and nearness to the great fold require that the Denver beds should take some part in the fold, and the yellowish, sandy strata which are imperfectly seen in the southern end of the railroad cutting do appear to have an easterly dip of 20° to 25°. These strata are thought to be near the base of the Denver series, although by no means of characteristic composition.

South Table Mountain, although lower, exhibits much better exposures of these Denver rocks than are found upon North Table Mountain. At its northeastern extremity there is a continuous outcrop, from the basalt downward, of about 170 feet of horizontal strata, a description of which has been given. Adjacent to the southeastern point is also a fine exposure of strata below the basalt, and at several places upon the northern and western slopes the more prominent horizons are well shown. Southeast of Castle Rock a few hundred yards there appears a particularly fine exposure of the most typical conglomerate of the series, at the horizon immediately below the basalt. The footpath from Golden up to Castle Rock also passes over characteristic outcrops, both near the basalt and on the ridge below, at about the 5,950-foot contour. Lower horizons of typical composition are shown at various places along the irrigation ditch, especially at the western base of Castle Rock.

Plant remains occur quite abundantly throughout the sandy strata within 300 feet of the basalt and have been found particularly well preserved along the southwestern slope of South Table Mountain.

All outcrops on South Mountain indicate a practical horizontality for the formation as a whole, although there are some minor irregularities. The basalt sheets, whose source is in dikes between Ralston Creek and Table Mountain, evidently flowed in a direction south-southeast upon the inclined sea-bottom, and the surface upon which they rest corresponds approximately to a definite horizon in the formation. Owing to the greater height of North Table Mountain it seems at first glance as if the present surface in contact with the basalt was more inclined than is actually the case. A careful estimate of the total fall of the surface upon which the basalt rests, from the northern edge of North Table Mountain to the southern edge of South Table Mountain, makes it 375 feet in a distance of 20,500 feet, which corresponds closely to a dip of 1°.

The western base of the formation.—From Clear Creek southward to Bear Creek the base of the Denver formation has been traced by the following data: In the bed of Kinner Run, the small stream which enters Golden from the southeast, there are several outcrops of importance. The first of these is in the town, just east of the court-house, where loose, crumbling beds are shown which contain much quartz in company with the eruptive material.

These strata are underlain by clays like those of the upper portion of the Arapahoe series, and it seems quite probable that the actual line of separation between the two formations is here shown. The rising ground to the southward carries the junction line to the westward, and outcrops of decided Denver strata are found due west of the Reform School in the bed of Kinner Run just below the ditch and old railroad grade crossings. In all intervening portions of Kinner Run the stream bed is excavated in alluvial deposits. At the point just mentioned, however, friable, leaf-bearing sandstones are shown with a dip of 27° to 30° in an easterly direction, and a strike about N. 20° W. Microscopical examination reveals beyond a doubt the characteristic composition of Denver beds. Less than 500 yards to the eastward the cut made for the ditch in the north edge of the terrace upon which the Reform School stands exposes horizontal beds of fine-grained conglomerate or grits of the same formation, while less than 300 yards to the westward the Arapahoe conglomerate is found with an easterly dip of 70° or more.

The relationship of the Denver beds to those of the Arapahoe series, and the position of both with regard to the great fold are still more clearly shown in the abandoned railroad cutting southwest of the Reform School and 450 yards south from the outcrop in Kinner Run. The cutting is in the terrace, and shows in its western portion Arapahoe beds from the upper part of the conglomeritic section, with very steep easterly dip. Succeeding these is a gap corresponding to the clay strata of the upper Arapahoe, and then brown and yellowish friable sandstones of the lower Denver formation, the latter having a dip of 20° to 30° eastward. The exact line between the formations is not visible, but can be located with sufficient accuracy from the approximate thickness of the Arapahoe clays above the conglomerate. It is here plain that the sharp bend in the fold, as expressed in the outcrops of the present surface, occurs in the upper part of the Arapahoe series, and the Denver strata are affected only in their lower members.

From the Reform School southward to the base of Green Mountain proper the dividing line between these two formations is necessarily drawn with reference to the conglomerate horizon of the Arapahoe, as that alone is well shown. Its strata can be traced for a mile or more, with a constant steep dip, beyond which there is a gap of nearly a mile. The strike and dip must be continued unchanged in this covered area, however, as the point at which the beds reappear, at the northern base of Green Mountain, is in the projection of the last known strikes to the north.

The form of Green Mountain is characterized throughout by smooth slopes, but there is a certain horizon traceable around its entire mass at which the steep upper slopes give way to more gentle ones. At this general horizon the deep excavations in the mass of the mountain give way to comparatively shallow ravines in the lower slopes. On the western slope the line between Denver and Arapahoe strata can be approximately determined from the persistent outcrops of the conglomerate of the latter formation, which can be found in vertical position, crossing the ridges between the ravines and minor drains. East of these outcrops there is usually a space in which at a few points only are found small clay outcrops. All ridges are covered by débris of bowlders from the mountain above, and the drains are mostly shallow and grassed over along this line. As all strata of the Arapahoe and the lower ones of the Denver series are vertical or dip very steeply all along the western base of the mountain, it is evident that the base of the latter formation must come at a distance above the Arapahoe conglomerate equal to the estimated thickness of the intervening clays In one of the ravines running west in the north part of the mountain distinct outcrops of Denver sandstones were found about 100 yards from the Arapahoe conglomerate in a direction normal to the strike of the latter. At this same outcrop the clays underneath the sandstone seem to be of the Arapahoe. Above this horizon are several outcrops of undoubted Denver strata, and at the base of the steeper slopes there appears the conglomerate bed made up of dark andesite pebbles, which can be followed along the whole western slope of the mountain, bearing always the same relation to the Arapahoe conglomerate. These two horizons run nearly parallel at a distance slightly greater than the thickness of the intervening strata, with occasional outcrops between them, and continue to maintain this position until the erosion of the southern slopes of the mountain cuts sufficiently down into the Denver beds to cause the outcrops of their less steeply dipping members to diverge somewhat from the line of the lower conglomerate, which continues with a gradual eastward curve in its strike to the banks of Bear Creek, opposite Mount Carbon. All outcrops which are found along this general line prove the presence of the Denver beds at the points where the deductions from the known dip and thickness of the lower formation would naturally put them.

As has been shown by Mr. Eldridge in the preceding chapter, the thickness of the Arapahoe strata in this region, as well as the location of its upper limit, can be most beautifully shown in one of the ravines upon the southwestern slope of the mountain. Hence the deduced position of the base of the Denver formation with reference to the very persistent exposures of Arapahoe conglomerate must be considered as nearly correct.

The Arapahoe conglomerate can easily be traced to the bank of Bear Creek, opposite Mount Carbon, where it is very clearly shown, in vertical position, close to the wagon road on the north side of the creek. A few hundred yards down the creek is the mouth of Coyote Gulch, whose banks show horizontal Denver strata. The fold is therefore very sharp here as well as along the base of Green Mountain. In following up the bed of Coyote Gulch many most characteristic exposures of the Denver beds are seen.

Green Mountain.—The massive hill bearing this name is almost exclusively made up of sandstones and conglomerates of the formation under discussion. Only at its western base, as described in a preceding section, are other series represented. Its peculiar form and gentle slopes result from the ready disintegration of the loosely cemented strata. A casual observer would scarcely think of referring the large, loose bowlders scattered over its surface to immediately underlying strata, and outcrops which clearly reveal this fact are rare, at least for the upper part of the mountain. Upon the western face is the only cliff-like exposure of any extent occurring, and this has been described in foregoing pages in detail. The ravines heading in the mountain mass all show minor outcrops in their beds, but the smooth slopes are usually débris covered. After leaving the upper slopes these ravines cut down into the finer-grained sandstones and conglomerates, giving evidence of the rock formation underlying the low, grassy country about the mountain on the south, east, and north.

South of Bear Creek.—Denver beds are well shown in the little knoll on the northern slope, near the east end of Mount Carbon. The strata exposed are conglomerate and grits in typical development, with plain cross-bedding and having a slight dip to the eastward. Everything is concealed on the flat, drift-covered top of the hill, and the northern slope has few distinct outcrops. The proximity of the vertical Arapahoe conglomerate to these nearly flat Denver beds shows that the fold is very sharp and its axis probably lies below the Denver.

South of Mount Carbon the line of the Arapahoe is clear, but it is no longer followed so closely by the Denver. This is shown by exposures about one mile southeast of Mount Carbon. Here is a distinct ridge of the Arapahoe conglomerate in vertical position, beyond which to the east is a shallow lake whose banks exhibit sandy and clayey strata of the Arapahoe in horizontal position. A county road runs due east from the north side of this lake and for about 3 miles traverses a cultivated district, in which there are a number of ponds formed for irrigation purposes, and no rock outcrops were found. This road is 1 or 2 miles south of Bear Creek and between them runs a low ridge bounding the valley proper, upon which there are several knolls. Denver strata form this ridge and may be seen in small outcrops. Along the southern base of the ridge are fields and several ponds. As far as can be determined at present this ridge represents the south line of the Denver here, the ponds and cultivated areas being most probably underlain by Arapahoe clays. A small quarry has been opened in cross-grained and rather friable Denver sandstones on the ridge a quarter of a mile north of the road and about 2½ miles east of Mount Carbon. About here the ridge swings around to the southeast, uniting with similar banks of the Platte River. Denver beds are found in many places along the line of the road above mentioned as it crosses this ridge and descends to the Platte Valley.

An outcrop of Denver beds appears at the water level at the western point of the great bend in the Platte north of Littleton. From here south no exposures have been found on the west side of the Platte, though the strata must curve in this direction to a point several miles south of Littleton. The flat west of Littleton and the drift-covered banks above were searched for outcrops in vain, though they may exist in undiscovered places.

Area between Bear and Clear creeks.—This entire block of country east of Green and Table mountains is underlain by Denver strata which appear in numerous places, as a rule either in the rounded knolls or in ravines and gullies. Even in some cultivated or grassy fields any slight excavation, as small irrigation ditches, will reveal crumbling brown sandstones or clays, which a microscopical examination shows to be composed largely of andesitic débris. The soil from disintegration of such material has a characteristic dark yellowish-brown color.

The northern bank of Bear Creek is abrupt, yet the slopes are usually smooth and rounded, with numerous little drains cutting into them. Though projecting rock faces are rare, this entire bank is practically one continuous outcrop of Denver beds, and illustrates admirably the way in which the strata resist erosion, while seemingly so easily attacked. A prominent conglomerate horizon is often identifiable by the black pebbles strewn abundantly over the surface.

About one mile west from the Platte a dark conglomerate forms an unusually prominent outcrop. It is evidently a local development, in much reduced thickness, of some bed elsewhere found as a conglomerate. Pebbles 6 to 8 inches in diameter are not uncommon, though the greater number do not exceed 2 inches. The variety is great, though all seem to be andesites. Heulandite and calcite in plain crystals or grains compose the cement of these pebbles. A total thickness of about 15 feet is mainly conglomerate, and it grades off to sandstone or grit, with few pebbles both above and below, and probably laterally in a similar manner.

The western bank of the Platte, from Bear Creek to Clear Creek, is formed by a line of low bluffs, along which, in many places, good outcrops of the Denver beds are exposed. The Platte cuts into this bank at some of its bends and lays bare dark concretionary sandstones, as at a point opposite Overland Park. Small irrigation ditches and the cuttings on the Denver, Leadville and Gunnison Railroad also reveal the characteristic strata at many points. In addition to these outcrops the small water courses often cut into the solid rock, and the edges of the bank, or knolls upon it, frequently show rock in place in the same manner as along the Bear Creek bluffs above referred to.

The best point to see the Denver beds on the Platte banks is opposite Overland Park. The river itself, a ditch, the railroad cutting, and a ravine coming from the west all have cut into and exposed some very typical sandstones, and semiconglomerates. Here some large dinosaur bones were found in the dark, hard nodules of one horizon.

In the interior of the area under discussion the principal drainage courses show more or less frequent outcrops. One heading in Green Mountain, and entering the Platte at Denver, has a great number of exposures along its bank.

The south bank of Clear Creek also presents a good series of exposures. Under the bowlder beds of this valley the Denver beds are shown by railroad and wagon-road cuttings at several places.

The banks of the Platte in the immediate vicinity of Denver are especially treated in a succeeding section.

North of Clear Creek.—East of Table Mountain the northern limit of the Denver beds follows quite closely the south bank of Van Bibber Creek to its junction with Ralston Creek near Arvada. Here again the formation is betrayed by a line of distinct low bluffs, and outcrops and evidences of the peculiar strata may be found along the whole line. The rather level tract between Van Bibber and Clear creeks is chiefly due to the bowlder beds of the latter valley. On a small hill half a mile west of the mouth of Van Bibber Creek these bowlder beds may be seen resting on Denver strata.

At about the mouth of Van Bibber Creek the Denver beds cross Ralston Creek and run up on the prominent hill north of Arvada. On this hill are several outcrops, and a prospect shaft is sunk some 15 feet into the sandstones on the eastern point of the hill. Only the capping of the hill is made of Denver strata, the Arapahoe being shown not far below the top and in the drain on the northern side. The northwestern limit is quite well defined where Mr. Eldridge found Denver strata near the top of a ridge, with Arapahoe not far below on either side. As has been explained, the area of the Denver strata between this hill and the Platte is to be considered as part of a shore-line deposit upon an uneven surface, and the border lines of the Denver are therefore only approximately correct, for outcrops are rare and many possible variations may be concealed by the heavy Pleistocene deposits of the region. The south slope of the hill mentioned above is covered and the Arapahoe may run from the west farther down Ralston Creek than has been indicated; indeed, the hill may be capped by an entirely isolated patch of the Denver strata. This does not seem at all probable, however.

Denver and vicinity.—Within a radius of 4 miles from the city hall in Denver there are a great many spots where the strata of the formation bearing the name of the city are well shown, and while one should go to Table Mountain to gain a first acquaintance with these horizons some of the exposures within the city limits are very good illustrations of some of the chief features of the series.

The best exposures are on the west bank of the Platte at numerous points in the small drains which enter the river between Overland Park and Clear Creek.

In the largest of these tributaries which heads on the eastern slope of Green Mountain and enters the Platte near the Larimer street bridge there are many good outcrops within a mile of the river. In these rocks Mr. Cannon found the skull of *Ceratops alticornis*, the first of the horned dinosaurs described by Professor Marsh, associated with other vertebrate remains.

Still nearer the city, in the ravine by the old St. Luke's Hospital, Highlands, there was formerly a very good outcrop of Denver sandstones and clays, with cross-bedding structure, and full of plant remains in certain layers. Here, too, occurs a thin local seam of coal, which has from time to time been rediscovered and announced in the papers as indicating the presence of valuable coal in North Denver. In these same strata Mr. T. W. Stanton found some molluscan remains, associated with plants, and a small but perfect crocodile tooth. This ravine has now been filled in grading streets.

At various excavations and cuttings at and about the Globe smelter the Denver sandstones have been well exposed. On the western bank of the Platte a good outcrop occurs at water level, at the foot of Thirty-seventh street, and another at Twentieth street. Close by the waterworks in West Denver and along the western bank of Lake Archer the Denver strata appear distinctly.

On the south bank of Cherry Creek, in Shackleton Place addition to Denver, a small outcrop occurs. Wells in Ashley's addition and at other places on Capitol Hill prove the presence of beds there, and the excavation for the reservoir on Capitol Hill has also disclosed Denver strata under the Pleistocene.

North of Sand Creek.—The area of Denver beds north of Sand Creek is very small and no good outcrops are known. A well sunk on the ridge about 2 miles northeast of where the Kansas Pacific Railroad crosses the creek struck Denver beds of clayey or shaly character and then passed into Laramie. One mile southeast of this hill an outcrop occurs. Deep Pleistocene deposits cover everything here, and the line of the Denver beds is drawn to connect the known line at the Platte with the line of outcrops along Coal Creek. That the ridge upon which the above well is situated is made up of Denver, along its southern slope at least, is probable from the known exposures along Sand Creek, both above and below the Kansas Pacific Railroad track. Most of these are on the south bank, but their natural connection is with the district to the north. For a mile along the southwestern bank of Sand Creek, extending from near the railroad downward, there is a continuous outcrop of typical Denver beds, composed of shales and sandstones, with lignitic seams. There are no outcrops on Sand Creek below this.

Area between Coal and Cherry creeks.—East and southeast of Denver, between the creeks named, the Denver formation extends for from 15 to 20 miles, underlying what is at present a barren cactus-covered plain, in which one would not suspect, at first glance, that numerous rock outcrops could be found, as is in fact the case. Near Denver the Pleistocene deposits bury the solid rock formation so deeply that exposures are rare, and that part of the plain to the east which is underlain by the Laramie is also poor in rock outcrops, while in the area of the Denver beds almost every watercourse has cut into the strata. The high ground east of the city, of which Capitol Hill is a part, presents very few good exposures, but the southern tributaries of Coal Creek, still farther east, are rich in outcrops, the more noteworthy of which will be specified.

Sand Creek is the name applied to the lower part of the important tributary of the Platte entering it just below Denver. About 2 miles above the Kansas and Pacific Railroad crossing the stream forks, the eastern branch being known as Coal Creek, while the more southerly one is called Toll-Gate Creek or simply Gate Creek. Coal Creek heads nearly 30 miles south-southeast from this junction, in the Monument Creek plateau region. Gate Creek has many branches which drain nearly all the interior of the region between Coal and Cherry creeks, and its headwaters are on the line where the Denver beds pass under the Monument Creek strata.

Passing up Coal Creek from the forks there are some fine-grained, shaly outcrops on the southern banks, in the angle between the Kansas and Pacific Railroad and the High-Line ditch, but they are not specially characteristic. Beyond the ditch crossing the first outcrop is almost exactly on the line of the eastern boundary of the map, where a little gully coming from the west has cut into and exposed a sandstone resting on clay. The sandstone is friable, with large, hard nodules characteristic of the formation in this region. The eruptive character of much of the material is clear. Apparently this part of Coal Creek is very near the line between the Denver and Laramie, the Arapahoe being absent.

One mile above the last-mentioned outcrop Murphy Creek joins Coal Creek from the south, only a narrow ridge separating them for 2 miles upward. This lower portion of the ridge is composed of Laramie, capped by a thin sheet of Monument Creek sandstone, a relation well shown on the Coal Creek side. No further exposures of the Denver beds occur on Coal Creek until a point 5 miles above the mouth of Murphy Creek is reached, an occurrence to be mentioned below.

Murphy Creek now becomes the parting line between Denver and Laramie strata, and 1 mile above its mouth there is an outcrop of Denver sandstones, with dark nodules on the western bank, while on the eastern the slope is underlain by the Laramie. Above this outcrop the Laramie seems to cross the western bank and extends up to where the old Smoky

Hill stage road crosses the creek in section 19. Just above this point Denver beds outcrop in the banks of the creek and are shown in numerous fine exposures at intervals along the stream for 4 miles, or nearly to the dark butte between the forks at the head of the creek.

The ridge east of Murphy Creek is capped by Monument Creek sandstones or grits, resting, as has been mentioned, upon Laramie at the lower end and for 5 miles up Coal Creek. At this point an unnamed stream enters Coal Creek from the south, in whose banks are good outcrops of Denver beds corresponding to those at the same horizon on Murphy Creek, to the westward 1½ miles. The Denver beds also appear on Coal Creek, on both banks, about half a mile above the mouth of the unnamed tributary, and again on the west bank 1 mile farther up. Monument Creek beds form the high ridge to the west and come down to the level of the creek next east of Murphy Creek, thus cutting off the Denver beds. These appear again 1½ miles farther up this creek in most typical form, a dark conglomerate with many augite-andesite pebbles and very little Archean débris. This outcrop is confined to the bed of the creek at its fork in section 16, and evidently represents a prominence formerly existing on the sea-bottom. Or perhaps it is more correct to say that the Monument Creek beds occurring below this outcrop were deposited in a depression in the sea-bottom, for this insular outcrop of the Denver strata is at about the horizon constituting the lower limits of the Monument Creek in the gulches to the westward, as may be seen by an examination of the map.

Some of these exposures on this, the eastern limit of the formation, are quite typical, possessing pebbles, leaves, and concretionary masses, and consisting sometimes of quite pure eruptive material. Others are to be identified in the field only by their visible connection with more typical beds, but so numerous are the outcrops in the chief drains that the relationships are seldom left obscure.

As to Gate Creek but little need be said in this place. Three of its large branches head near together west of the head of Murphy Creek and just beyond or above the horizon at which the Monument Creek beds conceal the Denver. The line of the two formations can be located very closely in each branch by the red-clay horizon of the upper series, as

Mr. Eldridge describes, and which naturally runs as a contour for some distance on the intermediate ridges. In following any one of these branches of Gate Creek it is found to have cut down into the solid rock, forming a little gorge or ravine in which the strata may be seen almost continuously for miles. This is specially true of the upper and middle portions, for in the lower the Pleistocene sometimes obscures everything for considerable distances.

The High-Line ditch crosses the country so low down that it is largely excavated in surface deposits, yet it cuts through them in many places, always revealing the Denver beds below.

Between Gate Creek and Cherry Creek is a broad, high ridge extending up to East Cherry Creek, on neither slope of which are there any noteworthy outcrops known. The surface is smooth, with gravel abundant in places, originating from the destruction of the bottom grits of the Monument Creek formation to the southward.

On Cherry Creek slope the line between the Denver and Monument creeks is found at about the same horizon as on Gate and Murphy creeks. This line crosses East Cherry Creek at a point about 5 miles from its junction with the main creek and is indicated by outcrops of Denver sandstones shortly below the reddish clays of the Monument Creek, as in the region to the east. In the southern branch of East Cherry Creek, entering it on about the line between sections 26 and 27, there is a characteristic outcrop of the Denver beds at a quarter of a mile above the junction, and the Monument Creek red clay is found a short distance above it. On the northern bank of East Cherry Creek, opposite the last mentioned gulch, the Denver beds are found within about 25 feet of the top of the ridge, near the head of a small gully, and above this is a thin capping of whitish sandstone undoubtedly forming the base of the Monument Creek at this point.

The line between the Denver and Monument Creek beds follows nearly a contour line from East Cherry Creek around to the crossing of Cherry Creek proper, a short distance above Parker's station on the Union Pacific, Denver and Gulf Railroad. The bluffs are capped by characteristic sandstones and clays of the Monument Creek, and various small water courses on the western slope all disclose more or less distinctly the approximate line between the formations. On a drain entering Cherry Creek from the east, at about the point where the railroad crosses, there are some very instructive exposures of the Denver beds, beginning just east of the wagon-road crossing and extending nearly half a mile upward in almost continuous line.

Mr. Eldridge noted the appearance of the Denver beds in the gulch just south of Parker's at a point above the railroad crossing, and this outcrop marks the upper limit of the known exposures of the Denver beds on Cherry Creek.

Area between Cherry Creek and the Platte River.—From Cherry Creek almost to the Platte the line between the Denver and Monument Creek formations is, in general, an undulating contact, nearly corresponding to a contour in some parts, but revealing some unconformities of deposition in others. The outcrops along the course of Happy Canyon and Gulch reveal an unconformity directly analogous to that on Murphy Creek. The Monument Creek beds here occur in sandstones and clays down almost to the level of the railroad, and extend upward to a point just beyond the southern limit of the map. But in section 18 the Denver beds reappear and are exposed for nearly 1 mile along the course of the gulch. This exposure occurs at an elevation normally occupied by the Denver strata east of Cherry Creek, and the unconformity is therefore caused by the greater depth of the Monument Creek sea in this portion. In the streams between Happy Canyon and the Platte the contact of Denver and Monument Creek formations rises somewhat, but does not again reach the elevation at which it is commonly found to the eastward of Cherry Creek.

On Big and Little Dry creeks, tributaries of the Platte, the Denver beds are shown in many places down to within a short distance of the river. Some of the outcrops are continued along their banks for considerable distances, and exhibit the formation in very typical development.

The High-Line ditch from Cherry Creek westward cuts into Denver beds so frequently that it furnishes a very fine route for examining the rocks as developed in this region. These exposures show that the sandstones of the Denver come very near to the surface over some areas, and it is not unlikely that natural outcrops may occur in many places. The examination of this part of the area was hurried and the routes chosen were those best calculated to show the extent of the formation and its limits.

From Happy Canyon around to the creek entering the Platte 3 miles south of Littleton, Mr. Eldridge determined the line of Denver and Monument Creek, as given upon the map, from numerous outcrops near the line. On various branches of this creek the Denver beds are well shown down to the crossing of the ditch, in the neighborhood of which there are some very fine outcrops illustrating the variation in composition peculiar to this portion of the formation, from causes now to be considered.

The southern limit of the Denver beds on the banks of the Platte is set by the original shore-line of the horizon represented. To explain this better let us recall the course of the boundary of the formation from Mount Carbon, on Bear Creek, eastward. The line was found to run at first in an easterly direction along the low ridge forming the south bank of Bear Creek, and then to turn southeast, the exact course being concealed by valley Pleistocene. On the eastern bank of the Platte, however, exposures have been found which indicate closely where the line must cross the river. In the Denver and Rio Grande Railroad cut in the ridge north of the old Platte Junction the Denver beds are exposed, while in a corresponding cut in the ridge to the south from that point the Arapahoe strata are clearly shown. The latter also appear in characteristic outcrops in the next gulch to the south and in many places along the ditch on both banks of this water course.

SOURCES OF MATERIALS IN THE SEDIMENTS.

The peculiar interest and importance attaching to the Denver formation depend so largely upon the nature and origin of the materials composing its sediments that special consideration of this point seems desirable.

For all the sedimentary formations which we now see in this district the elevated mountain masses in the Colorado Range formed the western border, and it is evident that this land area must have furnished by far the greater part of all rock materials in the stratified deposits. Of the other shores of the Denver sea, more or less distant, it can only be assumed that they were low, were themselves formed of sedimentary rocks, covered to some extent by vegetation, and that they were incapable, under any conditions that can be considered probable, of furnishing rock materials which could have more than a local influence upon the deposits in the sea. Hence in some subsequent paragraphs the western land area is for the time being treated as the only source for the coarser materials, at least, which it is necessary to consider.

The materials may be classed as the débris of Archean, of sedimentary, and of eruptive rocks, and they will be taken up in this order.

ARCHEAN DÉBRIS.

The sands, pebbles, and bowlders derived directly from Archean sources, which are found in the Denver formation, are similar in kind to those of the underlying Arapahoe strata, and came undoubtedly from the land areas to the westward. But such materials are practically limited to the upper part of the series, and when they appear the large size of the bowlders and the marked angular form of the sand grains in the cementing matrix become characteristic features.

SEDIMENTARY ROCKS.

Mingled with the Archean débris of the upper portions of the formation are small pebbles of distinctly recognizable sandstones and limestones, directly comparable to the material of beds which may be seen in the adjacent upturned sections of Mesozoic strata. In company with these are many pebbles or bowlders of a conglomerate, quickly and surely recognizable as derived from a certain layer at the base of the Dakota Cretaceous. All of these types are also found less abundantly in the conglomerate layers of the Arapahoe formation. It has been shown during the discussion of the preceding formations, that the western shore-line of each of them must be considered as having been near the base of the present foothills. Hence when débris from the Dakota or Jura is found in either the Arapahoe or Denver conglomerates, it must be assumed that the included fragments came from adjacent exposures of the already somewhat folded strata of Mesozoic age. We do not know of any other source of such materials, and do not need to seek any.

In the Denver strata of the plains a subordinate amount of quartz and feldspar originally derived from Archean sources is a feature of horizons which consist purely of eruptive materials in Table or Green mountains. This admixture is very largely derived from the soft, friable beds of the Arapahoe, which certainly formed the greater portion of the northern and southern shores of the Denver sea. The observed facts sustaining this view have been given in detail in a previous section of this chapter.

The conclusions reached in the preceding sections make it necessary to consider what materials might have been derived from the eastern shores, which were certainly made up of Laramie strata in great part. Probably the Laramie rocks exposed were mainly clays or shales, but it would be a difficult matter to prove that similar beds of the Denver series were made up in any great degree of Laramie débris, yet such is perhaps the case for some horizons. In the Denver series are strata scarcely distinguishable from Laramie shales, and though microscopical examination will usually reveal finely comminuted remains of eruptive rocks in these beds, yet the greater part of the substance can simply be denominated clay, of an origin so remote that it can not be determined.

ERUPTIVE DÉBRIS.

The feature which has been emphasized as preeminently characteristic of the Denver formation is its composition in so great part of eruptive rocks. These will be fully described in the petrographical chapter. They are there designated, almost without exception, as andesites, though of nearly every variety recognized within this family. The list includes mica, hornblende, augite, and hypersthene rocks, and there is besides a great range in silica and in the alkalies. It is quite possible that basaltic types may be present in some of the finer-grained layers of the formation, but they have not yet been observed.

Within the formation the eruptive materials range from bottom to top. The lower half is almost wholly composed of them, and the line between the Denver and Arapahoe deposits must be drawn, when the unconformity is not plain, at the point where the eruptive material appears in the otherwise very similar sediments. While eruptive pebbles and bowlders are abundantly mingled with Archean and sedimentary rocks in the upper horizons, a change in the variety of andesite here represented can be pointed out.

With regard to the origin of the eruptive materials it must be stated at the outset that *no known source can be assigned with any degree of plausibility for any one of the many types represented in these strata.* No andesite masses are known in all the wide Archean area to the westward, as far as the continental divide, though it is explicitly admitted that they may exist in local development. Their presence, should they ever be found, would only confirm the conclusions reached without knowledge of them.

The Arapahoe strata contain no eruptive rocks. Above the clays of the Arapahoe come beds deposited under similar conditions of sedimentation, but which exhibit a complete change in composition. Both of these fresh-water formations must have been of comparatively limited extent, and all the evidence tends to show that the Denver sea was even more circumscribed than that of the earlier epoch. The source of the materials in the Denver strata must then be sought for comparatively near at hand. The fact that very little Archean or sedimentary débris occurs in the lower 900 feet of the formation adjacent to the foothills not only supports this general conclusion, that the source of the andesites must have been near at hand, but practically determines the further forms of the solution to be offered. *The andesitic masses which furnished the materials for the lower part of the Denver sediments were so situated as to effectually prevent the access of all Archean and sedimentary débris to the sea of that epoch.* That is to say, the Archean and sedimentary rocks in the mountainous area drained by the tributaries of the Denver sea must have been covered by andesitic lava flows, so that no material other than the eruptive débris could appear in the Denver sediments, from this, the prominent source, until erosion had laid bare, here and there, small areas of granite, of gneiss, or of sandstone. The assumption of such a period of eruption for which there are no further known proofs than the existence of these sediments, may seem at first thought somewhat hazardous, but a careful consideration of the facts will show that no less sweeping statement can satisfactorily meet the requirements of the case.

In considering this question a factor of the utmost importance appears in the fineness of the earlier sediments of the Denver formation. For 900 feet the beds are sands, conglomerates, or sandy clays, in which few pebbles appear exceeding 3 inches in diameter. A study of the finer sands and clays shows that they are largely made up of grains which are simply remnants of pebbles and bowlders of massive andesites, of the types shown in a few layers by distinct pebbles. Some layers are doubtless composed of angular grains that may be ashes, or the débris of rapidly cooled lavas plunged into water; but it becomes more and more evident, through intimate acquaintance with these peculiar strata, that the 900 feet of beds represent a manifold greater mass of lava which has been destroyed in furnishing this material. How great these masses were it is useless to discuss beyond the plain conclusion that they must have been fully sufficient to conceal for a long period the Archean and sedimentary rocks adjacent to the Denver sea. Had the quartzose granites, gneisses, and other hard rocks of the continental area been exposed during the earlier stages of sedimentation they would certainly have been represented at least by quartz sand in the sandy or conglomeritic layers, and especially in the deposits nearest the shore-line. The gradual appearance of Archean materials and of the older sedimentary rocks upward in the Denver beds of Green Mountain also points clearly to a return to the conditions prevailing in the Arapahoe epoch.

Since the first description of the Denver beds, at which time the covering of the Archean rocks by vast floods of andesite was advocated, there have been several discoveries that seem to confirm the theory under discussion in a striking manner. The one with most direct bearing upon the case is the ascertaining that in Middle Park, almost directly opposite the Denver Basin, at the western base of the Colorado Range, there exists a sedimentary formation, resting unconformably upon the Cretaceous, which is directly comparable with the Denver formation in lithologic character and in its fossil plants. This formation was represented upon the Hayden maps as "doleritic breccia" in its lower part, where it consists of andesitic breccia, conglomerate, and sandstone, and as "Lignitic" (Laramie) in the upper part, where Archean débris gradually comes to predominance. This series of beds exceeds 2,000 feet in thickness.[1] This

[1] "The post-Laramie deposits of Middle Park, Colorado," by Whitman Cross: Proc. Colo. Sci. Soc., Vol. III, 1891.

formation proves the great extension of andesitic lavas on the western slope of the Colorado Range at the time assumed for the lava floods on the eastern side, and makes the assumption as to their magnitude far less venturesome than if it were unsupported.

The other discoveries which support the views advanced as to the great andesitic eruptions adjacent to the Denver sea are the identification of probably contemporaneous lake deposits, also composed of andesitic débris in great degree, in South Park, near Canyon, on the Animas River below Durango, and in the Elk Mountains, all in Colorado. These formations, which will be referred to more in detail in discussing the age of the Arapahoe and Denver formations, testify to very extensive contemporaneous andesite outbursts in various parts of Colorado, and make the conclusions reached for the Denver area seem quite probable.

In his most valuable presidential address before the Colorado Scientific Society, "Structural and Orographic Features of Rocky Mountain Geology," Mr. R. C. Hills[1] has argued that the andesitic materials of the Denver beds may more plausibly be derived from the known andesitic eruptions of South Park, through the drainage of the South Platte River, than from lava masses adjacent to the Denver sea. This hypothesis seems to the writer entirely untenable in view of the fact that the lower sediments of the Denver sea were accumulated very slowly, as shown by the character of the fine-grained clays, sands, and gravels of the section at the northeast extremity of South Table Mountain. These sediments must have contained a large proportion of material from the adjoining Archean continent had those materials been exposed during their deposition. Furthermore, the study of the Pikes Peak district[2] has made it appear probable that during the Denver epoch the drainage of South Park was to the southeast, into the Canyon bay, and that the Eocene volcanic accumulations to the south of the park diverted the chief drainage channel of the park into the present course of the South Platte River.

In connection with the theory of vast lava floods of andesite covering the slope of the continental area adjoining the Denver sea on the west, it

[1] Proc. Colo. Sci. Soc., Vol. III, Part III, 1891, pp. 359–458.

[2] Geologic Atlas of the United States, folio 7, Pikes Peak, U. S. Geol. Surv., 1894. Geology by Whitman Cross.

is to be mentioned that in the neighborhood of Idaho Springs, Georgetown, Empire, Central City, and other points on the eastern slope of the mountains, there are numerous dikes and massive bodies of igneous rocks which, while of granular or porphyritic structure, and usually coarsely crystalline, are in chemical and mineralogical composition very similar to some types of the andesites found in the Denver beds. They exhibit the characteristics of intrusive or deep-seated eruptives, which cooled far from the surface, and none of them, so far as known, can be thought of as a surface flow.

The rocks of these bodies were first known to the writer from their appearance in the bowlder beds of Clear Creek; subsequently through a few specimens kindly furnished by Mr. J. S. Randall, of Georgetown, and, finally, through personal visits to the localities mentioned. The rocks of the Clear Creek bowlder beds do not come from the foothills, for no such rocks are known in them, and Bear Creek, Ralston Creek, and other streams whose sources are in the foothills, do not show such rocks in the material which they bring down. The direct equivalents of many of them occur as dikes and stocks near Georgetown and Empire.

It is entirely in accord with the views of the writer to suppose that the diorites and diorite-porphyries of these dikes and irregular intrusive masses are the deep-seated equivalents of the surface flows represented as andesites in the Denver conglomerates. It is also true that the great outpouring of various lavas which must be assumed according to the foregoing considerations, necessitates an assumption that the channels through which the molten magma ascended still exist somewhere. But there is as yet no positive evidence connecting the dikes and irregular masses referred to with the surface flows assumed. The establishment of such a connection will carry with it a complete confirmation of the opinions which have been expressed as to the geological importance of the lithological characteristics of the Denver beds. Hence, while the possibility of this connection must not be overlooked in judging the opinions which have been expressed, no attempt will be made to elaborate this theoretical defense of the deductions which the facts are believed to warrant.

The western land masses adjacent to the Denver sea have alone been directly considered in the foregoing remarks. The only sections of any considerable thickness now exposed are those of Green or Table mountains, situated on the western shore-line. From the exposures on the plains we learn that while other shores did contribute noneruptive materials during the earlier part of the Denver epoch, the eruptive débris from the western area was at all times strongly predominant, and nothing appears, on extending the view, to invalidate the conclusions reached. At points on Coal Creek farthest removed from the western shore-line, and on Cherry Creek, near the Arapahoe beds of the southern shore, are strata consisting exclusively of eruptive materials, and a strong admixture of Archean débris is surely accompanied by evidences of its secondary and local source in the Arapahoe grits. While the influx of eruptive materials was always strong enough in these earlier periods to make itself everywhere predominant, it is not found that the sand washed in at times from the northern and southern Arapahoe shores ever became noticeable in contemporaneous deposits of Green or Table mountains.

SECTION III.—AGE OF THE ARAPAHOE AND DENVER FORMATIONS.

By Whitman Cross.

STATEMENT OF THE QUESTION.

Former classification of the formations.—Until the discoveries which are described in preceding chapters were made the strata of the Arapahoe and Denver formations had been uniformly assigned by geologists to the Laramie, under the accepted definition of the latter as the uppermost division of the conformable Cretaceous series; and not only had they been assigned to the Laramie, but no characteristics of any kind had been mentioned, or apparently observed, by which these upper beds might be even locally distinguished from the lower, coal-bearing horizon. This correlation was based on the presence of the true Laramie below the beds in question, on the failure to notice their peculiar and distinguishing characteristics, and on assumptions regarding the unity of the fossil flora, whose species were, however, collected from widely separated horizons in the Golden section.

The assignment to the Tertiary.—In the earliest descriptions of these formations by Mr. Eldridge and the writer they were assigned to the Tertiary.

The reason for this assignment was the discovery that between the Laramie and Arapahoe epochs there had occurred an orographic disturbance whose magnitude was measured, for this locality, by the presence in the Arapahoe strata of pebbles of highly indurated clastic rocks, sandstones, conglomerates, etc., clearly belonging to various geological horizons as far down as the Trias, representing erosion of 14,000 feet of strata, according to the section of the formations in question in the Denver region. The lithological character of the Denver beds showed that the interval of unknown duration between the Arapahoe and Denver epochs had witnessed the occurrence of volcanic eruptions on a gigantic scale, and also subsequent local erosion.

Up to the time when these formations were thus identified, great orographic movements in the Rocky Mountains had been commonly supposed to mark the ending of Mesozoic time, and to be in great measure the cause of the wonderful changes that took place at this period, especially in vertebrate life, as shown by the remains in the earliest known Eocene deposits. The beginning of Tertiary time was also known to be widely characterized by great volcanic outbreaks, recorded in the sediments of the Green River, Florissant, and other Eocene basins. Hence it seemed natural to place the Arapahoe and Denver beds in the Tertiary, as, perhaps, the earliest lake deposits of Cenozoic time. Examination of the paleontologic evidence available at the time showed either that it did not controvert the assignment, or, as in the case of the fossil plants, was entirely untrustworthy because the floras of the distinct horizons involved could not then be compared.

The recent discoveries of fossil vertebrate remains are said by paleontologists to show that the life of the epochs under discussion was much more nearly allied to Mesozoic than to Cenozoic types, and in deference to this opinion the post-Laramie formations are classed in this report with the Cretaceous. But such a course raises at once the question as to the nature and position of the boundary between Mesozoic and Cenozoic time in the Rocky Mountains, and broadens very materially the treatment which must be given to the problem.

Discoveries of allied formations.—Within the past few years a number of local formations have been discovered in Colorado and Montana which are more or less clearly equivalents of either the Arapahoe or the Denver beds. Few of them have been examined as yet in any detail, but all furnish valuable evidence bearing upon the question under discussion in this chapter, and this evidence shows that the stratigraphic and lithologic facts observed in the Denver Basin can not be lightly regarded as of purely local importance. On the contrary, these formations are so widely distributed and agree so perfectly in the trend of the evidence they afford that the consideration as to the age of the formations of the Denver area plainly involves a logical and consistent treatment of a most important period of Rocky Mountain history. The question as to the weight to be given the stratigraphic and lithologic facts of the Denver area broadens at once to a discussion of the dynamic history of the interval between Mesozoic and Cenozoic time, or of the transition from one to the other.

Questions of paleontology.—Since the identification of the Arapahoe and Denver formations there have been many important discoveries of fossil remains in the Laramie or in the younger group of local formations to which the Denver and Arapahoe belong. The most remarkable of these fossils are vertebrates, and in another chapter Professor Marsh briefly outlines the character of those most directly connected with the formations of the Denver Basin. The interpretation of this new evidence in its bearing upon the subject of this chapter necessitates the discussion of our present knowledge concerning the occurrence and distribution of these fossils, and also of the relation of paleontologic to other kinds of evidence, for there is not perfect harmony in the conclusions drawn from weighing the various kinds of evidence.

The fossil floras of the Laramie and post-Laramie formations have been recently revised by Mr. Knowlton, and a concise summary of his results will be found in a later chapter. The conclusions drawn from this revision illustrate the self-evident fact, too often disregarded, that the occurrence and distribution of fossils must first be ascertained and accurately recorded before they become of value in the classification of allied and associated formations.

In applying the data of paleontology to the present question it is necessary to review both present knowledge of the fossils and the general relation of such evidence to the problems of stratigraphical and historical geology.

Phases of the problem.—The discussion of the age of the Arapahoe and Denver formations is thus seen to involve many points of interest which may be summarily stated as follows:

1. Age of the two local formations.

2. Age of numerous allied formations.

3. Relations of, and weight to be assigned to, various classes of evidence.

4. Condition of knowledge of the faunas and floras of the formations in question.

5. History of the period between Mesozoic and Cenozoic times in the Rocky Mountains.

6. Designation of the boundary between these great divisions in the Rocky Mountains.

7. Relation between physical changes and faunal modifications in the general period involved.

8. Relations between the chronological systems necessary to express the history of physical changes in the earth, and of the development of life upon it, i. e., the desirability of a dual nomenclature.

It would be manifestly out of place to discuss all these broad questions in detail in a volume of essentially local character, and such a discussion is in this instance at present impossible, because of imperfect knowledge in many directions, but it will be the aim in the following pages to present the evidence in the special case in such a way as to indicate or suggest its value in respect to some of the broader problems which naturally develop from the one of local importance.

EVIDENCE OF LITHOLOGIC CONSTITUTION.

Conglomerates of the Arapahoe beds.—The conglomerates of the Arapahoe contain evidence of events in the long interval that separated their deposition from that of the sandstones and clays of the Laramie—events which can not be disregarded in spite of the apparent conformability of the two formations as now exposed in many places. Mr. Eldridge has described the various materials identified by him in the beds, but a brief recapitulation of the facts may not be out of place.

Aside from the débris of granite and gneiss, which must be expected in coarse sediments adjacent to a continent largely made up of those rocks, the Arapahoe conglomerate contains pebbles from various Mesozoic formations. Pieces of coal and friable sandstone were found in a few places. These may be considered as derived from the Laramie, which also seems the probable source for pebbles of fossil wood. Clay ironstone and certain dense earthy limestones are most plausibly from the Colorado and Montana Cretaceous, while hard, almost quartzitic, white sandstones may be referred to the Dakota. That the latter contributed to the Arapahoe sediments is most conclusively established by the pebbles of the very characteristic fine-grained conglomerate at its base. Red sandstone and certain limestone pebbles of the Arapahoe are probably derived from Jurassic strata, as they are not known to occur in any higher horizons. There are also present pebbles apparently of the Triassic sandstones and of cherty masses containing Carboniferous Beaumontia.

In distinction from the Denver beds the Arapahoe strata contain no pebbles of volcanic rocks, and by their constituents above mentioned they are markedly different from any other horizon below them in the foothill section. This lithologic character is evidence of important stratigraphic relations to be further considered in a succeeding section.

Volcanic materials of the Denver beds.—The sharp distinction to be drawn between the lithologic characters of the Denver and earlier sediments has been fully described and emphasized. While the volcanic types represented in the pebbles of the Denver beds all belong to the andesites, as far as observed, it is to be pointed out that the variety within that very large group is great, and indicates a source of supply which must have been long in accumulation. Whether from a single great volcano or from several different centers these various andesite lavas may safely be considered as the products of a very long period of volcanic activity which did not begin until after the close of the Arapahoe epoch. The basaltic magmas of the Denver epoch, preserved in Table Mountain, may belong to the close of this cycle of eruptions.

It will scarcely be questioned by anyone that the Denver epoch deserves to be recognized in any adequate chronology of geologic events in this region, but the full importance of the time in which these volcanic outbursts took place appears only after considering the facts presented by other deposits allied to those of the Denver sea. The great extent of the volcanic products, which must be assumed from the practical exclusion of other material from the Denver sediments, has been dwelt upon, and any claim that this feature is only of local importance is further answered in the deposits of other contemporaneous seas.

Texture of the Denver strata.—The fine grain of the Denver clays, tuffs, sandstones, and most of the conglomerates shows that they were accumulated very slowly and that the epoch of sedimentation was of no mean importance. The strata of very fine grain, such as the clays, tuffs, and sandstones, which may be compared in this respect with the beds of the Laramie, exceed the latter in thickness, and indicate that the Laramie and Denver epochs of sedimentation may have been of nearly equal duration. The Arapahoe strata are likewise of very fine grain, and in neither case can it be assumed that these deposits were much more rapidly accumulated than those of the Laramie.

Conclusions from lithologic evidence.—The pebbles of the Arapahoe formation show that in the interval between Laramie and Arapahoe deposition an orographic movement took place in this vicinity, so great that all the formations of the Cretaceous, and some still older ones, were elevated to form land masses adjacent to the Arapahoe sea or lake. As the Arapahoe conglomerate does not present a record of progressive erosion of these thousands of feet of Mesozoic beds it must be inferred that a long period of degradation not represented in known sediments preceded the Arapahoe and prepared the land surface which contributed from many horizons of older strata to the early conglomerates of this formation.

The Denver strata are most clearly characterized in their lithologic constitution and bear witness to important events in the preceding interval. The volcanic phenomena of this epoch, while affording criteria for distinguishing it from the preceding, do not bear upon the question of geologic age so strongly as the facts of the Arapahoe.

The strata of the Arapahoe and Denver have a total thickness much greater than that of the Laramie, and by their texture speak for epochs of sedimentation presumably equal in duration to that of the Laramie.

EVIDENCE OF STRATIGRAPHIC RELATIONS.

Stratigraphic break between Laramie and Arapahoe.—Erosion of the upper limb of the monoclinal foothill fold has destroyed the zone where the Arapahoe beds must have originally overlapped the Laramie and some older deposits with angular unconformity, unless it be that the Arapahoe basin was entirely excavated out of Laramie strata. Minor unconformity of this latter kind is shown in the plains area, as described by Mr. Eldridge.

The evidence of the lithologic character of the Arapahoe beds has been given, and the following deductions from that evidence seem unavoidable. Somewhere tributary to the Arapahoe sea many thousand feet of the Mesozoic strata were upturned and had already been greatly eroded prior to the new epoch of sedimentation, so that widely separated horizons contributed simultaneously to the basal conglomerate of the Arapahoe. It is most natural to assume that the present foothill fold, which is known to mark the line of progressive or repeated movement, elevated the western shore-line deposits of the older formations, and that the erosion of this western area produced the various pebbles of the Arapahoe. But the position of the land mass of these eroded Mesozoic sediments is of secondary importance compared with the facts of a great orographic movement which terminated the long succession of conformable Cretaceous sediments at the close of the Laramie. As the Arapahoe deposit seems to have been local in character, it was at first possible to assert that this orographic movement was not of importance in the broad area of the Rocky Mountains. But the facts of the Middle Park and Livingston beds, and the inferences present knowledge justifies in other described localities, all tend to show that this stratigraphic break was extensive, and recent discoveries have uniformly increased its importance.

Relation between Denver and Arapahoe beds.—As far as known the Denver lake basin was eroded out of the Arapahoe strata, and to the northeast of Denver it would seem that the preceding formation was entirely destroyed, allowing the Denver to rest on the Laramie. There is no known reason for the assumption that the Denver beds overlapped the Arapahoe on the west, but it is plain from the fact that red and white sandstone and the Dakota conglomerate are prominent among the first noneruptive materials to appear in Denver sediments, that the western shore of the Denver sea consisted in part of the same stratified rocks that contributed to the Arapahoe, which had been long concealed with granite and gneiss beneath the volcanic flood.

Suggestions from other facts.—While the equivalent of the Arapahoe has not been identified in the sections on the Animas River, on the Grand River, or in Montana, where direct equivalents of the Denver beds lie between the Laramie and the lowest recognized Eocene, it is a noteworthy fact that the Laramie is not especially thick in these places. In other words, it does not appear that the Laramie epoch of deposition continued in these localities during the long time represented by the Arapahoe and the preceding interval of elevation and erosion. As far as inference may be drawn from this fact, it is to the effect that the pre-Arapahoe uplift terminated Laramie deposition throughout the mountain district of Colorado, and at least locally in Montana. Subsequent deposition would at present seem to have been more local during the Arapahoe than in the Denver epoch, in Colorado at least.

EVIDENCE OF ALLIED FORMATIONS.

The formations to be mentioned as allied either to the Arapahoe or Denver occur chiefly in Colorado, on all sides of the mountain area, and in its larger elevated basins or parks. One of the newly differentiated series of strata occurs in Montana, and indications point to the presence of similar formations in the intermediate area of Wyoming.

Valuable information concerning several of these formations has been given by R. C. Hills in a presidential address before the Colorado Scientific Society.[1] The present writer has personally examined several of the deposits, and in 1892 published a general review of what was then known

[1] Orographic and structural features of Rocky Mountain geology: Proc. Colo. Sci. Soc., Vol. III, Part III, 1891, pp. 359–458.

of the various formations in question.[1] Little can at present be added to that summary, which is much more complete in details than that which is to follow.

The Middle Park beds.—Across the Colorado Range from Denver is the elevated basin of Middle Park, containing a great series of strata represented upon the Hayden map of Colorado as Laramie. These beds were of special interest at the time of their discovery by Marvine, in 1873, by reason of the marked angular unconformity with the underlying Cretaceous section, which was taken as confirmatory evidence that the "Lignitic" beds were Eocene. When the Laramie was defined as conformable with the Cretaceous series below, the facts of the Middle Park beds were conveniently regarded as of local importance, a procedure commonly resorted to when new discoveries controvert old ideas.

As Marvine's description[2] of the Middle Park beds showed them to be not only unconformable with the Cretaceous section, but also lithologically similar to the Denver beds, a correlation with the latter was at once suggested, and the region was visited in 1889 by Mr. G. L. Cannon, jr., of Denver, and in 1891 by the writer, both under direction of Mr. Emmons The result of these visits was published in 1892.[3]

The strata in Middle Park designated as Laramie by the Hayden survey extend from a point south of the Grand River northward, forming the high divide between Middle and North Parks, and occupying a large area in the latter region. According to Marvine these strata are 5,500 feet in thickness. And Marvine did not include with them an underlying bedded formation, called by him "doleritic breccia," to which he assigned a maximum thickness of 800 or 900 feet. In the article above cited the writer has reviewed in detail the facts and descriptions of Marvine, and in the following paragraphs will be given the facts concerning these strata as now understood.

The "doleritic breccia" of Marvine is a series of dark tuffs, conglomerates, and breccia beds, made up of a large series of andesitic fragments,

[1] Post-Laramie deposits of Colorado: Am. Jour. Sci., 3d series, Vol. XLIV, 1892, pp. 19–42.

[2] Seventh Ann. Rept. U. S. G. and G. S., for 1873.

[3] The post-Laramie beds of Middle Park, Colo., by Whitman Cross: Proc. Colo. Sci. Soc., Vol. III, 1891.

of types identical with those in the Denver formation. These beds are coarser in texture and are laterally more variable than the Denver strata, but resemble them very much in many details. The sharp line drawn by Marvine between the "breccia" and his "Lignitic" series does not appear justifiable. While Marvine does not refer to volcanic materials in the upper series, there is in fact a gradation between the lower, dark, almost purely andesitic strata and the lighter-colored beds above, in which granitic débris usually predominates, although micaceous and hornblendic andesites are abundant for more than 2,000 feet upward in the series—as far as the writer's observations go.

Plant remains are the only fossils as yet known from the Middle Park strata. These were found by the Hayden survey party in the "Lignitic" series only, but they occur also in the dark tuff layers of the lower beds. A number of the species described by Lesquereux as from Middle Park are now known to have come from the Eocene lake bed at Florissant, Colo. The entire known fossil flora of the Middle Park series has been studied by Mr. Knowlton, and the result will appear in his forthcoming monograph on the Laramie and allied floras. It is sufficient to say here that twenty-five satisfactory species are known from these strata, and that by far the strongest alliance is with the flora of the Denver formations.

Along the Grand River near Hot Sulphur Springs the stratigraphic relations of the Middle Park beds are clearly shown. They here rest upon the upturned and eroded section of the Mesozoic series, from the Jura to the Fox Hills, and overlap the former to the granite. No Laramie is here seen, whether from erosion or nondeposition is not definitely shown, but from the fact that coal-bearing strata are present in North Park it may be inferred that the Laramie once existed in Middle Park, but was entirely removed by the erosion preceding the deposition of the Middle Park beds.

It is not definitely known at present whether the entire thickness of 6,400 feet of strata—taking Marvine's measurement—belongs in fact to one formation, but no reason for doubting this has appeared as yet. For nearly 3,000 feet the series is certainly one, lithologically, stratigraphically, and in its fossil plants.

From the foregoing statements it appears that in Middle and North parks there exists a formation very similar to the Denver beds, which has also been classed with the Laramie. It seems probable that the two formations were laid down almost contemporaneously. If the two series be considered as of the same age, the evidence of the Middle Park beds strongly confirms the deductions made from the Arapahoe and Denver formations concerning geologic events in the epochs immediately succeeding the Laramie.

No strata corresponding to the Arapahoe have yet been found beneath the Middle Park beds, but they may well exist in places not yet carefully examined. The folding and great erosion which preceded the Arapahoe on the eastern side of the mountains are paralleled by the elevation and degradation which succeeded the uppermost member of the conformable Cretaceous series in Middle Park, preparing the surface on which the tuffs and conglomerates rest. The material of the latter was manifestly derived from a great series of volcanic eruptions similar in character and variety to those assumed for the slope adjacent to the Denver sea. Whether the thickness of the Middle Park beds be taken at 3,000 or 6,400 feet, they testify to a long epoch of gradual subsidence contemporaneous with deposition.

Strata near Canyon.—In his cited address Mr. R. C. Hills referred to remnants of a formation resembling the Denver beds that occur south of the Arkansas River in the vicinity of Canyon, Colo. Directed by information personally given by Mr. Hills, Mr. Eldridge examined the district and found apparent equivalents of both Arapahoe and Denver beds. The analogue of the former is a heavy conglomerate, resting upon the Laramie, upturned with it in the foothill section, but exhibiting among its pebbles fragments recognized by Mr. Eldridge as derived from the Niobrara and Dakota Cretaceous and from the Jura. These tell the same story of uplifting and erosion which is contained in the Arapahoe conglomerate.

The formation resembling the Denver beds is made up of a variety of andesitic rocks and is lithologically almost identical with the formation named.

No fossils have been found in either of these formations, but their occurrence is noteworthy in connection with others. If they belong to the post-Laramie group they testify to the extent of the orographic disturbances and volcanic eruptions of the time immediately succeeding the Laramie.

Formations of the Huerfano Basin.—On the eastern side of the mountains, in Huerfano Basin, Mr. R. C. Hills has found and described[1] a series of strata which he subdivided as follows:

Huerfano series....	Huerfano beds, 3,300 feet = Bridger group.	
	Cuchara beds, 300 feet.	Lower Eocene.
	Poison Canyon beds, 3,500 feet.	

Great angular unconformity exists between the Laramie and the Poison Canyon beds, but none has been detected between the several members of the new series. The Huerfano beds are assigned to the Bridger Eocene from the presence of Tillotherium, Hyrochyus, Glyptosaurus, Palæosyops, and other vertebrates. The Cuchara and Poison Canyon beds are separated on lithological grounds, and no fossils have been found in them. The former formation consists of "pink and white massive sandstones;" the latter of "soft sandstones and fine conglomerates of a yellowish tinge, with occasional bands of yellow clay or marl." It is believed by Mr. Hills that the Cuchara and Poison Canyon beds are probably contemporaneous with some of the other post-Laramie formations here referred to.

The Animas River beds.—In the article already cited on the post-Laramie deposits of Colorado, the writer referred to a series of strata occurring on the Animas River below Durango, which had been visited by Mr. T. W. Stanton and found to be very similar to the Denver beds. In the summer of 1894 the writer was able to hurriedly examine this series of beds as exposed on the railroad below Durango, and found them to resemble the typical Denver beds in a very high degree. These strata occur above the Laramie and below the Puerco, and, as far as the present meager observations show, are conformable with both of them where now preserved. The beds are some 700 feet or more in thickness, and are composed of yellowish-brown clays, tuffs, sandstones, and conglomerates, in which andesitic material greatly predominates, and present a variety rivaling that in the Denver beds.

[1] The recently discovered Tertiary beds of the Huerfano River Basin, Colorado: Proc. Colo. Sci. Soc., Vol. III, 1888, p. 148.

Additional notes on the Huerfano beds: ibid., Vol. III, 1889, p. 217.

Remarks on the classification of the Huerfano Eocene: ibid., Vol. IV.

A few fossil plants occur, but those found thus far are poorly preserved, and the only identifiable species collected is *Magnolia tenuinervis* Lx., a common Denver bed species originally described from Table Mountain. No invertebrate fossils have been found as yet, but it seems probable that a number of vertebrate species, described by Cope as from the Laramie of the Animas River section, came out of the strata which so closely resemble the Denver formation.

In an article discussing the relations of the Puerco and Laramie deposits[1] Professor Cope refers to the succession of beds on the Animas River, saying: "According to the observations of Mr. David Baldwin the Laramie beds succeed [the Puerco] downward, conformably it is thought by Mr. Baldwin; and have a thickness of 2,000 feet at Animas City, New Mexico [Colorado?]. A few fossils sent from time to time by Mr. Baldwin identify the Laramie. This is especially done by the teeth of the dinosaurian genus Dysganus Cope, which is restricted to the Laramie formation elsewhere. Also by the presence of the genera Lælaps and Diclonius, which in like manner do not extend upward into the Puerco beds."

According to the statement of Professor Cope, made personally to the writer and quoted with his permission, these fossils were collected incidentally to the investigation of the Puerco fauna and for the purpose of identifying the underlying formation. He believes it most probable that they came from what are here called the Animas beds, which extend for several hundred feet below the Puerco. Professor Cope now regards the Dysganus and Diclonius as closely allied to the horned dinosaurs (Ceratopsidæ Marsh, Agathaumidæ Cope), which, as will be shown, form the most characteristic element of the vertebrate fauna known in the Arapahoe and Denver beds.

The Animas beds, as this post-Laramie formation may be called, are to be regarded as a most direct equivalent of the Denver beds, identical in peculiar lithologic character, lying between typical Laramie and Puerco, and containing fossils which, so far as known, indicate a similar fauna and flora. This occurrence on the border of Colorado and New Mexico, and south of the San Juan Mountains, is evidence of the great importance

[1] Am. Naturalist, Vol. XIX, 1885, p. 985.

of the long-continued volcanic outbursts which the formations thus far mentioned show to have occurred at about the same time in widely separated districts.

The Ohio Creek and Ruby formations.—In the area covered by the Anthracite sheet[1] in the West Elk Mountains, Colorado, occur two formations which are analogous to the Arapahoe and Denver beds. One of these, the Ohio Creek formation, is known only in two small isolated remnants, resting on an eroded surface of the Laramie. The strata are loose, friable sandstones, grits, and fine conglomerates, and contain unidentifiable plant remains. The conglomerates contain many chert pebbles carrying crinoid stems and other apparently Carboniferous fossils. From this fact it is argued by Mr. R. C. Hills, who personally investigated both the formations in question, that between the Laramie and Ohio Creek epochs there was great erosion, cutting through the entire Cretaceous section, at least.

In the Ruby Range of the Anthracite sheet is a formation 2,000 feet in thickness, resting with apparent conformity on the Laramie, but consisting almost entirely of andesitic débris, forming tuffs, sandstones, conglomerates, etc., of purplish color, and much indurated in this locality through numerous dikes of igneous rock. The "Ruby formation," as it has been called, has been traced by Mr. R. C. Hills continuously for more than 80 miles to the northward, beyond Grand River, where it decreases in thickness to 300 feet. At this point the formation is overlain by the Wasatch Eocene and underlain by "200 feet of soft, white sandstones and yellow clay," below which are the firm, gray sandstones of the Laramie. Mr. Hills suggests a correlation between the soft sandstones and the Ohio Creek beds. No fossils are known in either of the new formations aside from carbonized plant stems.

It thus appears that in the region between the Gunnison and the Grand rivers there is an extensive formation, consisting, like the Denver beds, of fine andesitic débris, and occupying a position between the Wasatch and the Laramie. The Ohio Creek beds are less distinctly an equivalent of the Arapahoe, the principal evidence in this direction being that while these strata are not definitely known beneath the Ruby series the basal

[1] Geologic Atlas of the United States, Anthracite-Crested Butte folio, No. 12, 1895.

conglomerate of the latter usually contains chert pebbles with crinoid stems, which may very probably have come from the erosion of the Ohio Creek beds in the vicinity. The latter formation is certainly preserved only in small remnants.

Northwestern Colorado.—The Ruby beds do not seem to be present in the northwestern part of Colorado, where the Laramie coal measures are well developed. But in his often-cited address Mr. Hills states his opinion that the upper portion of what has been called Laramie, on the Yampa River and elsewhere, will finally prove to be a distinct formation, and in that case analogous with the Arapahoe and identical with the soft, yellowish sandstones occurring on the Grand River between the Ruby beds and the Laramie. The only evidence adduced by Mr. Hills in favor of this view is the fact that the lower part of the questionable series of strata consists of normal Laramie beds, firm, even-grained sandstones, clays, and coal seams of excellent quality. Such normal beds are present on the Yampa in a thickness equal to their usual development elsewhere in Colorado. Above them occurs a series of "soft sandy strata with some shales and clays," containing beds of impure lignite, and of general different physical appearance from the underlying unquestionable Laramie. The Wasatch Eocene overlies this section.

This opinion, although unsupported by definite evidence, is worthy of much consideration, coming, as it does, from the geologist who is far more familiar with the Laramie and its associated formations in Colorado, Wyoming, and adjacent territory, than anyone else.

The Livingston formation, Montana.—The recent investigations of Mr. W. H. Weed and Dr. A. C. Peale in the district covered by the Livingston and Three Forks atlas sheets show that a formation directly analogous with the Denver occurs in Montana.[1]

The Livingston formation, as it has been called by Mr. Weed, occurs in typical development in the Bozeman coal field, where it overlies the Laramie. It had been classed with the latter previous to the investigations

[1] Geologic Atlas of the United States, Folio 1, Livingston sheet, 1894; Folio 20, Three Forks sheet, by A. C. Peale, 1895. The Laramie and the overlying Livingston formation in Montana, by W. H. Weed and F. H. Knowlton: Bull. U. S. Geol. Survey No. 105, 1893.

of Mr. Weed, largely owing to the same error which was committed in the Denver field, namely, of grouping together as one flora the plants from the coal horizon in the Laramie and those from a somewhat higher horizon in what now prove to be Livingston strata. As the "Laramie flora" of 1877, when these plants were determined by Lesquereux, consisted very largely of the Denver plants from Table Mountain, it is natural that the fossil plants of the two horizons in the Bozeman field should have seemed to belong together.

The Livingston formation is about 7,000 feet in thickness and is overlain by the Fort Union beds. Its lithologic character is almost identical with that of the Denver beds, the sandstones, conglomerates, and tuffs consisting chiefly of andesitic débris of great variety. In consequence the strata are dark-brown or yellowish-brown in color, and contrast distinctly with the quartzose sandstones of the Laramie with which they had been previously classed.

Mr. Weed and Mr. Peale both found the Livingston beds transgressing the upturned edges of the underlying Mesozoic, although in less marked degree than is the case for the Middle Park beds of Colorado.

The fossil floras of the Bozeman coal beds and of the Livingston beds have been carefully revised by Mr. Knowlton, with the result that a marked difference appears between them. The Livingston flora contains 29 species, of which 22 have a known distribution in other places; 12 of them occur in the Denver flora, 6 in the underlying Bozeman coal horizon, or in other undoubted Laramie beds, and 4 in the Fort Union. This shows a strong affinity with the Denver and a less marked alliance with the Laramie and Fort Union floras.

No vertebrate fossils have as yet been discovered in the Livingston beds, but two horizons within the division called the "leaf beds" by Mr. Weed have yielded invertebrates. At one of these horizons a few fresh-water forms, including *Goniobasis tenuicarinata*, were found, all having a resemblance to species known in the Fort Union beds. The species named occur also in the Denver beds. The other invertebrate fauna consists of brackish-water forms, viz: *Ostrea subtrigonalis*, *Corbicula cytheriformis*, *Corbula subtrigonalis*, and *C. subtrigonalis* var. *perundata*. These forms occur below that at which the fresh-water mollusks were found. In describing the Judith River beds it is stated that Messrs. Weed and Stanton have found these same brackish-water species on Judith River, above fresh-water fauna. This fact shows, then, that these brackish-water forms occur above the stratigraphic break at the base of the Livingston, and hence they are not competent to decide whether strata containing them are Laramie or post-Laramie, the main question under discussion in this section.

EVIDENCE OF FOSSIL PLANTS.

Historical statement.—The typical Denver beds of Table Mountain contain one of the largest and most fully described fossil floras known in this country. Nevertheless, until quite recently, this flora has been of little value in discussing the age of the formation containing it, or even the question as to the separation of the Denver and Laramie. In 1889, while describing the "Denver Tertiary formation," the writer gave facts showing that while the fossil plants collected at Golden formed a large part of the so-called "Laramie flora," it was impossible to ascertain from the published descriptions, from the labels accompanying specimens in the National Museum, from catalogues, or other published sources, whether the larger part of the species described come from the Laramie coal measures or from the Denver beds. It was then evident that until a very thorough revision of both old and new material, from the Laramie and Denver alike, had been completed, no safe conclusions could be drawn from the fossil floras upon the question of distinguishing the two formations.

This revision has now been nearly completed, as appears in the section by Mr. Knowlton, in Chapter VII, and it is unnecessary to repeat much of the detail showing how the published data concerning the Laramie and Denver floras became so lamentably inaccurate. But this history of the fossil plants is so applicable in its moral to the present condition of other fossil evidence that the leading facts will be given.

More than 160 species of fossil plants from the vicinity of Golden were described by the late Leo Lesquereux, and assigned to the "Laramie flora." These plants were collected during several years, by many persons, chiefly by Prof. Arthur Lakes, of Golden, and Professor Lesquereux himself, and by various members of the Hayden survey. Although it is expressly stated by the geologists in their reports, and by Lesquereux in his monographs, that several widely separated plant horizons existed, as, for example, the vertical coal beds and the horizontal strata of Table Mountain, the published descriptions in many cases do not specify locality further than as "Golden, Colo." Nor do the original labels or catalogues contain more.

Thus at the time the Denver beds were first described the published fossil flora of Golden consisted of over 100 species. In his monograph "Cretaceous and Tertiary Floras" (1883) Lesquereux specifies the coal measures of the Laramie as the "habitat" of but 3 species and only 13 are referred to Table Mountain. By searching the original descriptions and noting incidental references in the various reports it may be ascertained that 9 species came from the coal measures and 16 from Table Mountain. Of the remaining 75 per cent of the Golden flora, as known in 1888, the writer has been unable to find published or otherwise recorded evidence of the horizons from which they were obtained.

In 1888 Lesquereux added 68 species to the flora of Golden, without specifying the horizon of a single one of them. In 1886 Prof. L. F. Ward published his synopsis of the Laramie Flora and in his table of distribution included all the species of Lesquereux from Golden, most of which were from unknown horizons. At various times in the course of the investigation of the Denver beds, fossil plants were sent to Profs. L. F. Ward and J. S. Newberry, with the request that if possible they should discriminate between Denver and Laramie floras. In every case the reply was that no difference could be seen. The evident explanation of this inability to distinguish the two floras was that what was by them considered the "Laramie flora" embraced also all known Denver plants, and the data did not exist in the published record by which the species from the two formations could be separated for comparison.

From examination of the published data concerning the Middle Park, Bozeman, and other local floras, especially those of Wyoming localities, it appears that an entire revision of the earlier publications is necessary before a correct list of Laramie plants can be compared with that of post-Laramie species.

The explanation of all this early laxity in the records concerning the localities and geologic horizons from which so many fossil plants were obtained is apparently twofold. No doubt the prime cause of the trouble is to be found in the conditions of the reconnaissance work during which the early collections were made. A flood of new material from various collectors, in many different localities, was poured upon the paleobotanist each year, and he was expected to determine the species and correlate the formations at once. The recording of locality and horizon, even when known, was to a great extent impossible without the aid of a large clerical force. But it is also clear that the necessity of such a record was not duly appreciated either by geologist or paleontologist. Both placed a value upon fossils, a large proportion of which were new to science, which could legitimately be given to them only by a series of accurate observations, accurately recorded.

Present knowledge of the fossil plants.—In Chapter VII Mr. Knowlton states the extent of the revision of the Laramie and allied floras which has been attempted, and gives in summary form the result for the formations of the Denver Basin. Owing to the vast amount of material to be examined and the necessity for new collections and observations in some important localities, this revision is still far from complete, but as regards Colorado, where the stratigraphic relations of the plant-bearing horizons are best known, the revision is most advanced and the results most satisfactory.

The Denver flora, as at present known, embraces 150 species, the Laramie flora of this district contains 98 species, and but 15 species are common to both formations. For this district, then, the floras are very markedly distinct.

If the entire known Laramie flora of Colorado, embracing large collections from the coal fields of Canyon, Walsenburg, Raton, and the West Elk Mountains, be compared with the Denver flora, it is found that out of more than 100 species in the Laramie of Colorado only a very few have been found in the Denver beds. Further comparisons, as with the Laramie floras reported from Wyoming and farther north, are as yet impracticable.

The floras of the Middle Park and Livingston formations have already been stated to resemble the Denver very closely.

The Arapahoe formation was found by Mr. Eldridge to contain poorly preserved fossil leaves at a number of localities within the Denver region, but none determinable was collected. But in the course of the recent collections made for Mr. Emmons by Professor Lakes, a leaf-bearing stratum was found near Sedalia, south of Denver, in what are apparently Arapahoe beds. This local flora contains 19 species, 3 of which are new; 2 are known elsewhere only in the flora of Carbon, Wyo.; and all of the 14 remaining species have been found in the Denver beds. Of the 14 Denver species, 7 have no other known distribution, but 5 are found in the true Laramie, 1 in the Livingston beds, and 1 on Sand Creek, east of Denver, in beds whose exact locality is not known. This analysis brings out a strong relationship to the Denver flora and also an affinity with the Laramie, seemingly stronger than that of the Denver flora for the Laramie. The presence of Carbon species is in the line of the suggestion made elsewhere that the beds of Carbon and some other localities in Wyoming may prove to be of Arapahoe age.

In his summary Mr. Knowlton distinguishes the locality of Sand Creek with 10 species, for the reason that these plants, all collected by the members of the Hayden survey, come from a locality where the Arapahoe rests on the Laramie (see map), and where both carry fossil plants. The specimens preserved in the National Museum do not satisfactorily indicate the horizon from which they came. It seems probable that a part of them came from the Arapahoe beds and a part from the Laramie.

Conclusions from fossil plants.—From the large Denver and Laramie floras, containing so few species in common, it would appear that the two epochs were separated by an interval in which the change in vegetation was very important. During this interval the Arapahoe beds were deposited, but present knowledge of the plant life of that epoch is too meager to be of value in correlating that formation.

The most important conclusion to be drawn from the consideration of the fossil plants applies with equal force to other classes of fossils, namely, that conscientious observation and record of stratigraphic facts concerning beds in which new fossils are found are necessary to give those fossils value as evidence in geological correlation, especially in the case of allied or adjacent formations. The disregard of this self-evident proposition has already delayed an understanding of some important problems of Rocky Mountain geology, and has caused a great deal of labor in clearing away a confusion which need never have existed.

EVIDENCE OF INVERTEBRATE FOSSILS.

The only invertebrate fossils thus far found in the Denver beds were obtained by Mr. T. W. Stanton in 1886 from a ravine near the old St. Luke's Hospital, in Highlands, Denver. These were submitted to Dr. C. A. White for determination. *Viviparus trochiformis* and *Goniobasis tenuicarinata* are the only specifically identifiable forms, while imperfect shells referred to Corbicula, Physa, and Unio are also present. These species of Viviparus and Goniobasis are common in the Laramie and are also known in the Fort Union, and in what Dr. C. A. White has called the Wasatch Eocene, in Utah. The other forms also possess a wide range, and it is clear that these fossils are without value in the discussion to which this chapter is devoted.

EVIDENCE OF VERTEBRATES.

Known vertebrate fossils of the Denver and Arapahoe.—As far as is known to the writer, no vertebrate fossil had been described or positively identified from the Laramie, Arapahoe, or Denver formations of the Denver Basin before the beginning of the investigations recorded in this volume (1881).[1] A few had been found by Prof. A. Lakes, of Golden, and during the progress of the work a considerable number of bones were discovered by Mr. G. L. Cannon, jr., of Denver, and by Mr. Eldridge and the writer. The collection of this material extended over a number of years. The fossils obtained were for the most part isolated bones or fragments, and all or nearly all of them were sent to Prof. O. C. Marsh for examination.

Owing to the fact that few connected parts of skeletons have been found, and because the bones belong for the most part to new types, many of them have as yet been identified only in a general way, yet a number

[1] As mentioned in a later section of this chapter, it is possible that certain dinosaurs and other vertebrate fossils from Bijou Creek, described by Professor Cope, came from strata of Arapahoe age. The locality is beyond the limits of the Denver Basin as the term is here used.

of genera and species have been based on some of the best preserved specimens from the Denver Basin. A large number of the remains belong, moreover, more or less distinctly, to dinosaurian forms which have been discovered in much greater perfection in other localities within the last few years, so that a review of these other discoveries is necessary in discussing the geological importance of the fossils of the Denver area.

Of the vertebrates from the formations now under discussion the first to be described by Professor Marsh was found in place in the Denver beds near the Platte River, in Highlands. It was at first described as *Bison alticornis*, and assumed by Professor Marsh to probably indicate a Pliocene formation.[1] In 1889 this fossil was recognized by him as belonging to the new family of horned dinosaurs, the Ceratopsidæ, which he had meantime founded on specimens discovered in Montana.[2] Other remains from the Denver Basin were at this time referred to the same family, and in more recent years, as various representatives of dinosaurian types have been described from the collections made in Wyoming or Montana, some of the less perfect bones of the Denver region have been referred to the new species. Some other vertebrate forms have also been identified, and at present the list of species known from the post-Laramie of the Denver region is as follows:

Arapahoe formation:
- Dinosaurs: *Ceratops montanus.*
  - *Triceratops galeus* (type).
  - *Claosaurus annectens.*
  - *Ceratops alticornis.*

Denver formation:
- Dinosaurs: *Ceratops alticornis* (type).
  - *Ornithomimus velox* (type).
  - *Triceratops horridus.*
  - *Claosaurus annectens.*
- Turtles: *Compsemys victus.*
  - *Trionyx foveatus.*
- Crocodile: *Crocodilus humilus.*
- Fish: *Lepidotus occidentalis.*

[1] Notice of new fossil mammals: Am. Jour. Sci., Vol. XXXIV, 1887, p. 323.

[2] A new family of horned Dinosauria from the Cretaceous: Am. Jour. Sci., Vol. XXXVI, 1888, p. 477. Notice of new American Dinosauria: Ibid., 1889, p. 331.

It is probable that the last four species of this list occur also abundantly in the Arapahoe beds. From this list it appears that very few species are restricted to either formation, even with the present imperfect knowledge of the fauna.

Horizons from which the fossils were obtained.—All the determinable species of vertebrates referred to above were found either in the Arapahoe or Denver strata. The better preserved ones came from the Denver beds exposed in the ravines tributary to the Platte River in or within a few miles of the city of Denver. Others were found on the slopes of Green Mountain in the outcrops of the Denver beds, and one at least came from Table Mountain.

The fossils assigned to the Arapahoe were nearly all obtained by Mr. Eldridge, either directly embedded in the grits of this formation or in the gravel resulting from the surface disintegration of these beds. The principal localities are north of Clear Creek and west of the Platte River.

The Ceratops fauna of other localities.—Since the description of the first representative of the Ceratopsidæ by Professor Marsh, in 1888, a large number of allied dinosaurian forms and many associated vertebrate fossils of other types have been discovered by him and grouped as the "Ceratops fauna." It also appears that a number of forms previously described by Cope belong to this family of horned dinosaurs.

According to the statements of Professor Marsh, Wyoming and Montana have yielded great numbers of fossils assigned to the Ceratops fauna. In Wyoming most of the species were found in Converse County, near the eastern border of the State, and in Montana the Judith River Basin has produced a large number of the forms described by Marsh and Cope.

As mentioned in describing the post-Laramie beds of the Animas River, this region has yielded several dinosaurian types from strata not far below the Puerco. These were described by Cope, as well as some similar forms from Bijou Creek, about 40 miles east of Denver. A representative of the horned dinosaurs was also described in 1872 by Cope, from Black Butte, in Wyoming, under the name Agathaumas. This is now regarded by both Cope and Marsh as allied to Ceratops.

In association with the Ceratopsidæ in these various localities are representatives of other dinosaurian families, and also crocodiles, turtles, fishes, birds, and a remarkable mammalian fauna. There are also mollusks and fossil plants.

Geological significance of the Ceratops fauna.—The vertebrate fossils grouped by Professor Marsh in the Ceratops fauna have hitherto been referred to by him as coming "from the Laramie of Wyoming," of Montana, or of Colorado, and no doubt has been expressed by paleontologists of this country concerning the reference of the strata containing these remains to the Cretaceous rather than to the Eocene. The fauna is said to exhibit pronounced Mesozoic affinities and remote connection with the earliest Tertiary forms. In the closing discussion of evidence further reference will be made to the basis for this opinion, but it is desired to show in this place that present knowledge does not permit the use of the Ceratops fauna, extensive and remarkable as it is, in distinguishing the post-Laramie from the Laramie proper. The cause of the inability to use this remarkable fauna lies in the fact that the distribution of the species within the series of formations in question is not satisfactorily known—precisely the difficulty hitherto experienced with the fossil flora. A review of the facts concerning the leading localities makes this clear.

The Ceratops beds as a "horizon."—The strata in which the Ceratopsidæ and associated fossils occur have been grouped by Professor Marsh as the "Ceratops beds," and frequently referred to by him as constituting "a well-marked horizon." Although such a use of the term "horizon" may be satisfactory to the vertebrate paleontologist, it is clear, on the grounds already presented, that it does not adequately express the facts of stratigraphy.

The Ceratops "horizon" in the Denver region embraces the Arapahoe and Denver formations, and if the Laramie proper of other regions contains the same fauna, the "horizon" really embraces three stratigraphically distinct formations. Aside from its inaccuracy, it seems to the writer that this use of the term "horizon" is quite unjustifiable, for it can not but be misleading to those unacquainted with the regions involved.

The first Ceratops (*C. montanus*) was described by Professor Marsh in December, 1888.[1] The locality and horizon in which the new fossil was

[1] Am. Jour. Sci., 3d series, Vol. XXXVI, 1888, p. 477.

obtained were given only in general terms. It was said that it was found "in place, in the Laramie deposits of the Cretaceous, in Montana * * *." "The associated fossils found with the present specimen are remains of other dinosaurs, crocodiles, turtles, and fishes, mostly of Cretaceous types. The mollusks in the same beds indicate fresh-water deposits." It is also remarked that "remains of the same reptile, or one nearly allied, had previously been found in Colorado, in deposits of about the same age, by Mr. G. H. Eldridge." In fact all the remains found by Mr. Eldridge came from the Arapahoe strata, so that the horizon of this species in the Denver Basin is indicated.

In April, 1889, Professor Marsh described *Ceratops horridus*,[1] the locality and horizon being stated as follows:

"The present specimen is from the Laramie formation of Wyoming, but fragmentary remains, which may be referred provisionally to the same species, have been found in Colorado."

The latter reference is to material from the Denver beds. The species was later assigned to the new genus Triceratops.

The genus Triceratops was established by Professor Marsh in August, 1889,[2] with three species. The type "was discovered in the Laramie formation of Wyoming." "A much smaller species is represented by various remains probably from the same horizon in Colorado." The type of this smaller form, *T. galeus*, was in fact obtained by Mr. Eldridge in the Arapahoe beds of the Denver Basin.

In December, 1889, one year after the description of the first recognized Ceratops, Professor Marsh gave a description of the skull of the Ceratopsidæ, prefacing it with some remarks on the geological occurrence.[3] He asserted that "the geological horizon of these strange reptiles is a distinct one in the Upper Cretaceous, and has now been traced nearly 800 miles along the eastern flank of the Rocky Mountains. It is marked almost everywhere by remains of these reptiles, and hence the strata may be called the Ceratops beds. They are fresh-water or brackish deposits, which form

[1] Am. Jour. Sci., 3d series, Vol. XXXVII, p. 334.

[2] Am. Jour. Sci., 3d series, Vol. XXXVIII, p. 173.

[3] Am. Jour. Sci., 3d series, Vol. XXXVIII, p. 501.

a part of the so-called Laramie, but are below the uppermost beds referred to that group."

The statement that "a distinct horizon" has been "traced nearly 800 miles" and that "it is marked almost everywhere" by certain fossils would imply either that actual continuity had been proved or that the stratigraphic position of the fossil-bearing strata had been found to be clearly the same at numerous localities not far apart. But when Professor Marsh made the above assertion the Denver region was the only one in which the position of the Ceratops-bearing beds had been established in complete sections, and here they were found to be separated from the typical Laramie below them by a great stratigraphic break. Moreover, none of the described fossils was found east of the mountains between the Denver Basin and Converse County, Wyo., a distance of 200 miles. As far, then, as the new fossils themselves are concerned they prove either a great extension of the Arapahoe and Denver (post-Laramie of this report), or a distribution of the fossils in question beyond the limits of what may properly be termed one formation or horizon.

It is plainly of primary importance to ascertain whether any of the strata containing the so-called Ceratops fauna really belong to the true Laramie, as distinguished from the Arapahoe, or whether they all belong to the latter formation. A review of the known facts concerning the published localities will now be given.

The Ceratops beds of Converse County, Wyo.—The most important locality for the Ceratops fauna as yet discovered is that of Converse County, Wyo., for the reason that every species belonging to that fauna thus far described by Professor Marsh from Wyoming was found there, and these species form much the greater part of the total vertebrate fauna as now known. This statement is made on the authority of Mr. J. B. Hatcher, now of Princeton College, under whom, as Professor Marsh's assistant, all the fossils in question were collected. In the original descriptions by Professor Marsh the fossils were said to have been obtained in "the Laramie of Wyoming" or "the Ceratops beds of Wyoming." It is important to emphasize the fact that not one of the described species came from the typical Laramie strata of southern Wyoming or from their demonstrated equivalent. It becomes manifestly of interest to analyze critically the grounds upon which the strata of Converse County containing the Ceratops fauna have been referred to the Laramie, and to compare them with the Ceratops-bearing formations of the Denver Basin, whose stratigraphic relations to the Laramie have been described.

While Professor Marsh has himself given no details of locality in describing species, there appeared in 1893 an article on "The Ceratops beds of Converse County, Wyo.," by J. B. Hatcher,[1] prepared and published with Professor Marsh's approval. The article gives many valuable data concerning the character and position of the strata in question and specially states the reasons for believing them to be true Laramie.

Converse County lies on the eastern border of Wyoming, as shown in fig. 24 of this volume. The beds are best exposed on the eastern and southern borders of a synclinal basin. Near the southeastern limit the Ceratops beds dip to the northwest at angles varying from 16° to 29° and rest with apparent conformity on Fox Hills strata, identified by their marine invertebrate fauna. To the northwest the Ceratops beds become nearly horizontal and pass under strata of more recent age, referred to below. It is important to notice that according to Mr. Hatcher, "the eastern shore of the fresh waters, in which the Ceratops beds were deposited, was nearly that of the present border of these beds. The eastern limit of the fresh waters was confined to the western slope of the Black Hills and that chain of minor uplifts connecting them with the Laramie Range to the southwest." If this be true it is plain that the Ceratops "horizon" has not been traced so continuously along the eastern base of the mountains as might be supposed from the statement of Professor Marsh, above quoted.

The Ceratops beds of Converse County are 3,000 feet in thickness. At the base is a nonfossiliferous, fine-grained, white or yellowish-brown sandstone member, 400 feet in thickness. The lower division of 150 feet is well stratified; the upper 250 feet massive in texture. Above this sandstone comes a complex of sandstones, shales, clays, marls, limestones, and thin, impure lignite beds. It would appear that this sandstone corresponds in general lithological character to the basal sandstone of the Laramie as

[1] Am. Jour. Sci., 3d series, Vol. XLV, 1893, p. 135.

developed in Colorado, but, as Mr. Hatcher admits, its separation from the Fox Hills is arbitrary, and neither brackish-water shells, plants, nor coal beds are present to indicate its identity with the Laramie. The assignment of this sandstone to the Ceratops beds is supported only by absence of unconformity and the similarity of the heavy sandstone to the thin beds of the upper series.

The fossil-bearing member of the Ceratops beds consists, in Mr. Hatcher's language, "of alternating sandstones, shales, and lignite, with occasional local deposits of limestones and marls. The different strata of the series are not always continuous, a stratum of sandstone giving way to one of shales, and vice versa. This is especially true of the upper two-thirds of the beds." "The shales are quite soft and loosely compacted, composed mostly of clay with more or less sand in places. The prevailing color is dark-brown, but they are sometimes red or bluish." "The lignites occur in thin seams, never more than a few inches thick, of only limited extent, and with many impurities. At no place in the 'Ceratops beds' of this region have workable coal beds been found." "Intercalated with the sandstones, shales, and lignites, are quite local deposits of limestones, clays, and marls. The latter are composed almost entirely of fresh-water shells, fragments of bone, teeth, etc." "All the deposits of the 'Ceratops beds' of this region bear evidence of having been laid down in fresh waters. Among the invertebrate fossils found in them, only fresh-water forms are known. There is no evidence that marine or brackish waters have ever had access to this region since the recession of the former at the close of the Fox Hills period."

This description of the Converse County Ceratops beds shows them to be quite different from the Laramie of Colorado, or of southern Wyoming, but similar in many ways to the Arapahoe beds, or to the strata of debatable age in other localities. It would not be justifiable to assert at present that the beds of the true Laramie never possess such a variable character and such a loose, friable texture as is shown by the strata in question, but it is certainly fair to point out that this constitution is met with in the post-Laramie and later fresh-water deposits, and that so eminent an authority on the Laramie and associated formations as Mr. R. C. Hills has laid special emphasis on this different constitution of strata in discussing the formations of the Yampa district in Colorado.

The invertebrates of the Ceratops beds, found often in intimate association with the dinosaurian remains, are thought by Mr. Hatcher to be evidence of the Laramie age of the beds. He mentions five species identified by Dr. C E. Beecher, and states that there are others. It is said that some of them are "known from the typical Laramie," and some "are characteristic of it." The weight of this evidence in the present discussion clearly depends upon what is considered "typical Laramie." The known distribution of the five species mentioned by Mr. Hatcher is given in the subjoined table, prepared for the writer by Mr. T. W. Stanton, accompanied by some remarks on the localities, which are published with Mr. Stanton's kind permission:

	Black Butte, Wyoming.	Crow Creek, north Colorado.	Lebo Creek, Montana.	Near Fort Union, Mont.	Fort Clarke, Mont.	Valley of the Yellowstone.	Heart River, Mont.	Separation, Wyoming.	Weber, Utah.
Unio couesii White		......		......	......	......	......	......	......
Sphærium formosum M. & H	......	......	......	×	......	......	......	......	
Limnæa compactilis Meek	......	......	......	......	......	......	......		......
Campeloma multilineata M. & H	......	×	×	......				......	......
Tulotoma thompsoni White	×	......	......	......		......	......	......	......

Concerning these localities Mr. Stanton's comments are as follows:

The locality on Crow Creek, northern Colorado, seems to be in the true Laramie, and the Black Butte locality has usually been referred to the same formation. The invertebrates from Black Butte come from beds below the dinosaurian remains, according to Dr. White. The localities near Fort Union, Fort Clarke, Heart River, and in the valley of the Yellowstone are in the Fort Union beds. The two species from Lebo Creek are there associated with a number of other species that occur in the original Fort Union area. The Weber, Utah, locality is in the Wasatch Eocene, and that at Separation, Wyoming, is considered as probably Laramie by Dr. White.

From the foregoing it is plain that the shells mentioned by Mr. Hatcher do not serve as evidence for the Laramie age of the Converse County beds as strongly as they show their intimate relation to the Fort Union formation, now commonly regarded as Eocene. This fauna can not be characterized as a Laramie fauna except by including the Fort Union in the Laramie, a view formerly prevailing, it is true, but now abandoned by all the recent writers on this question. As regards the reference of the Converse County beds to the Laramie or post-Laramie on the occurrence of these shells, their evidence would seem strongly in favor of the post-Laramie. In a succeeding section the evidence concerning Black Butte is reviewed and it is plain that reasonable doubts may be entertained in regard to the assignment of the saurian beds at that point to the Laramie. The formation overlying the Ceratops beds with apparent conformity on the west side of the Converse County basin is said by Mr. Hatcher to be of about the same thickness (3,000 feet) and constitution, but it is destitute of fossils except for an abundant flora. The large number of leaves sent by Mr. Hatcher to the National Museum have been examined by Mr. F. H. Knowlton, who has kindly authorized the statement in this place that but few identifiable species are present. The greater part of the material consists of one species, *Platanus raynoldsii*, a representative species of the Denver beds flora and also known in the Fort Union.

Reviewing the facts given by Mr. Hatcher concerning the strata of Wyoming, which have yielded the Ceratops fauna of Professor Marsh, with regard to the assignment of these strata to the Laramie or Post-Laramie, it appears to the writer that the question is by no means settled, and that a reference to the post-Laramie has much in its favor. The invertebrate fossils would certainly favor such a reference should any weight be attached to the few species above named. And the vertebrate fauna shows strong alliance with that of the Arapahoe and Denver formations, while the other localities which have yielded these remains are all more or less open to the suspicion that they may also be post-Laramie. The lithological character of the fossil-bearing beds allies them rather with the post-Laramie than with the Laramie.

The conformity of the series with the Fox Hills is considered the most weighty line of evidence by Mr. Hatcher, but in the light of the circumstances of this particular case it is clear that too much weight may easily be laid upon this fact. The Arapahoe and Laramie beds seem conformable as far as they have been traced along the line of the foothill fold, but the conglomerate reveals the extent of the stratigraphic break really existing between the formations. The pre-Arapahoe uplift seems to have been greatest in the mountain areas of Colorado and Montana, but a study of the various known facts leads the writer to the view, presented in more detail below, that large areas adjacent to the mountains were raised somewhat above sea-level at the time of the more pronounced mountain uplift, and that in the interval before subsidence caused the lakes of the Arapahoe to be formed the land surface of the Laramie sediments on the plains may have been very little modified while great erosion took place in the mountains. Or the loose and unconsolidated Laramie sediments of the plains, being not much elevated above baselevel, may have wasted so evenly that subsequent deposits upon them now seem conformable.

The beds of Converse County, of the Judith River Basin in Montana, and the area between them, the Animas River beds below Durango, and the post-Laramie formations of other districts, occupy positions removed from the regions of greatest disturbance, and it is natural that they should seem conformable with the underlying strata, whatever they may be. In the Livingston region the post-Laramie formation of that name lies with apparent conformity on the Laramie, as seen in the Bozeman and other sections, but to the westward its base transgresses the edges of the Laramie, and in the Three Forks area a great angular unconformity is seen at the base of the Livingston.

There are many places in the West where the section of visible sedimentary formations from the Cambrian to the Cretaceous seems a conformable one, and it has frequently been spoken of as such. But the researches of the last two decades have proven the existence of many important stratigraphic breaks in this series, which are in certain places shown as great unconformities but can not be identified at other points. Especially in the plains country adjacent to the Rocky Mountains conformity of formations can not be assumed to prove continuity of sedimentation. The visible conformity between the Ceratops beds and the Fox Hills in Converse County can not be accepted, contrary to other evidence, as proving the former to have been deposited in the epoch next succeeding the Fox Hills.

Ceratopsidæ from Black Butte, Wyoming.—While none of the types described by Professor Marsh come from the typical Laramie of southern Wyoming, a representative of this family was described from Black Butte by Professor Cope, in 1872, under the name Agathaumas,[1] which is now recognized by both paleontologists as belonging to the horned dinosaurs. This occurrence does not, however, prove the extension of the Ceratops fauna downward into Laramie strata equivalent to the Laramie of the Denver field, for the Black Butte locality is one concerning which geologists have differed in their observations, some thinking to have found evidence of a true break, others not, and it is clear that much more field work in that region is necessary to harmonize the evidence of fossil plants, vertebrates, and the published stratigraphic data.

The dinosaurian horizon at Black Butte is above a line at which Major Powell observed what he has described as an important physical break[2] in the series of 5,000 or 6,000 feet of strata assigned by others as a whole to the Laramie. The saurian layer is also very near the top of the series and is hence in the part which must correspond with the Arapahoe or Denver in case any subdivision of this section is carried through. The fossil flora of Black Butte is neither distinctly Laramie nor Denver according to Mr. Knowlton, having the intermediate character which might be expected of the Arapahoe flora. The invertebrates of Black Butte are partly brackish and partly fresh water forms. The former are known in other deposits supposed to belong to the lower part of the Laramie, while the latter range upward into post-Laramie and Fort Union strata. It can only be said that none of the lines of evidence is competent to satisfactorily decide the position of the Black Butte deposits.

Other Ceratops localities in Wyoming.—Through the courtesy of Mr. J. B. Hatcher the writer is able to state that representatives of the Ceratopsidæ have been discovered on the south side of the Seminole Mountains, and on the west side of the North Platte River directly opposite the mouth of Medicine Bow River, Wyoming. This locality is 20 miles north of Fort

[1] Am. Nat., Vol. VI, 1872, p. 669. Proc. Acad. Nat. Sci., Phila., 1872, p. 279. Proc. Am. Phil. Soc., XII, 1872, p. 481.

[2] Geology of the Uinta Mountains, p. 72.

Fred Steele, on the Union Pacific Railroad, and 28 miles northwest of Carbon Station. As a glance at the atlas of the Fortieth Parallel Survey will show, it is very probable that this dinosaurian locality is in the same formation which occurs about Carbon. This latter locality has yielded a number of fossil leaves which have been included in the Laramie flora by Lesquereux, Ward, and others. The paleobotanists have, however, always recognized that the Carbon flora was similar to that of Table Mountain, at Golden, and this similarity is confirmed by Mr. Knowlton's recent review, although a table of species is not yet ready for publication. It will be remembered, also, that two species of the Sedalia flora, supposed to be Arapahoe, are known elsewhere only at Carbon.

In closing his discussion of the Middle Park beds[1] the writer pointed out that while no equivalents of the Arapahoe were known between the eroded Cretaceous section and the Middle Park equivalent of the Denver, the Carbon and Black Butte floras were so much like the Denver flora, and the localities so situated with regard to the mountain area of Middle and North Parks, as to make natural the suggestion "that the plant-bearing beds of these two localities (Carbon and Black Butte) may possibly represent the deposits contemporaneous with the erosion preceding the Middle Park period." This suggestion seems to become more and more plausible as the distinction between the Laramie and Denver floras becomes better known. If the new Ceratops locality is actually in the same formation with the plant beds of Carbon an important field for investigation is certainly indicated.

Mr. Hatcher also states that remains of the Ceratopsidæ have been found on the eastern slope of the Big Horn Mountains, about 40 miles south of Buffalo, Wyo.

The Ceratops beds of Montana.—Next to the locality of Converse County, Wyo., that of Judith River Basin, in Montana, is the most important known locality for the Ceratops fauna. It was here that Prof. E. D. Cope discovered several representatives of this fauna in 1876, the genera Dysganus and Monoclonius of Cope being now recognized as horned dinosaurs. While the original description of Professor Cope was in an article entitled

[1] The post-Laramie beds of Middle Park, Colo.: Proc. Colo. Sci. Soc., Vol. III, 1891.

"Descriptions of some vertebrate remains from the Fort Union beds of Montana,"[1] the localities and stratigraphical position of the strata yielding these remains were very clearly given by Professor Cope[2] in the next year, and it then appeared that the "Judith River beds," one of the local divisions of Hayden's "Lignitic" series, was the immediate formation from which the fossils were obtained. According to the personal communication of Mr. J. B. Hatcher, nearly all of the forms described by Professor Marsh "from the Laramie of Montana" were obtained by Mr. Hatcher in the same series of strata in the Judith River region which contained the fossils described by Professor Cope. Without reviewing in detail the literature of these beds it is desired to point out the fact that the Judith River strata may perhaps represent the Arapahoe or some other post-Laramie formation, and not the true Laramie of Colorado and Wyoming.

The explorations of the Hayden survey and other later examinations of the Judith River and adjoining districts have shown a complex of somewhat variable sandstones, shales, clays, and lignites containing in various horizons fresh and brackish water shells and the vertebrate fauna of Cope and Marsh. Below this complex is the Fox Hills Cretaceous and above it the Fort Union formation, the latter boundary not being as yet well established. On account of stratigraphic relation to the Fox Hills, and from the evidence of the faunas mentioned, the reference of these strata to the Laramie has not previously been questioned, so far as the writer is aware.

Instead of reviewing past descriptions of the Judith River country the following notes by Mr. T. W. Stanton, who visited the region in 1894 in company with Mr. W. H. Weed, are given with his permission. They pertain only to the lower part of the series, but the main question under discussion is as to the lower known limit of the Ceratops fauna. Mr. Stanton gives the following description of the section near the mouth of the Judith River:

The fresh-water Judith River beds are well exposed in bluffs on Dog Creek, 4 or 5 miles from the mouth of Judith River, and also on the north side of the Missouri within 3 or 4 miles of the same place. The section in this neighborhood shows about

[1] Proc. Acad. Nat. Sci., Phila., Vol. XXVIII, 1876, p. 248.
[2] Bull. U. S. G. and G. S., Vol. III, 1877, p. 565.

650 feet of marine Cretaceous strata overlain by 300 to 350 feet of fresh-water beds. The succession of strata and thickness as estimated by Mr. W. H. Weed are as follows, beginning at the base:

1. Soft, dark clay shales.
2. Band of ferruginous sandstone with *Avicula linguiformis, Inoceramus cripsii, Baroda wyomingensis, Placenticeras placenta*, etc.
3. Shales like No. 1.
4. Coarse gray laminated sandstone.
5. Carbonaceous shales with bed of lignite at base 100
6. Brown sandstone with great numbers of *Cardium speciosum* and a few other species 30
7. Sandy shales 25
8. Dark clay shales with concretions containing *Baculites ovatus* in lower portion and sandy bands and concretions near the top with a characteristic Fox Hills fauna including—

Nucula sp.	Liopistha (Cymella) undata.
Clisocolus cordatus.	Pholodomya subventricosa.
Callista nebrascensis.	Mactra formosa.
Tellina æquilateralis.	Lunatia subcrassa.
Tancredia americana.	Baculites ovatus.

The total thickness of this bed was not seen at any one place, but it is at least 350 feet.

Immediately above these dark shales is a bed of greenish-yellow sandstone which occasionally forms bluff exposures 50 or 60 feet high, but usually only slightly exposed in steep slopes and largely covered by wash from the softer and lighter-colored beds above. This was taken as the dividing line between the marine and fresh water beds, though no fossils excepting silicified wood were found in the lower 200 feet of the latter. The remainder of the section, about 300 feet in thickness, is apparently conformable with the underlying beds, but is quite distinct from them in color and texture. It consists of alternations of light-colored, soft, friable sandstones, clays, and marls, with some seams of lignite and purplish carbonaceous bands. Fossils are abundant in the upper 200 feet, consisting of fragments of silicified wood, bones, and numerous invertebrates. The latter include the following species:

Sphærium recticardinale.	Goniobasis sublævis.
Sphærium planum.	Goniobasis subtortuosa.
Unio danæ.	Goniobasis sp. closely related to G. tenuicarinata.
Unio cryptorhynchus.	Campeloma vetula.
Anodonta propatoris.	Vetrina? obliqua.
Viviparus conradi.	Physa copei.
Helix veternus.	

At the top of the exposure above these fresh-water beds there is a band of brackish-water fossils, reported by both Meek and Hayden and by Cope, which contain *Ostrea subtrigonalis*, *Anomia* sp. *Corbicula occidentalis*, *Corbula cytheriformis*, *Goniobasis convexa*, etc. This band was not seen by me in the neighborhood of Judith River, but I afterwards saw it near Havre, Mont., holding the same position above the fresh-water beds.

These brackish-water shells are specifically identical with those found by Mr. Weed in the Livingston beds; hence they do not indicate the Laramie age of the Judith River beds. The same considerations concerning apparent conformity with the Fox Hills which were urged in discussing the Converse County beds apply to the Judith River beds, and it seems to the writer that they are not shown to be typical Laramie by the evidence at present available.

Dinosaur-bearing beds near Castle Gate, Utah.—In the summer of 1894 Mr. T. W. Stanton found bones of a dinosaur near Castle Gate, Utah, in sandstones occurring above the Laramie coal beds of that region and below the Wasatch strata of the plateau. The remains in question were submitted to Prof. O. C. Marsh, who identified them as belonging to *Claosaurus annectens* Marsh, first found in the Ceratops beds of Converse County, Wyo., and afterwards identified in the Arapahoe strata, near Denver. It is therefore of much interest to compare the Utah section with the others in which the same dinosaur has been found. Mr. Stanton has kindly offered the following notes upon the Upper Cretaceous section of Price River Canyon, near Castle Gate, and of the series up to the undoubted Wasatch Eocene:

The lowest beds exposed in this neighborhood are dark clay shales, with occasional bands of sandstone, in which a few specimens of *Inoceramus proximus*, which is characteristic of the Montana formation, have been found. Farther southwest, in Castle Valley, a much lower horizon in the same series of dark shales yields *Prionocyclus wyomingensis*, *Scaphites warreni*, *Inoceramus dimidius*, and other characteristic fossils of the Colorado formation.

Above the horizon at which *Inoceramus proximus* was found the strata consist of alternations of shale and irregular, heavy beds of brown and gray sandstones, the latter greatly predominating and forming probably four-fifths of the entire thickness of 500 feet up to the principal Castle Gate coal bed. About 200 feet below the coal there is a fossiliferous band of shale in which a few brackish-water Laramie fossils were found. The species are *Ostrea glabra* M. & H., *Corbula subtrigonalis* M. & H., *Modiola regularis* White, and a few other indeterminate forms. Specimens of *Ostrea* were obtained to within 100 feet of the coal.

Above the Castle Gate coal mine there are about 300 feet of alternating brownish sandstones and shales, with several seams of coal and some thin, calcareous bands, in one of which, about 150 feet above the main coal bed, a few species of fresh-water mollusca were found. These include *Viviparus panguitchensis* White, *Viviparus trochiformis* M. & H., *Goniobasis tenuicarinata* M. & H., and indeterminate species of *Bulinus*, *Physa*, *Limnæa*, *Planorbis*, *Unio*, and *Sphærium*. They show rather close relationship with the fauna that occurs at a much higher horizon.

Next in ascending order is a series of heavy-bedded, brownish-gray sandstones usually forming vertical cliffs and having an estimated thickness of 800 or 1,000 feet. At the foot of one of these cliffs, just north of Castle Gate, some bones of a large reptile were found in a mass of sandstone that had evidently fallen from the cliff. These were submitted to Prof. O. C. Marsh, who reports that "they agree in essential particulars with the type specimens of *Claosaurus annectens*, which occurs in the Ceratops beds of the upper Laramie of Wyoming."

Overlying this massive sandstone is a series of similar sandstones in beds 20 or 30 feet thick, alternating with shales, and having a total thickness of about 300 feet, and these merge into a series containing a greater proportion of shale and some bands of fresh-water limestone in which invertebrate fossils are very abundant, including the following:

Unio mendax White.
Physa pleromatis White.
Viviparus trochiformis M. & H.
Viviparus leidyi M. & H.
Goniobasis tenuicarinata M. & H.
Goniobasis filifera White.
Limnæa tenuicostata M. & H.
Hydrobia utahensis White.
Cypris saupetensis White.

These all occur in the lower portion of the series referred by Dr. C. A. White to the Wasatch formation (Bull. U. S. G. S. No. 34, p. 10) on the higher hills near Castle Gate and at Pleasant Valley Junction and other localities in that region. Several of the species are identical with forms that occur in the Fort Union beds on the Missouri River, and some of them also occur in beds believed to belong to the true Laramie of Colorado and Wyoming.

The entire series from the marine Cretaceous up into the fresh-water Eocene seems to be conformable, and there are no sudden changes in the character of the sediments. The close relationship, and in some cases specific identity, of the fresh-water mollusca in the coal-bearing series and in the Wasatch also favor Dr. White's view that sedimentation was continuous from the one into the other.

From Castle Gate the Laramie coal beds may be traced with practical continuity to Grand River in Colorado, about 180 miles, and at the latter locality the Ruby formation, one of the apparent equivalents of the Denver beds, occurs between the Laramie and the Wasatch. As stated in an earlier part of this section, the Ruby formation reaches a thickness of 2,000 feet in the West Elk Mountains. It is also to be borne in mind that in the Anthracite district of Colorado there is a formation—the Ohio Creek—which is the probable though not demonstrated equivalent of the Arapahoe.

If the Castle Gate section be assumed to be the product of continuous sedimentation from the Fox Hills to and including the Wasatch Eocene, as advocated by Dr. C. A. White for certain regions, it is still true that the several time-intervals of the Laramie, Arapahoe, Denver, and also the Puerco, must be represented in that section, and the Claosaurus, having been found in the upper sandstone member of the group of strata referable to the Cretaceous, is most plausibly of one of the post-Laramie epochs. This is rendered still more plausible by the character of the invertebrate fauna occurring below the vertebrate horizon, which is much more closely related to the Fort Union or Wasatch faunas than to any known from unquestionable Laramie.

If the sedimentation was not continuous in the Utah seas, then there are stratigraphic breaks in the series of apparently conformable beds. As to the equivalent of the Puerco in the section, it remains to be demonstrated that the Wasatch of the New Mexico section, which rests on the Puerco, is the same as the Wasatch of Utah, as identified by the invertebrate paleontologists. Furthermore, it is well known that while Professor Cope, who has defined and studied the Puerco, refers it to the Mesozoic, as "post-Cretaceous," Professor Marsh includes it with the lower Wasatch Eocene.

Bijou Creek, Colorado.—About 40 miles east of Denver is the valley of Bijou Creek, one of the typical streams of the plains, rising some 25 miles northeast of Colorado Springs and coursing a little east of north to the Platte River, a distance of about 80 miles. The upper portion of its course is in the Monument Creek strata, while near its mouth are true Laramie beds, according to Dr. C. A. White,[1] who, in 1877, collected such common Laramie shells as *Ostrea glabra*, *Anomia micronema*, *Corbula subtrigonalis*, *Melania wyomingensis*, and several species of Corbicula. From the locality

[1] Eleventh Ann. Rept. U. S. G. and G. Survey of Terr., p. 189.

where the above fossils were found to Bijou Basin, at the head of the creek, Dr. White was unable to find any other fossil-bearing horizon, and but few outcrops of strata were seen north of the Kansas Pacific Railroad crossing.

In Monograph II of the Hayden survey, Prof. E. D. Cope described two dinosaurian fossils from Colorado under the names *Polyonax mortuarius* and *Cionodon arctatus*. These forms are now regarded by Cope[1] as belonging to the Ceratopsidæ, Polyonax corresponding to Triceratops Marsh, while the position of Cionodon, which is known only from teeth, is not certainly established. Marsh also considers Polyonax to be a horned dinosaur, though not surely separable from Agathaumas Cope. With the above forms occurs a Hadrosaurus, and the turtles Compsemys and Trionyx. So far as the writer is aware, Professor Cope has not given the localities of these fossils in connection with descriptions of them, but on personal inquiry he kindly stated that they were obtained on Bijou Creek, about 40 miles east of Denver, but he could not specify the exact locality.

The locality of Bijou Creek is interesting, as its general position in certain important particulars is much like that of the Converse County, Wyo., locality, and that of the Judith River Basin in Montana. In all these cases the beds lie some distance away from the main mountain range, and the connection with the more complete sections commonly found in the foothill region is interrupted. As in Wyoming and Montana, so in Bijou Valley, the first natural assumption of the collector would be that the strata containing the vertebrates belonged to the Laramie. But as the Laramie of the Colorado foothills is not known to contain these or allied remains while the Arapahoe beds do contain them, and as the latter, in all probability, once extended much farther out into the plains area than the eastern boundary of the Denver map, it seems strongly probable that the dinosaurs described by Professor Cope came from Arapahoe beds reappearing from beneath Denver and Monument Creek sediments in the valley of Bijou Creek.

CONCLUSIONS FROM EVIDENCE.

Individuality of formations established.—The facts of stratigraphy and lithology seem to the writer much more than sufficient to prove that the Arapahoe and Denver formations are entitled to recognition as distinct formations.

[1] Am. Naturalist, Vol. XXIII, 1889, p. 906.

The only question is as to the extent of the separation from the Laramie, and more knowledge in various directions is necessary to determine this point. It is noticeable that the developments of the past few years have steadily increased the importance of these formations. The evidence of fossil plants has been shown by Mr. Knowlton to confirm that of stratigraphy as to the distinctness of the Laramie and Denver formations, and this result leads to the hope that when the Laramie fauna has been carefully examined in respect to the distribution of its members all lines of evidence may be found in accord. A few years ago the Laramie flora was deemed as indivisible as is the fauna to-day.

A study of the facts which have been presented brings out certain features of the time-intervals between the close of the Laramie and the close of the Denver epochs which it may be well to recapitulate in this place.

The pre-Arapahoe uplift.—The Arapahoe sediments of the Denver Basin testify beyond question to a preceding uplift which terminated Laramie deposition in this vicinity. By this movement some adjacent area of Mesozoic rocks was greatly elevated and was eroded to an unknown but considerable extent before the beginning of deposition in the Arapahoe lake or sea. This latter conclusion follows from the fact that the early conglomerates of the Arapahoe contain pebbles from various horizons. The Arapahoe sediments do not record a progressive erosion, cutting deeper and deeper into the uplifted Mesozoic area, so much as they tell of an already eroded surface.

In Middle Park the entire Mesozoic section was upturned and eroded prior to the Denver epoch. It is reasonable to suppose that this elevation was contemporaneous with that of the Denver Basin. In the mountain area tributary to the Canyon district the apparent evidence of the strata described above indicates an uplift similar to that near Denver. In the West Elk Mountains an uplift is less certainly proven. From the general character of the Laramie in Colorado, and its observed thickness, it may even be inferred that the pre-Arapahoe uplift terminated Laramie sedimentation throughout the mountain district. No evidence is known to the writer showing that Laramie deposition was ended by any other orographic movement within the area of Colorado.

In the Livingston area of Montana the known facts speak for an order of events similar to that of Middle Park.

The Arapahoe epoch.—As pointed out in the preceding section, the Arapahoe epoch of sedimentation represents only a part of the time of erosion which followed the pre-Arapahoe uplift. When further identifications and correlations of formations have been made, it may be possible to extend the scope of this epoch to cover the entire period of erosion and contemporaneous sedimentation.

In many ways the Arapahoe epoch was probably much more important than the Denver, though its deposits are less widely identified at present. It is plain that far from shore-lines the sandstones and shales of the Arapahoe might readily be lithologically indistinguishable from those of the Laramie, and if it shall be proven that the pre-Arapahoe uplift extended through Wyoming into Montana, the deposits of the Arapahoe epoch are to be sought for in these States in the upper portions of the great sections which have been referred to the Laramie, provided these sections are not incomplete through removal of the Laramie before the Arapahoe deposition began.

The influence of the great pre-Arapahoe uplift upon life existing at the close of the Laramie is unfortunately not yet known to a degree allowing much discussion. The fossil plants found must be intermediate in character between those of the Laramie and Denver, and allied to both. The vertebrates of the Arapahoe are highly modified and specialized types, but when and how they acquired their remarkable characters is not known. If it be true that the Ceratopsidæ were not modified by the climatic and other changes of the pre-Arapahoe interval it may well be wondered what caused their sudden extermination.

Pre-Denver volcanic eruptions.—The numerous deposits of andesitic tuff, sandtone, and conglomerate, which have been described, testify to enormous outpourings of andesitic lavas all over Colorado and extensively in Montana, and at nearly the same time. It will be evident to all that this is a very remarkable and important event in the volcanic history of the Rocky Mountains. But in judging of this epoch as an element in the general history, it is probable that the chief data available for forming that judgment can be fully appreciated only by petrologists.

It is a striking feature of all the deposits of andesitic material that they show a great range of andesitic types, making it probable that a very long series of eruptions occurred, in the course of which marked changes in the composition of the volcanic products took place. To the petrologist this variation from basic to acidic extremes within the andesitic group means a long period during which chemical differentiation went on, producing magmas of widely different constitution. The variation of lavas in the Denver beds is much greater than that shown in many of the largest known volcanoes, such as Ætna and the Hawaiian Islands.

The andesitic eruptions of Colorado can not be regarded as mere interruptions of Arapahoe sedimentation, for the reason that in Middle Park, on the Animas River, and in the Elk Mountains, the beds of volcanic material rest directly on the Laramie, or on an eroded surface, not on any equivalent of the Arapahoe. It is quite possible that no sedimentation took place in these regions from the close of the Laramie epoch until the time of subsidence which led to the Denver and equivalent deposits. To one appreciating the enormous amount of molten material extravasated in this period it must suggest itself that the subsidence which so generally followed the eruptions was in some measure a result of the enormous outpouring.

The Denver epoch.—The importance of the Denver epoch is to be measured by the thickness and character of its sediments and by its fossils. The strata show the epoch to have been one of subsidence in several localities and to an extent making it probable that large continental areas were involved. In the Denver Basin the remaining beds of this epoch are 1,400 feet in thickness; the Ruby beds of the West Elk Mountains are 2,000 feet thick; and Marvine assigns 6,400 feet of strata to his "Lignitic" and "doleritic breccia." These thicknesses are equal to or exceed those of the Laramie in the same districts.

The materials forming the Denver beds are softer than those of the Laramie sandstones, and much less abrasion, and hence probably a shorter time, is represented in the accumulation of Denver sandstones than in the case of texturally similar rocks of the Laramie. But the time represented by the Denver and equivalent formations is one of much importance.

The plant life of the Denver epoch was materially different from that of the Laramie, as shown by Mr. Knowlton in Chapter VII; but until the flora of the Arapahoe is much better known we can not tell how much of the modification was produced during the interval immediately preceding the Denver, and how much during the earlier intervals.

The vertebrates of the Arapahoe and Denver beds thus far identified are so few compared with those of Wyoming and Montana that until the distribution of the latter in the several fossil-bearing horizons has been clearly established it can not be known whether the Denver fauna has peculiarities distinguishing it from that of the Arapahoe.

Post-Denver interval.—The Denver formation may be probably considered as the uppermost member of the Cretaceous, now that the Fort Union beds of Montana have been recognized as Eocene from their rich fossil flora. If the Denver beds are so regarded, the time-interval succeeding their deposition is a most important one as marking the boundary between Mesozoic and Cenozoic times in the Rocky Mountains. In the Denver Basin no undisputed Eocene strata have been preserved, if, indeed, they were ever deposited in this region. But there are three known localities where formations apparently the equivalents of the Denver beds rest upon the typical Laramie, and are overlain by the lowest Eocene deposits of the respective regions. These localities are: On the Animas River, in Colorado and New Mexico, where the Puerco formation overlies the Animas beds; on Grand River, in western Colorado, where the Ruby beds are overlain by the Wasatch, and in Montana, where the Livingston formation is overlain by the Fort Union. In these three localities one may hope to find some evidence as to the orographic or other dynamic disturbances which are commonly assumed to have characterized this interval.

Field researches in these regions have not as yet been sufficiently thorough to demonstrate the absence of phenomena indicating orographic disturbance, but no evidence of important movements has been announced. In fact, as far as the writer is aware there is no described case of unconformity or dynamic disturbance which has hitherto been supposed to belong to the post-Cretaceous interval which may not as well be referred to the pre-Arapahoe movement. In all cases where the lowest recognized

Eocene formation is found resting unconformably on the Laramie or older strata, it must still be a matter for proof as to whether the movement thus recorded took place before or after the post-Laramie epochs which have been described above. In other words it appears that at present there is no distinct evidence of an especially important earth movement succeeding the Cretaceous period, if the Denver beds are assigned to the Mesozoic, while that preceding the Arapahoe seems from present knowledge to have been of the character and magnitude usually assumed for the disturbance closing the Mesozoic.

As the stratigraphic data now available do not satisfactorily determine the preeminent importance of the post-Denver interval, the evidence of fossils must be relied upon to justify the reference of the Arapahoe and Denver formations to the Cretaceous. While an exhaustive discussion of this question can not be entered upon in this place, the writer wishes to briefly state the inferences which seem to him justifiable from a consideration of the facts already presented.

Evidence of fossil plants.—It is shown by Mr. Knowlton that the Denver flora is remarkably distinct from that of the Laramie of the Denver Basin, only 15 species being now known in both formations out of a total flora of 148 species. An equally satisfactory comparison of the Denver flora with that of the Fort Union can not be made until the latter has been revised, but Mr. Knowlton informs the writer that at least 13 species seem common to the Denver and Fort Union floras. The Middle Park and Livingston floras are included with that of the Denver beds in these statements. These figures do not indicate a much greater break in plant life between the Denver and Fort Union epochs than is found between Laramie and Denver.

In general character the Fort Union and Laramie floras are so closely related that for a long time these formations were assigned to the same geologic epoch. It does not appear then that the climatic influences of the post-Denver interval modified plant life to a superlative degree.

Invertebrate fossils.—The Laramie seas have commonly been regarded as transitional in character between the true marine waters of the Fox Hills Cretaceous and the fresh-water lakes of the Eocene. In harmony with this idea the invertebrate fossils represent brackish-water or fresh-water forms, with a few known in the Fox Hills. Many of the fresh-water species are also known to range upward into Wasatch or Fort Union Eocene beds. As mentioned in discussing the section at Castle Gate, Utah, the gradation in character of the invertebrate fauna from the Fox Hills to the Wasatch is so gradual and the section apparently so complete as to cause Dr. C. A. White to suggest that in this region sedimentation was continuous into Eocene times. But this view is opposed by the evidence offered by vertebrate paleontology and does not accord well with the facts of stratigraphy that have been set forth.

It is at least plain that until the distribution of the invertebrate fossils through the various formations under consideration is much better known than at present the evidence of vertebrate animals and fossil plants is more useful than that of the Mollusca. Even the presence of brackish-water shells does not prove the strata containing them to be of true Laramie age, for Mr. Weed has found in the Livingston formation forms which, according to Mr. Stanton, are identical with some from the Judith River beds.

Vertebrate fossils.—As shown by Professor Marsh in another chapter, the vertebrate fauna of the Laramie and the formations here termed the post-Laramie is a very remarkable one, and the consensus of opinion among paleontologists that this great fauna is strongly Mesozoic in its affinities has determined the present reference of the Arapahoe and Denver to the Cretaceous. As has been shown, it is only in this broad way that this vertebrate fauna can now be used as evidence in the question under discussion in this chapter, and it will be well to examine the grounds upon which the positive opinion as to the geological significance of these fossils rests.

The leading elements of this fauna are the dinosaurs and the mammals, both represented by many genera and species, nearly all of them new. The mammals are considered by Professor Marsh as mainly allied to Jurassic types, but it is believed by Professors Cope and Osborn that they are intimately related to the mammals of the Puerco. The latter is referred by Professor Marsh to the base of the Eocene (lower Wasatch), while Professor Cope classes it with the Mesozoic. The wide differences of opinion thus brought out clearly deprives these mammalian remains of much of their value in the present discussion.

The dinosaurs of the Ceratops beds are highly modified and specialized forms unknown as yet in other parts of the world, except, perhaps, in the Gosau formation of Austria, and the conclusion that they necessarily indicate a Mesozoic age implies some reason why they may not have survived into the early Tertiary.

In the light of the facts which have been presented concerning the several epochs succeeding the Laramie, it is not clear to the writer why this belief that the dinosaurs, or, indeed, the whole vertebrate fauna, surely indicate a Mesozoic age should be so positively maintained as is done by the vertebrate paleontologists.

If the dinosaurs of the Ceratops fauna did actually live in the Laramie epoch of Colorado they survived a great orographic movement and its accompanying climatic changes, and continued through the Arapahoe and Denver epochs so little modified that Professor Marsh has not detected any changes corresponding to the stratigraphic time divisions. This is all the more remarkable since the fossil plants show a great modification during this time, and it has been commonly claimed that enormous and highly specialized vertebrate animals are particularly sensitive to conditions of environment. If the Laramie vertebrates were unaffected by the known dynamic phenomena of the Colorado region in post-Laramie times, it may well be asked what caused their extermination in the post-Denver interval, where as yet no evidence of orographic movements comparable with that of the pre-Arapahoe have been found. And if their extinction was due in large measure to other causes than those associated with dynamic phenomena, may that extinction not have been deferred until the Eocene?

These considerations seem to the writer ample ground for the demand that the causes leading to the extinction of the Ceratops fauna should be definitely connected with some orographic disturbance at the close of the Denver epoch before their presence in the Arapahoe and Denver beds can be admitted as full proof of the Mesozoic age of these formations. ””

Is a dual nomenclature desirable?—The vertebrate fauna of the post-Laramie beds is said by paleontologists to be strongly Mesozoic in its affinities. The post-Laramie formations are later than the beginning of the great Rocky Mountain revolution which has heretofore been considered to mark the close of Mesozoic time in the mountainous regions of western North America.

It has been generally assumed that the revolution caused in some way the great change in life observed in the fossils of the earliest Eocene deposits as compared with those of the Cretaceous. But recent discoveries show that the gap in life grows less as knowledge increases, while accumulating evidence continually enhances the importance of the orographic movement occurring between the Laramie and Arapahoe epochs.

Applying the criterion of continental development as it has been applied in the past, the pre-Arapahoe movement, which terminated the long series of conformable Cretaceous sediments, marks the end of Mesozoic time. Applying the criterion of life, and especially of vertebrate life, the post-Laramie epochs may be assigned to the Cretaceous.

It is not the writer's desire to advocate the establishment of a dual nomenclature for the case under discussion, but simply to recognize this aspect of the question as the logical deduction from the evidence that has thus far been presented. Investigation must be carried on in many directions before the relative importance of the various factors of this problem can be established. The importance of the pre-Arapahoe movement in comparison with later ones which are not as yet so clearly defined must be carefully demonstrated. The distribution of all classes of fossil remains through the series of formations must be studied, and the extinction of the Mesozoic types of vertebrates must be connected with the great movement of orographic importance by something more tangible than mere assumption

SECTION IV.—MONUMENT CREEK FORMATION.

By George H. Eldridge.

STRATIGRAPHY.

The name "Monument Creek" was first applied by Dr. F. V. Hayden to the series of strata which forms the prominent divide between the Platte and Arkansas rivers, extending from the base of the Colorado Range eastward. This use of the term is provisionally accepted in this report. About the middle of the series is a well-defined break in deposition, the divisions above and below which may, upon systematic study, be found to be distinct formations.

The Monument Creek formation occurs along the southern edge of the Denver field in the steep slopes of a high mesa and also stretches from its base prairieward in thin sheets. The floor of the lake in which the Monument Creek was deposited was more or less irregular from erosion, and in one part or another consisted of the clays and sandstones of the Laramie, Arapahoe, or Denver formations. In the foothill region the Monument Creek lies in contact with the Arapahoe; between Platte River and Cherry Creek a few hundred feet of Denver beds exist, which further to the east disappear. North and east of Coal Creek, on the eastern edge of the field, both Denver and Arapahoe are wanting and the Monument Creek rests directly upon the clays of the Laramie.

The Monument Creek consists of conglomerates, sandstones, and bright, vari-colored, arenaceous shales. These alternate with one another, but the conglomerates are especially prominent in the upper division, while the sandstones and shales are about equally distributed throughout the whole formation in beds from 20 to 40 feet thick. Only a portion of the lower division of the Monument Creek extends within the Denver field. This displays marked regularity in the succession and composition of its beds, except at the very base, where, owing to the uneven floor, the material varies from conglomerate through sandstone to arenaceous shale. A short distance above the base are two broad bands of green shale, separated by one of pink and capped by a fine grit or sandstone, which is soft and friable and easily disintegrates. These are succeeded, beyond the field, by other similar beds of shale, sandstone, and conglomerate.

The sandstones and grits of the lower division are mostly of Archean or sedimentary débris; in the upper division eruptive material of several kinds, including a rhyolitic tuff, occurs. Between the two divisions is a local development of rhyolitic tuff, which probably supplies the fragments of this rock in the beds above.

The thickness of the Monument Creek or of its parts is undetermined. Both divisions vary, owing to erosion, past or recent. A rough estimate is 900 feet for the lower division, 400 for the upper, and 40 or 50 feet for the thickness of the intervening rhyolitic tuff.

The age of the Monument Creek is for the present considered Miocene, on vertebrate paleontological evidence.[1]

LIFE.

The life of the Monument Creek, so far as known, has been described by Professors Marsh and Cope. It will not be discussed in this report, since the formation enters so little into the stratigraphy of the Denver field.

STRATIGRAPHICAL RELATIONS.

The uneven and rolling floor of the Miocene lake in which this formation was deposited deserves special remark. Though changes in level have probably taken place from time to time in the area constituting the Denver field by which certain areas of beds have been elevated and others, perhaps, equally depressed, there is abundant evidence that erosion also has played an important part in the early topography of the country, in times prior to the deposition of the Monument Creek group. This fact is brought out by the prominent hills and hollows which occur at the line of union between the Monument Creek and underlying formations, and it is especially well demonstrated in the relations between the Laramie and the Monument Creek in the vicinity of Scranton, and in those between the Denver and the Monument Creek to the east and south of this. In the latter case, not only are bosses of the Denver formation found projecting through the Monument Creek beds wherever a favoring gulch has been cut sufficiently deep, but along the line of union generally there is a constantly varying height in the pre-Miocene surface, the amount of variations at times reaching 100 to 150 feet. The most striking instance of erosion, perhaps, must have occurred at the close of the period in which the Denver formation was deposited, consisting of the removal, prior to the deposition of the Monument Creek, of an enormous amount of the older beds. This is evident from the difference in the topographic and geologic horizons between the upper beds of the Denver, which appear in the summit of Green Mountain, and those immediately underlying the Monument Creek along the southern border of the field, the former being both topographically and geologically far above the latter.

[1] Prof. E. D. Cope, Ann. Rept. U. S. Geol. and Geog. Survey of the Territories, Vol. VII, Colorado, 1873, p. 430.

CHAPTER IV.

By S. F. Emmons.

PLEISTOCENE GEOLOGY.[1]

No systematic study has yet been made of the Quaternary phenomena of the Rocky Mountain region, nor has any attempt been made to correlate the surface phenomena of the plains with those of the Mississippi Valley.

It is well known that the higher mountain regions of the West were once occupied by extensive glaciers of the alpine type, which, however, had no connection with the continental glaciers that covered such enormous areas in the more northern portions of the continent. In spite of this want of direct connection of the former phenomena with those that are generally recognized as belonging to the Glacial period, it is fair to assume that the greatest extension of these alpine glaciers was nearly contemporaneous with that of the great northern ice sheets, or continental glaciers.

Although the Rocky Mountains of Colorado constitute the greatest area of high mountain masses in the whole Cordilleran system, and its higher portions bear abundant evidence of its former occupation by glacial ice, as yet no undoubted evidence has been found of the extension of its glaciers below a level of 8,000 feet. As the foothill and plains region, which was the subject of the present investigation, lies entirely below this level, our studies have not enabled us to trace any direct and definite connection

[1] Based on observations made under instructions from the writer, by Prof. George L. Cannon, jr., of the Denver High School, during the summers of 1888 and 1889. Mr. Cannon has already published an article on the "Quaternam of the Denver Basin" in the Proceedings of the Colorado Scientific Society, Vol. III, p. 48.

between its surface phenomena and those which may be definitely connected with the Glacial period. They will therefore be described independently and by themselves, with no attempt at correlation with similar phenomena in outside regions beyond the indication of certain lines of investigation that may be profitably followed by those who in future time may undertake to establish systematic connection between the Pleistocene phenomena observed in the various regions west of the Mississippi and Missouri valleys

The descriptions given below, while specially applicable to the area represented on the Denver atlas sheet, hold good in a general way for a large portion of the plains area of eastern Colorado, reconnaissances having been made for the purposes of this investigation over the portions of this belt adjoining the various railroad lines from Cheyenne southward to the Arkansas Valley.

The period during which the geological events outlined here occurred may be divided into an earlier and a later erosion epoch, with an intermediate epoch of deposition, which may be termed, from the character of its most important deposit, the loessial epoch.

EARLIER EROSION EPOCH.

To what extent the topographical features produced during this epoch had already been outlined by erosion during Tertiary time, or prior to the Glacial period, there is now, so far as known, no means of determining. The latest Tertiary formation observed in this area, the Monument Creek beds, reached the foothills of the range at a level which is now between 7,500 and 8,000 feet above sea-level, and the original upper surface of the Denver beds was probably a few hundred feet lower, their present greatest elevation at the top of Green Mountain being about 7,000 feet. No recent conglomerate has been recognized which can surely be correlated with that often found along the mountain flanks overtopping all Tertiary beds, and which, from analogy with its best-defined representative at present known, the Wyoming or Bishops Mountain conglomerate of the Uinta Mountains, may be assumed to have been formed previous to the greatest extension of the ice of the Glacial period. On the other hand, opposite to Green Mountain there is evidence of a former peneplain at about 7,500 feet extending westward through a gap in the Archean foothills to the upper and glaciated portion of the Clear Creek Valley, which might have been occupied by such a conglomerate that had since been entirely removed by erosion.[1] Whether such a conglomerate existed in this region or not, it is fair to assume from the relics of ancient peneplains now existing, such as the mesa region on the Arkansas divide, Raspberry and Dawsons buttes, and Green Mountain, that, at the commencement of the earlier erosion epoch, the Denver Basin was a gently sloping plain reaching an elevation of about 7,500 feet at the present foothills. Whether the erosion commenced before Glacial time or not, it is probable that the greater part of its work was accomplished during that time, when erosive action must have been far more vigorous and destructive than before or since.

Modern erosion, as will be shown later, has accomplished but little more than the partial removal of the material that was deposited over the plains area in the intermediate period. An idea of the amount of this earlier erosion may be formed when we consider that the beds of the tortuous V-shaped canyons of the principal streams that to-day issue from the mountains, and which have been carved out of the hard crystalline rocks, are for many miles above their mouth a thousand feet lower than the actual summit of Green Mountain, and that the present site of the city of Denver, over which the comparatively undisturbed Denver beds then stretched, is now 1,800 feet below the higher members of that formation on Green Mountain. It is impossible now to determine how much thinner these beds became as the distance from the source of their material along the foothills increased, or to calculate what allowance should be made for the original slope of the beds, but it is safe to assume that 1,000 to 1,200 feet of these recent beds have been removed from the lower portions of the modern valleys.

This period must have been one of enormous precipitation as compared with that of the present day, and its rivers were consequently many times

[1]Mr. Cannon is inclined to consider the bowlder beds that at present cap Green Mountain to be relics of such a conglomerate. Mr. Cross, on the other hand, who has made a more detailed study of that mountain, considers them part of the Denver beds, whose disintegration would amply account for the numerous bowlders of various rocks, mostly Archean, that lie upon its present summit.

larger than the modern streams, as evidenced by the relative dimensions of their beds. With unimportant exceptions the streams of the present day have followed the same general courses as did their former gigantic representatives. As a consequence of the humid climate that must have prevailed, the erosion of the plains kept pace with the corrasion of the streams, producing a surface of low relief, of broad, shallow valleys and slopes that rarely exceed an angle of 5° with the horizon.

LOESSIAL EPOCH.

Following the period of erosion and waste, in consequence of some cause not yet definitely determined, but which probably resulted in a reduction of the general slope of the region, and may have been accompanied by some climatic changes, came a period of gradual increase of deposition over ablation, during which the stream beds were choked and filled with coarse gravel and sand, succeeded by finer material, until at length the whole region was covered with a varying but great depth of the finest silt.

The deposits formed during this period of deposition—which, as before indicated, has been called the loessial epoch—and prior to the modern erosion period, which has given the finishing touches to the surface sculpturing of the present day, may be divided into—

1. The river drift, including the fluvial loess.
2. The loess proper, including the glacio-natant drift.
3. The highland drift.

As will be seen later, it is possible that the glacio-natant and highland drift were formed almost contemporaneously, and are phases of the same general phenomenon, differing with local conditions of deposition.

RIVER DRIFT.

The wide drainage channels formed during the earlier erosion epoch were filled by alternations of coarse and fine gravels, sand, and clay, with cobbles and occasional bowlders up to 2 and 3 feet in diameter at the bottom, which present the characteristics common to ordinary river drift, such as cross-bedding and abrupt changes vertically and laterally. The material of which the drift is composed varies with that which constituted the floor of the basin that the ancient stream drained. Thus the drift of the ancient

Platte, like that of the modern Platte, is almost entirely the detritus of Archean rocks, and from the prevalence of pink orthoclase the gravel has a ruddy tinge that renders it easily distinguishable, even at a distance, from the whitish sand of its southern affluents. The latter, especially Plum Creek, have contributed considerable quantities of rock fragments characteristic of their respective basins, such as rhyolitic tuff from Castle Rock, cherts with poorly preserved Carboniferous fossils and Paleozoic red sandstones from Perrys Park, silicified wood and the harder sandstone of the Monument Creek beds, and smoky-quartz crystals from the granite of the Front Range.

The Platte drift is moreover distinguished from that of the smaller streams by being more generally stratified, and its gravel is commonly covered with rusty stains, resulting from the decomposition of the iron sands, and occasionally also with carbonaceous material, perhaps a remnant of former vegetation. These stains are generally absent from the drift of the smaller streams.

The western tributaries of the older Platte, which also drained Archean areas, contain only occasional fragments of basalt and andesite to distinguish their drift from that of the Platte. They contain also placer gold in quantities generally too minute for profitable working, but with considerable accompaniment of heavy, black sands. The size of the constituents of the drift varies in an inverse ratio with the distance which they have traveled. Thus the coarser sands of Clear Creek are readily distinguished from those of the Platte, and the latter again from the finer material of Plum, Cherry, or Sand creeks. At Sterling, about 150 miles below Denver, on the Platte, the drift of both the ancient and modern streams is reduced to a coarse sand.

The maximum observed thickness of the river drift, which is dependent on the width of its bed and the slope of the bed rock, is 25 feet, and 15 feet may probably be taken as a fair average of that of the larger streams.

Although modern erosion has removed a greater part of the mantle of loess from the drift deposits of the ancient streams, enough still remains to partly obscure their outlines, and measurements of the width of their beds can be only approximate. At Denver the attenuated western edge of the Platte drift may be noticed at many places along the western bank of the present stream, but its eastern rim is everywhere buried under the loess on the edges of the terrace known as Capitol Hill. Its extent is shown by wells that have passed through the loess into the sandstone below without finding it. It is probably safe to estimate the width of the ancient channel at a mile or more, while that of Clear, Sand, and Cherry creeks may be taken at half a mile, and a quarter of a mile may be allowed for the width of such streams as Bear, Deer, and Turkey creeks. Wherever examined the ancient stream bed was a giant as compared with its modern representative.

Fossils.—The character of these deposits is not such as to preserve remains of mollusks or plants, but a few vertebrate remains have been obtained from excavations for cellars of the larger buildings in the city of Denver, such as molars of a species of elephant and a few isolated bison bones.[1]

In Douglas County, sec. 36, T. 6 S., R. 67 W., a bone was discovered by Mr. Charles A. Coryell, in a tunnel driven in the ancient drift of Newlin gulch, at 47 feet from its mouth and 25 feet below the surface, encased in and partially replaced by arkose material. This was submitted to Prof. O. C. Marsh for identification, and was pronounced by him to be portions of the vertebræ of a cow bison, which had grown together as the result of some injury to the back received just below the hump. Although the bone is fossilized, it presents no anatomical features that distinguish it from the modern bison. If, as seems possible, and even probable, the injury to the vertebral column was caused by the weapon of a hunter, it would give a very ancient date for buffalo hunting upon the plains.

FLUVIAL LOESS.

Along the western bank of the Platte near Denver the river drift passes upward through layers of sand and gravel which frequently exhibit a cross-bedded structure, into a silt from which the layers of sand have disappeared, though the stratification still remains, and which closely resembles the loess proper. It has, however, a larger proportion of argillaceous material, and is distinguished from the latter by its considerable content of

[1] From the cellar of the Power House, corner of Lawrence and Eighteenth streets, and of the McClintock Block, corner of Larimer and Sixteenth streets. The latter are now in the collection of the Mercantile Library.

grains derived from the Denver beds and by its resistance to the passage of bowlders such as constitute the glacio-natant drift in the loess proper.

The maximum observed thickness of this formation is 35 feet. It has been noted in isolated patches from Overland Park to the Seventh Street Bridge, the largest being that at the mouth of Green Mountain (Dry) Creek. Its greatest width, at right angles to the course of the stream, is about one-fourth of a mile.

The exposed surfaces of the fluvial loess are frequently stained with calcareous material, and pulverulent calcareous concretions abound in the silt.

Minute mollusks of the genera Pupa, Planorbis, Succinea, Physa, and Limnea are common fossils in the fluvial loess. Numerous bones of the ancient horse, bison, and elephant, together with those of small rodents, have also been found in it.

THE LOESS.

The eastern portion of Colorado below the present level of 5,800 feet, wherever not denuded by recent erosion, is covered by a mantle of fine, porous, nonindurated material that possesses the physical characteristics of a typical loess. It has the cuboidal fracture and remarkable homogeneity that produces vertical faces of erosion, and bears no evident relation to the varying composition of the floor upon which it rests. Near the foothills its color is dark-brown; at Denver it has faded to an ash-brown or reddish-buff, while in the eastern portion of the State it is nearly devoid of coloring matter. For about a yard below the surface it has a somewhat darker stain from the infiltration of carbonaceous matter, resulting from the decomposition of the scanty vegetation of the plains. Except for these accidental variations of color there is nothing in the external appearance of the material that would enable one to distinguish samples obtained from localities hundreds of miles apart. Material having similar characteristics extends through Kansas and Nebraska to the Missouri Valley. Loess, as is well known, is not a definite chemical compound, but a mechanical mixture of very finely comminuted detritus, more or less decomposed, and generally, though not necessarily, infiltrated with carbonates (and sometimes phosphates) of lime and magnesia.

The loess of eastern Colorado shows in its physical characteristics indications of some changes in chemical composition. Thus the lower portions, where exposed, contain frequent white, pulverulent spots, due to the infiltration and concentration of carbonate of lime from the upper beds, which sometimes, though rarely, develop into the männchen forms found in the Rhine loess. A general decrease in argillaceous material as the distance from the mountains increases is shown in loss of plasticity and decreasing ability of the loess to maintain vertical faces in artificial excavations. The paler color of the loess and of the bricks made from it indicates also a decreasing proportion of ferric constituents.

Chemical and microscopical examinations were made of a few characteristic specimens of loess and soil from different parts of the region under consideration. These confirm in general the above indications, and show, moreover, that the fineness of grain and the degree of decomposition of the component parts of the material are also proportional to the distance from its source. It contains in all cases a large proportion of fine sand, separable by washing, whose grains are generally under a millimeter, but rarely less than a tenth of a millimeter, in diameter.

In the loess from North Denver a rough calculation showed that this sand contains about 40 per cent of quartz, 50 per cent of feldspar, and 10 per cent of other constituents. The latter include white mica and magnetite, with augite and hornblende. The feldspars are more or less decomposed, and the quartz grains are sometimes rounded, sometimes angular. Some of the material taken at 20 feet from the surface is recognizable as eruptive and probably derived from the Denver beds. This loess is friable, crumbling easily in the fingers, and appears to contain no cementing material, as is confirmed by the absence of carbonates in its analysis.

The loess from eastern Colorado, near Wray, is a fine-grained, slightly coherent sand, with a coating of carbonate of lime covering the grains and acting as cement. The sand itself contains the same constituents as the Denver loess, but the quartz is in larger proportion. At some distance from the surface it is more coherent from its greater proportion of carbonates, and the concretions contain sufficient lime to make nearly 80 per cent of carbonate if it is all in that form.

The loess-like earth from Cheyenne contains a greater variety of minerals among its constituents than any of the samples examined, and a larger proportion of cementing material. The former may be explained by the proximity of their probable source, the pink granite near Sherman, and the latter may have been derived from the Tertiary limestone which occurs in the vicinity. Among the microscopic grains are several minerals having a high angle of refraction, one of which is apparently isotropic and resembles a diamond.

In the following table are given the analyses of samples of loess from Colorado, to which are added, for purposes of comparison, those of loess from the Mississippi and Rhine valleys:

Analyses of loess.

Sample	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Locality	Golden.	North Denver.	North Denver.	Wray, Colo.	Cheyenne, Wyo.	Dubuque, Ia.	Galena, Wis.	Kansas City, Mo.	Vicksburg, Miss.	The Rhine.
Depth	Surface.	8 feet.	20 feet.	(?)	Surface.	(*a*)	(*a*)	(*a*)	(*a*)	(*b*)
Analyist	Hillebrand.	Eakins.	Eakins.	Eakins.	Eakins.	Riggs.	Riggs.	Riggs.	Riggs.	A. Bischof.
SiO_2	72.312	69.27	60.97	70.63	67.10	72.68	64.61	74.46	60.69	62.43
Al_2O_3	12.664	13.51	15.67	10.43	10.26	12.03	10.64	12.26	7.95	7.51
Fe_2O_3	4.669	3.74	5.22	2.58	2.52	3.53	2.61	3.25	2.61	5.14
FeO	....	1.02	.35	.48	.31	.96	.51	.12	.67	....
CaO	1.147	2.29	2.77	4.64	5.88	1.59	5.41	1.69	8.96	9.87
MgO	.914	1.09	1.60	1.13	1.24	1.11	3.69	1.12	4.56	1.65
CO_2	....	Tr.	.31	2.59	3.67	.39	6.31	.49	9.63	9.34
P_2O_5	.228	.45	.19	.20	.11	.23	.06	.09	.13	....
K_2O	3.748	3.14	2.28	2.50	2.68	2.13	2.06	1.83	1.08	*c* 1.75
Na_2O	2.472	1.70	.97	1.29	1.42	1.68	1.35	1.43	1.17	
H_2O (ignition)	1.797	4.19	9.83	3.77	5.09	2.50	2.05	2.70	1.14	2.31
MnO, TiO_2, SO_3, and C	....			......	...	[illegible]	[illegible]	[illegible]	[illegible]	
Total	99.981	100.40	100.16	100.24	100.28	100.21	99.99	99.78	99.54	100.00

a Sixth Ann. Rept. U. S. Geol. Survey, p. 282.
b Chem. u. Phys. Geologie v. G. Bischof, Bonn, 1863, Vol. I, p. 504.
c By difference.

Sample I was taken from near the foothills at Golden, and shows in its higher proportion of alkalis that the material is relatively little decomposed.

Sample II is from 8 feet below the surface on the Boulevard near Ashland avenue, North Denver, and is regarded as typical of the Denver loess.

Sample III is from 20 feet below the surface near St. Luke's Hospital, North Denver, and is regarded as an early loess. It contains grains of eruptive rock similar to that in the Denver beds.

Sample IV is typical eastern Colorado loess from near Wray, Colo., in which carbonates have increased from practically nothing to over 8 per cent.

Sample V is a loess-like earth from near the State House at Cheyenne, Wyo.

In spite of its great homogeneity, Mr. Cannon thinks that he has found evidence, in the vicinity of Denver, of variations in degree of compactness and induration of the loess in its behavior where excavated, portions yielding readily to the shovel, other portions requiring vigorous use of the pick. Moreover, on vertical surfaces exposed to æolian erosion a marked horizontal stratification may be observed.

The loess appears to attain its greatest development on what is known as the Flats, near the eastern State line, where its maximum thickness, as shown by wells sunk through it to the water-bearing stratum below, is 225 feet. The average thickness over what is known as the rain belt of Colorado may be taken at about 125 feet. In the vicinity of Denver it has nowhere been found thicker than 40 feet, nor are any such great thicknesses found within the Denver Basin. This may be attributed in part probably to original deposition and in part to greater subsequent erosion.

Fossils.—Neither invertebrate fossils nor plant remains have been observed in the loess of the Denver Basin. It seems better adapted, however, for the preservation of vertebrate remains. Bones of two species of Elephas and of ancestors of the modern bison are not uncommon. Portions of six skeletons of an ancient species of horse, differing but slightly from the modern *Equus caballus*, have been found within the limits of the city of Denver; also an isolated metapodial bone bearing considerable resemblance to that of a camel.[1] Skeletons of frogs, snakes, and such small rodents as Cynomys, Geomys, etc., have also been found near Denver, but may be foreign intrusions.

Mr. Thomas Belt[2] has recorded the discovery by him of human remains, consisting of the top of a skull and a portion of a rib, in a cutting in undisturbed loess on the Colorado Central Railroad between the Platte and Clear Creek, at a depth of 3 feet 9 inches from the surface. His sudden death and the loss of his specimens and notes unfortunately prevented a thoroughly satisfactory verification of this discovery. An examination of the spot where the bones were found shows that his assumption that the loess is undisturbed is probably correct, but no more human remains were discovered.

[1] Professor Cragin, of the Colorado College, pronounces some bones submitted to him from both river drift and loess (and possibly from the fluvial loess), and supposed to be bison bones, to be species of Auchenia, allied to llama, alpaca, and more remotely to the camel.

[2] Proc. Am. Assoc. Adv. Sci., St. Louis meeting, August, 1878, p. 298.

GLACIO-NATANT DRIFT.

Wherever in the Denver Basin a good exposure of the contact between the loess and the underlying sandstones is observed, the bed-rock is generally found to be strewn more or less thickly with rock débris that must have been brought from a considerable distance. It is often found not directly at the contact but suspended in the body of the loess up to a distance of 2 or 3 feet from the bed rock. This débris is mostly well rounded, though angular fragments are occasionally found. The size of the fragments mostly exceeds the power of transportation of streams of the present day, and sometimes attains a yard in diameter. They are frequently covered by a coating of calcareous cement, up to an inch in thickness.

On eminences below the level of 5,800 feet, from which the loess has been mostly or entirely removed, the former presence of this drift is indicated by the bowlders left on the surface, which, in such cases, can be distinguished from the upland drift only by their calcareous coating. The presence of the drift is also indicated, where the loess still remains, by bowlders taken out from wells just before the sandstone bed rock is reached. The vicinity of Denver is consequently the best place to observe it, and it is characteristically shown on the hills near Berkeley Lake, Overland Park, and the former Gentlemen's Driving Park; also on the mesa between Bear and Clear creeks and the Platte River. A considerable portion of the drift on Capitol Hill, in Denver, has been derived from the neighborhood of Dawsons Butte, which is 40 miles distant. It is noticeable that material from the Arkansas divide region is rarely, if ever, found on the north and west side of the Platte; nor is the material from the mountains about Golden, which is strewn abundantly over the hills west of the Platte, found to the east of it. The small grains of sand in the loess show a like diversity of origin with the stones in the glacio-natant drifts.

Where an ancient river bed is covered by the loess, the large number of pebbles derived from the head waters of the stream that occur in the loess will often serve to indicate the former course of the stream. Thus a considerable portion of the ancient channel of Sand Creek is now buried under a northern continuation of Capitol Hill, and may be traced by fragments of silicified wood and of rhyolite from the Arkansas divide region. The coarse grain of the loess composing the western edge of Capitol Hill is due to the fact that it covers a portion of the ancient channel of Cherry Creek.

UPLAND DRIFT.

Large quantities of erratic bowlders of more or less rounded form are found above the level of 5,800 feet along the foothills and on the mesas running out from them, as well as on isolated buttes in the plains that exceed this elevation, that are scarcely to be distinguished from the glacio-natant drift, except by their elevated position, by the absence of the calcareous coating, and by a generally fresher and less decomposed surface.

The material of which this drift is composed shows that it is mainly derived from the Archean areas of the mountain region, and along the foothills it is often accompanied by finer débris and transported soil. It may be seen to best advantage on the mesas near Colorado Springs and Palmer Lake, and also about Cheyenne. Similar material is also found in the valleys between the Dakota hogback and the Archean foothills. To this class of deposits the name of Upland drift has been provisionally assigned by Mr. Cannon, though it is by no means certain that the material is in all cases of contemporaneous deposition and constitutes a well-defined formation. More detailed study will be required to elucidate this point.[1]

MODERN EROSION EPOCH.

The change from a period of deposition to one of erosion and removal may be assumed to have been caused by a change in the general slope of the region, or by a relative elevation of the region nearer the sources of the streams in the mountains. Data are as yet wanting for determining the nature and amount of this elevation, but that some changes of level have taken place in recent times is rendered probable by the occurrence of faults in the ancient river drift and loess.

[1] The writer is inclined to believe that the material found on the higher mesas of the plains area is a residuary formation resulting from the disintegration in place of an unstratified conglomerate, similar in origin to the Wyoming conglomerate of the Uinta Mountains, which at some period of general floods, probably before the ancient erosion epoch, spread as sheets of coarse gravel and bowlders over the general surface of the country to a considerable distance from the mountains, varying greatly in thickness, however, according to the configuration of the surface.

Whatever may have been the cause, whether increased precipitation or greater slope of the region, or both combined, there came a time when erosion attacked the accumulations of the previous epoch. The denuding agencies effected the removal of the loess from the river valleys and of large portions of the river drift, leaving the remainder of the latter deposit in continuous terraces along the sides of the flood-plains. They also deepened, for an average distance of 50 feet below their former bed-rocks, the grooves through which the old streams ran. The courses of the main channels do not always coincide with those of the channels of former times. As a rule the excavation commenced on the sides of the stream where the gravel was less thick than in the center. Lateral corrasion also made incursions into the sandstone banks, and near the mouths of the smaller streams new channels, diverging from the course of the stream, have been formed. The old channel of Cherry Creek diverges from its modern course and forms the side of Capitol Hill as far as Seventeenth street, where it turns toward the Platte, the characteristic gravel being found in cellars on Seventeenth and Eighteenth streets. The same gravel was found in the excavation for the State Capitol beneath a thickness of 20 feet of loess. In the smaller creeks material from formations outside of the present drainage area of these streams has been derived from the river drift of the old streams which extended into the region from which the erratic material was obtained. Small amounts of glacio-natant drift are sometimes carried into the stream from overhanging bluffs, e. g., the bluffs on Cherry Creek near Shackleton Place. Large amounts of loess were removed from the higher elevations, and in the area bounded by the foothills, the Platte, and Clear Creek often nothing remains but the glacio-natant bowlders with their white incrustations to indicate a former considerable thickness of superincumbent soil. North and south of this area the amount of denudation has been less; only the high ridges and knolls, protruding above the general surface, exhibit the basal portion of the loess, and a sandstone exposure is quite rare.

The loess, having been deposited in layers corresponding with the inequalities of the eroded sandstone floor beneath, presents surface features which in their broader outlines rudely conform to the reliefs of the buried surface. The minor details of sculpture, owing to the different materials in which the carving is effected and the diminished force of the degrading agencies, necessarily present different features. The characteristic resistance of loessial material to lateral erosion, and its readiness to submit to vertical corrasion, are admirably adapted to produce vertical lines of relief. On Sand Creek, cliffs of this material show vertical faces 30 to 40 feet high, and oppose a resistance to weathering and the lateral corrasion of the stream comparable to that of an indurated sandstone.

The surface of the loess, except near the streams, where the edges are drained by finished drainage systems, is covered by a series of low ridges and knolls, and of shallow troughs and circular basins varying greatly in diameter and depth. No apparent system can be noticed in the arrangement of these features, nor do any of the ordinary agencies of erosion appear to explain their peculiar formation. Something of a similar nature has recently been noticed in the æolian loess of Asia, where it seems to have been formed by subsidence due to the removal of the lower layers by the action of underground streams. Where the bottom of a basin is formed in semi-indurated loess, the fine silt brought down from the surrounding slopes will form a sufficiently impervious layer to permit in dry areas the existence of small playa ponds, and in the rain-belt country and in irrigated districts of permanent ponds. The playas are of great value to stockmen in lessening the distance that animals must travel for water and thereby extending the amount of available range. The poor homesteader is saved, by proximity to a playa, the considerable expense of sinking a well for the purpose of watering his stock, and is only obliged to bring a few barrels of water for household purposes from the well of some more fortunate neighbor.

Æolian agencies have accomplished important work in finishing the minutiæ of the surface features. The patches of cactus (Opuntia) and the mats of the moss-like buffalo grass afford poor protection to the violent winds of the region. The loosened silt, resembling the surface on which it is deposited, can not be readily detected after a storm has moistened the soil. How far it assimilates with the surface, and to what extent it is washed into the streams, is a problem for future solution. At the foot of a slope of loess considerable accumulations of the coarser portions of the formation will be found, the result of checking the carrying capacity of the water flowing over the surface by the lessening of the slope on reaching level ground. East of Boxelder or Running Creek, sand dunes, formed by sand blown in from the east, make their appearance and increase in magnitude as one goes east. In eastern Colorado in many places the loess is concealed for miles by a deposit of whitish sand.

Cloudbursts, i. e., the precipitation of a large body of water in a limited area within the space of a few minutes, produce some extraordinary effects. On a plain some distance from a stream bed and a mile from the mountain from which the bowlders traveled, trains of stones have been found, some weighing 25 pounds or over, resting directly upon tufts of water-swept grass. Contrary to the proverbial inability of traveling stones to acquire accumulations, some of these bowlders in passing over a surface of argillaceous soil have acted as the nucleus for the formation of a ball of earth over a yard in diameter. Deposits of alluvium of small extent occupy the river beds below the level of the river-drift terraces.

When the material transported by a local storm reaches some of the dry stream beds of the plains, it is arrested by the absorption of its transporting force, water, and in this way there are left in the stream bed considerable deposits of sand, which when moistened occasionally form extensive quicksands. Such a bed on Kiowa Creek near Denver has so successfully swallowed a locomotive that in spite of diligent search it has never been found.

ECONOMIC FEATURES OF THE PLEISTOCENE DEPOSITS.

RIVER DRIFT.

PLACER GOLD.

The small quantities of gold contained in the river drift have played an important part in the early development of the city of Denver, and even of the State of Colorado. It was in the Platte River drift, near the present city hall, that one of the first discoveries of gold in the Rocky Mountain region was made, and to this was due the location of the first town site, originally known as Auraria. The richest grounds were found along the banks of the Platte from Overland Park to the Rio Grande workshops. None of the placers, were, however, sufficiently rich to yield large returns by the rude methods of working practiced at that day, and they were soon abandoned for the more promising deposits in the mountains about Central City and across the range in South Park. A few hundred dollars in gold are still obtained annually from surreptitious washings by the people near the Rio Grande shops. Placers of some value have been worked in former times near Elizabeth, Golden, and Arvada, and during the recent hard times a considerable number of men have earned wages in panning and sluicing the beds of the Platte and of Cherry and Clear creeks. In the digging of cellars in the business portion of the city, ground is frequently found that yields well to the pan, and were the land not more valuable for other purposes this ground might be made to pay by hydraulic washing.

Newlin Gulch placers.—Within the past year (1895) public attention has been directed to the so-called placer deposits of Newlin Gulch, a tributary of Cherry Creek that joins the valley of the latter a short distance below Parker Station, which is about 23 miles southeast of Denver, on the Denver and Gulf Railroad. A somewhat hasty examination by the writer has shown that these deposits are composed of detrital material resulting from the abrasion of the lower part of the Monument Creek beds, and which constitutes the river drift of an ancient stream bed. It is not possible to trace out the entire course of this ancient stream, but, in the limited area examined, it corresponds in general with that of the modern Newlin Gulch, which has, however, been cut down to a lower level, thus leaving the drift of the former valley in terraces and under talus slopes between the bluffs of undisturbed Tertiary strata and the bed of the modern stream. Tunnels have been driven into these ancient drift deposits at various points on either side of the gulch for a distance of 2 or 3 miles above the point where the Castleton ditch crosses it in a siphon. These tunnels are from 5 to 50 feet above the present stream bed, and disclose streaks of more or less iron-stained gravels which show abundant colors of gold to the pan, and are said by the miners to contain from $2 to $20 or more in gold to the ton. There is no running water in the gulch during the greater part of the year, but a water-bearing stratum, which yields a moderate flow, exists at the base of the Monument Creek beds, where they rest on the more clayey and impervious strata that form the base of the Monument Creek and the upper part of the Denver formation in this region. Outcrops of these beds are difficult to distinguish, as they readily disintegrate into soil, and the limits of the two formations in this region, as indicated on the map, have been drawn on grounds of probability between actually observed outcrops, often considerable distances apart.

In Newlin Gulch an actual outcrop of Denver beds forms a steep 25-foot bank on the west side of the stream, due west of Parkers Station and a short distance below the Castleton ditch, with 4 or 5 feet of auriferous gravels at the top. The Denver beds show at the base of the bluffs on the east side of the valley for perhaps a quarter of a mile higher up, and their presence is proved still further by the seepage of water at the base of the conglomerate gravel beds. In a well sunk in the stream bed about a mile upstream, which has a depth of 50 feet, the impervious stratum which forms the lower 15 feet of the well was found to consist of material characteristic of the Denver formation.

From the relative level of the points of contact of the two formations, as thus determined, and from the further fact that in the side ravines which have cut below this contact the flow of water is only on the north side, it would appear that the upper surface of the Denver formation in this region has a slight inclination to the southward.

Similarly situated auriferous gravels are said to exist in another tributary of Cherry Creek, a few miles south of Newlin Gulch, but so far as known none have yet been discovered in the valley of Plum Creek, which is much nearer the mountains from which the gold must have originally been derived.

Whether these deposits can be profitably worked on a sufficiently large scale to constitute an important source of gold is dependent not only upon the richness of the gravels themselves but also upon the width and extent of the ancient river bed and upon the cost of bringing in the water necessary to work them. These are problems for the mining engineer rather than for the geologist, and, in the light of present developments, seem well worthy of his attention.

They are of particular interest from a geological standpoint at the present time on account of the interest that attaches to the South African conglomerates, which have been supposed by some to be fossil placers. The material of which the Monument Creek beds here consist is chiefly granite, granite-gneiss, and quartzite, with some pegmatitic quartz; in other words, material in which gold is known to occur in the adjoining Colorado Range. South and west of the heads of Newlin and adjoining gulches these undisturbed beds extend in an apparently unbroken mesa as far as the eye can reach. Tests made of the disintegrated material on the top of the mesa show a small but fairly uniform content of gold in the beds. From these facts and from the character of the auriferous gravels it seems evident that the gold was not derived directly from the mountains, but is a concentration of that which had been carried out in the waters of the lake to a distance of at least 15 miles from its shore. The gold in the placers is generally well rounded and flattened, and in quite small particles, the largest observed being from 2 to 4 millimeters in diameter and less than half a millimeter thick.

WATER.

Owing to its porosity the river drift readily absorbs large amounts of the water coming from rain and seepage from irrigation canals, and wells sunk to it often yield excellent water.

In the smaller towns this quality of the beds obviates for a time the necessity of constructing sewers, but the water in wells thereby becomes polluted and with an increase of population the gradual accumulation of decaying organic matter is liable to generate disease.

A farm situated on river drift will require a greater quantity of water for irrigating purposes than one situated on the more impervious loess, and this difference may limit its profitable cultivation in dry seasons.

LOESS.

SOIL.

The loess of the Denver Basin forms a soil that, though lacking in organic matter, needs only the vivifying action of water to produce large and frequent crops. It is thus peculiarly well adapted for a region of farming under irrigation. No part of it, however, is sufficiently impervious to resist the passage of water through it, and this passage tends to rob the surface of its soluble elements of plant food and concentrate them in the lower levels. Hence the soil covering a thick deposit of loess is not generally so rich as that covering an area from which the upper and leached-out portions have been removed. Thus the soil of Capitol Hill is inferior to that in Highlands, where the loess is comparatively thin. In places where it is thin, trees and plants that have deep roots often manage to dispense with irrigation, since their roots reach the moister portions near its base.

WATER.

The loess is all more or less porous, so that water percolates through it to the bed-rock below, and where a permanent supply of water is needed, wells must be sunk entirely through it. This constitutes a serious impediment to the settlement of the areas on the divides in the eastern part of the State where great thicknesses of loess remain, as the expense of sinking a well over 100 feet deep is too great to be borne by the ordinary homesteader. The height of the water-saturated loess above bed-rock depends naturally on the varying conditions of the bed-rock, and on the amount of water received from the surface. It is hence found to be much higher below irrigation ditches than above them, and a lowering of several feet is noticeable in the water of wells below ditches when the water is shut off from them in the autumn.

In spite of its general porosity, there appear to be certain portions or layers that are sufficiently impervious to retain some of the percolating water, and thus constitute a false bed-rock. Fields resting on such layers will require less water than others, and deep plowing will sometimes injure them by breaking up the more impervious layer. The seepage of water often aids in producing an artificial layer of the impervious type, so that after some years of irrigation fields require less irrigation than at first.

Below irrigating ditches the depth of wells affords good criteria for determining the thickness of the loess, but is less certain above, as it is often necessary to bore for a considerable distance into the bed-rock before a permanent supply of water can be obtained.

BRICK CLAYS.

The loess affords the greater portion of the brick earth used in the State, and, although somewhat deficient in argillaceous constituents, makes an ordinary brick that answers the requirements of the climate. The alluvium of the streams is also used for the same purpose.

Small portions of gold in the silt have become concentrated on the surface of the sand rock beneath the loess, but it has not been found in sufficient abundance for profitable extraction.

ORIGIN OF THE LOESS.

It was not practicable in the course of the present investigation to make such an exhaustive study of the material that has here been given this name as would definitely correlate it with similar material in the Mississippi Valley or throw any new light upon the general question of the origin of loess. Still, it may be well to discuss briefly the facts that have been determined which bear upon this question.

The origin of loess has long been the object of much speculation among geologists, and various theories have been advanced to account for it. For a long time the theory most generally received in Europe, where it was first observed and studied, was that it is glacial silt, accumulated in temporary and somewhat ill-defined basins, but difficulty has always existed in accounting satisfactorily for the inclosing of these basins, on account of the peculiar positions, in reference to the present topographical configuration of the region, in which the loess is sometimes found.

Von Richthofen's study of the great loess deposits of northwestern China and his demonstration that they are the accumulation of wind-transported material from the great steppes of the interior of Asia, produced a great change in theoretical views of geologists, and a probable æolian origin was adopted by many for the loess of Europe and even of the Mississippi Valley.

The geologists who of late years have made studies of the loess of the Mississippi Valley generally tend, on the other hand, to return to a glacial origin for the loess of that region. The latest writer[1] on the subject

[1] W. J. McGee, Pleistocene history of northeast Iowa: Eleventh Ann. Rept. U. S. Geol. Survey, 1881, p. 302.

expresses himself without reserve in the following unqualified terms: "The deposit represents the finer grist of the ice mill laid down in ice-bound lakes and gorges as the Pleistocene glacier shrunk by surface melting and retreated northward." Chamberlin and Salisbury, as a result of their extremely careful and exhaustive studies of the loess of the Upper Mississippi Valley, are less decided in the expressions of their views.[1] While admitting the advantages of the æolian theory in certain respects, they find that it does not account for the conspicuous stratification of the thicker parts of the deposit along the great waterways, for the occasional presence of aquatic shells, etc., and conclude that the loess is an assorted variety of glacial silt directly derived from glacial waters, and that the time of deposit was during the closing stages of the second episode of the first Glacial epoch. After mature consideration of the difficulty of accounting for such a body of water as would admit of the deposition of so finely divided a silt over practically the whole length of the Mississippi Valley, and with the peculiar distribution that the present deposits possess, they conclude that, owing to crustal deformation, the present slope of the land toward the ocean was so reduced that the water was in an intermediate condition between a broad river and a lake.

The deposits considered by the above writers are confined to areas which were within the drainage system of the great northern ice sheet, and in general occupy broad belts along the general waterways represented at present by the valleys of the Mississippi and Missouri rivers. Westward across the plains through Nebraska and Kansas stretch similar deposits which have not yet been carefully studied, but from a perusal of existing descriptions and somewhat hasty personal observations the writer has little doubt that they are part of and were once continuous with the deposits that have been described above. According to Aughey,[2] the loess of Nebraska has an average thickness of 40 to 60 feet, and in places is found 100, 150, and even 200 feet in thickness. R. Hay,[3] who for some reason not apparent in his report, designates it the Tertiary marl, describes the loess

[1] Driftless area of the Upper Mississippi Valley: Eighth Ann. Rept. U. S. Geol. Survey, 1885, pp. 286–307.

[2] [Eighth] Ann. Rept. U. S. Geol. and Geog. Surv. Terr. for 1874 (Hayden), 1876, p. 245.

[3] A geological reconnaissance in southwest Kansas: Bull. U. S. Geol. Survey No. 57, 1890, p. 35.

as thickest on the high prairies between the main water courses, where wells are sunk through it to depths of 100, 150, and 180 feet in order to reach the water-bearing stratum (Tertiary grit) below. From the descriptions given by the above-named observers there would appear to be a very close correspondence in physical characteristics between the loess of Kansas and Nebraska and that of eastern Colorado, but no microscopic or trustworthy chemical examinations[1] appear to have been made of the material from either of those States.

As compared with the loess of the Mississippi Valley, the loess of Colorado would appear to be somewhat coarser, though data are wanting for any definite comparison. The greater part of the former, up to 80 or 90 per cent according to Chamberlin and Salisbury, is not more than 0.0025 mm. in diameter, while the coarser sand, which constitutes a considerable through not a definitely known proportion of the Colorado loess, has a grain between 0.1 and 1 mm. in diameter. The grain of the Colorado loess, moreover, appears to decrease in size as the distance from the mountains increases.

The chemical composition of a mechanical mixture like the loess is not an absolute means of correlation between widely separated bodies of material, but is rather useful in indicating local differences of origin in the same general region. Still, a comparison of the analysis of material from the two localities discloses nothing inconsistent with similarity of origin.

The Colorado loess exhibits an appearance of stratification that in its lower portions, near the waterways, is very marked, which is in favor of a subaqueous deposition. A still stronger argument in this direction is afforded by the glacio-natant till, which can best be accounted for as having been dropped from floating ice while the sediments were still in a sufficiently incoherent condition to admit of the fragments sinking through to or near their base. The fact that the deposits extend up only to a given level, and are wanting above that level, is probably the strongest argument against the æolian and in favor of the aqueous theory.

[1] Aughey's report gives five analyses of loess from different parts of Nebraska, but these bear such internal evidence of having been either badly made or incorrectly reported that no reliance is placed upon them.

As against the suggestion which has been made that the loess deposits of the Great Plains are material that has been transported by the prevailing west winds across the mountains from the arid interior basins of the Cordilleran system, as were the Chinese deposits from the steppes of the interior of Asia, is the negative evidence of the absence, so far as the writer's observations go, of similar deposits in the higher valleys of the mountains themselves.

On an assumption, similar to that of Chamberlin, that the deposit is a rearranged glacial silt, most of the above facts can be satisfactorily explained. The relative coarseness of the material would be due in part to the inferior mass of ice, as compared with the great continental ice sheet, which had ground it down, and in part also to the nearness to its source and its consequent relatively earlier deposition. If the sheet of water in which it was deposited did not uniformly cover the entire region, the more finely comminuted material, especially in the vicinity of the ice front, might have been blown into the water in considerable quantity, and thus have produced some of the assorting in the final deposit which distinguishes loess in general from actual glacial silt. The difficulty commences, however, when one attempts to account for the water body in which this material was deposited. The deposition of such finely comminuted material from a body of water requires a long time and extremely tranquil conditions. It was thought at first that the upper valley of the Platte might have been at one time an inclosed basin, and special investigations were made for finding relics of some barrier that might have inclosed it, but in vain. It was found, on the contrary, that on the present watershed, between the Platte Valley and the head of the Republican River, the deposits of loess are now thicker than in any other part of the basin, and were probably once continuous with those of Kansas and Nebraska; hence the sheet of water in which the loess was deposited must have extended more or less continuously over the whole plains area. Such a body of water, with little or no movement, could not have existed with the present slope of that area, but its bed must have been nearly level.

It has already been stated[1] that since Pliocene times the Great Plains

[1] Rept. Geol. Explor. 40th Par. (King), Vol. I, Systematic Geology, pp. 488–489.

area must have been tilted up from a nearly level position so as to produce a relative difference of level between its eastern and western borders of nearly 7,000 feet, and if this be admitted the conditions essential for a slow-moving body of fluvio-lacustrine water in which the loess could have been deposited, as suggested by Chamberlin, might have been fulfilled. But previous to the loessial epoch, as has been already shown, there was a time of more rapid erosion than that of the present day, which involved a decided slope of the land; though with greatly increased volume of water, under the then prevailing conditions of precipitation, this slope may not have been so great as that which exists at the present day. It is conceivable that with the immense freshets that may be assumed to have occurred during the melting of the ice, enormous amounts of rolled gravels may have swept down from the mountains, and when the slope of the stream beds was not sufficient to carry them forward the finer material may have been spread out in a more or less continuous sheet over the adjoining country. The deposit which, according to Hay, is so prevalent under the loess of Kansas, constituting the water-bearing belt of that region, which he denominates the Tertiary grit, might be perhaps contemporaneous with the river drift.

It were useless in the present state of knowledge to attempt to speculate upon the age of the deposits that have just been considered, relative to the supposed divisions of the Glacial period. Gilbert's investigations in the Great Basin have shown that two periods of great precipitation prevailed during Pleistocene time, with an intermediate period of relative aridity, which he assumes to have been more or less contemporaneous with the Glacial period. The writer found evidence in the vicinity of Leadville of two maximal extensions of the ice, separated by a warmer period, during which it was partially melted and a great body of water was impounded at the head of the Arkansas Valley. But it is by no means proved that these maximal extensions corresponded with those of the continental ice sheet. Still less is it possible to correlate either of them definitely with the deposits described above, and this must be left for later investigation by special students.

CHAPTER V.

By Whitman Cross.

IGNEOUS FORMATIONS.

SECTION I.—GEOLOGICAL OCCURRENCE.

INTRODUCTION.

The igneous rocks occurring within or adjacent to the Denver Basin occupy but little space in comparison with the sedimentary rocks. In making this statement the granites and gneisses of the supposed Archean complex are not taken into account. These are no doubt igneous in origin to a very great extent, but, as already explained by Mr. Emmons, no special study of the pre-Cambrian rocks has been undertaken, and they are, therefore, left out of consideration.

Of the rocks to be discussed, basalt is the only one of much importance. From its occurrences conclusions may be drawn bearing upon several points of structural or historical geology.

BASALT.

Basalt appears on the plains, adjacent to the foothills, in dikes and in surface flows or sheets. None of the latter were poured out upon surfaces corresponding at all to surfaces of the present time, but they were originally surface flows. All masses come undoubtedly from a common source, though differing somewhat in composition and structure, owing to the varying conditions attending their consolidation. The dikes are to be considered as the channels through which the lava of the streams and sheets came to the surface. That they are now exposed at practically the same horizons as the sheets which issued from them is due to dynamic movements which are discussed in Chapter I. We now see but a remnant of the sheet which once existed, and have little data for the estimation of its former extent.

THE VALMONT DIKE.

Three miles east of Boulder, on the south bank of Boulder Creek, just above the little town of Valmont, there begins a sharp ridge which runs due east, almost continuously, for 2 miles. This ridge is caused by a vertical dike of doleritic basalt cutting at this horizon the Cretaceous shales and clays of the Fox Hills formation. The upper part of the ridge, toward its western end, is formed by a wall of basalt 20 to 40 feet wide which projects a few feet above the débris-covered slopes, beneath which lie horizontal shales. Near the abrupt western end the dike reaches its greatest height, which is not more than 200 feet above the creek bed. For more than 1 mile its course is nearly straight, with an undulating, gradually descending crest. The eastern extension is represented by a succession of knolls and small cones lying somewhat irregularly in the strike of the main dike, with smooth spaces between them, indicating that the superficial continuity of the basalt is broken. These isolated basalt masses are less and less prominent eastward, and the last observed outcrop, almost exactly 2 miles from Valmont, is simply a low mound lying in a pasture on the north side of the road. On the northern side the slopes of the ridge are abrupt; on the south, toward the western end, a terrace abuts against it, rising nearly to the level of the dike.

The rock forming the dike is compact, dark-gray, macrocrystalline basalt, properly designated a dolerite from its structure. It is fully described in the second section of this chapter. In the main part of the dike the rock is divided into quadrangular blocks of varying size, by three systems of fissures which run in horizontal and vertical directions, the vertical fissures being respectively parallel and normal to the side walls of the mass. The cracks parallel to the walls of the dike are nearest together, and in places the structure is practically tabular. No transverse columnar structure is developed.

From the above facts we may derive support for the supposition that the present exposures of the Valmont dike represent portions of an eruptive channel far below the horizon which constituted the surface at the time of eruption, for the structure found indicates that contraction resulting from the cooling of the mass did not progress so predominantly from the walls inward, as is often found to have been the case in dikes where a pronounced transverse columnar structure is visible. The more uniform cooling may be considered natural if we assume the dike to have been the channel through which large volumes of lava passed to the surface, thus heating up the adjacent strata before the final cooling began.

The strata traversed by the dike do not seem to have been much altered by the basalt, but the contact is so generally covered by débris that little direct evidence on this point is obtainable. However, it would be contrary to experience elsewhere in this district if any pronounced metamorphism should be found on the contact of the basalt and sedimentaries.

The walls of many fissures are coated by calcareous deposits, indicating former spring action. At the mound forming the eastern extremity of the dike the edges of the rocks are rounded and worn, apparently by the spring waters which deposited the white tufaceous matter now filling the wide cracks.

Hayden and Marvine refer to this dike in the Annual Report of the Hayden Survey for 1873[1] and a sketch showing the west end is given, but the statements are somewhat inaccurate.

THE RALSTON DIKE.

The second dike of importance is situated about 2 miles northwest of the northern edge of Table Mountain, and 14 miles a little west of south from Valmont. The dike rises abruptly on the south bank of Ralston Creek, about half a mile west of Murphy's coal mine, and extends for more than 1 mile nearly due south. Facing the creek the dike exhibits a broad cliff more than 1,000 feet wide and 350 to 500 feet high, with rude vertical columnar structure in places. Basalt is seen in place nearly down to the creek bed, while on the north bank are the Cretaceous shales and clays, and two or three narrow dikes of basalt, none exceeding 6 feet in width, which can be traced to the northwest for nearly 1 mile, where they disappear under the drift terrace. Excepting these comparatively insignificant offshoots, no basalt is known on the north side of the creek.

To the south the dike seems to be double, for there are two nearly

[1] Ann. Rept. U. S. Geol. and Geog. Surv. Terr. for 1873, pp. 29, 130.

parallel ridges inclosing a long, narrow basin containing a stagnant pool for which there is no drainage outlet. The western ridge is the larger and higher. It runs with a quite regular crest, upon which are two points, one of them reaching a height of 663 feet above Ralston Creek at the north end of the dike. Both ridges present unbroken outcrops along the top, while the outer slope of each is débris covered and partially grassed over up to within a short distance of the crest. On these slopes, however, shaly outcrops appear here and there so distinctly that it is plain that the contact with the basalt is not far from the actual outcrops of the latter. The inner slopes of both ridges are also quite smooth, but basalt appears occasionally, down almost to the level of the basin. Mr. Eldridge found some few shaly outcrops of Pierre strata on the west side of the basin, and the representation of the map, that this basin is caused by an included mass of Cretaceous shales, has much in its favor.

The two ridges unite at the north, and would apparently do so at the south were not the point of junction covered by a terrace formation.

At the south end of the western ridge the contact with Pierre shales is very clearly seen, while the eastern passes under the drift.

The rock of the whole mass is more compact, and hence darker, than that of the Valmont dike, and is quite similer to that of the Table Mountain sheets. A jointed structure producing thin, quadrangular plates or tablets, from 1 to 3 inches in thickness, is well developed on both ridges. These plates ring clearly when struck, and consist of quite fresh rock. A spherical sundering is locally seen, and the weathering of the basalt toward the southern end of the dike produces small, rudely spherical balls like those covering portions of the surface of Table Mountain.

The tabular structure referred to above has in part a relation to the walls of the dike, which seems to the writer to be peculiar. In the lower or eastern arm of the dike the tablets are formed by vertical cracks, parallel and normal to the side walls, and crossed by horizontal ones. The tablets are, however, arranged at right angles to the walls of the mass, not parallel to them, as would seem most natural. It would appear, therefore, that the maximum contraction in this mass was in the direction of its greatest length. As has been stated, this dike is situated practically parallel to the strike of the inclosing shales; and it is a demonstrated fact that the conductivity of sedimentary rocks is far greater parallel to their stratification than normal to it, yet it seems remarkable that this difference should have been felt throughout a mass of basalt 1 mile in length by 350 yards in width. This tabular sundering is perhaps best developed near the center of the eastern dike, opposite the basin. In this connection it is to be noted that the included Pierre shales must have become very highly heated and, as a consequence of their position, could not cool faster than the surrounding basalt. In further explanation of this unusual structure, it may be suggested that the continued passage of molten lava through this channel so heated the upturned shales on both sides that the greater conductivity parallel to the strike may have been able to manifest itself throughout the mass.

The large arm of this dike exhibits upon the crest near the northern end a pronounced tabular structure, in which the plates stand nearly vertical and are arranged in a gentle curve with the convex side to the north, i. e., the plates are approximately parallel to the probable end of the outline of the dike. The above-mentioned law of conductivity in sedimentary rocks no doubt explains this local structure. Tabular sundering is, however, not marked in the greater part of this arm, the joints producing no regular structure.

HILLS BETWEEN THE RALSTON DIKE AND TABLE MOUNTAIN.

Between the Ralston dike and Van Bibber Creek[1] are a number of small knolls or hills representing irregular arms of basalt which penetrate Cretaceous strata. These outcrops all lie nearly southeast from the south end of the Ralston dike, and in the direction of Table Mountain.

Beginning near the Ralston dike, the first basalt outcrop is in a round knoll. Only the top shows basalt in place, and shaly strata outcrop on all sides not far below. About 200 feet west of this is a short dike of irregular outcrop.

Between 700 and 800 feet southeast from the above knoll is a very irregular cone 150 feet high. This is caused by a dike which cuts through the apex of the cone, approximately parallel to the strike of the strata, but

[1] The local name of this small water course is Dry Creek, but as there are several others of the same name within the limits of this map, the name used upon the Hayden map is retained.

having an easterly dip, while the sandy shales dip 75° to 90° westerly. The contact surface is visible in several places, particularly on the west side, and the line is found to be quite irregular in detail. It runs higher up on the west slope than on the east. The sandy shales in contact with the eruptive rock are baked and hard, but no marked changes have been produced in them.

East and south of this cone, at distances of a few hundred feet, are two small masses of dike form.

A much larger body than any of the foregoing is that whose southern end is almost in the bed of the small arm of Van Bibber Creek, heading near Schooley's quarry, to the northwest, and which extends northward in irregular dike form for 1,500 feet, with an average width of 150 feet. Few distinct contacts are visible about this mass, and its outline as drawn upon the map is fixed in accordance with the rule used for all of these bodies in Cretaceous shales, viz, where the surface configuration is determined by the erosion of such soft material from about an undecomposed massive rock—as basalt—the contact lines must be quite closely indicated by the actual outcrops of the latter.

The remaining basalt body of note here included is the largest of the group. It lies directly east of the preceding, and forms a low and rather rounded hill. Between the two is a grassy depression. From east to west this mass measures about 1,500 feet, and from north to south 2,000 feet.

In all these masses the rock type is the same as in the Ralston dike, though a little more compact, especially in the smaller ones. Spherical sundering is very well shown in the largest body.

As already mentioned, it is rare that the contact surface is well shown in any of these masses, but it is perfectly clear from their relation to one another and to the known position of the strata that all represent eruptive channels which are approximately vertical and that the eruption occurred after the strata were folded about as at present. All consist of the type of rock shown by the two sheets of Table Mountain, and it is natural to consider the Ralston dike and the larger irregular masses near by as the channel through which the material of the surface flows came up. The smaller bodies are undoubtedly offshoots from one or the other of the larger ones, which may themselves be connected at no great distance from the surface.

Without visiting these outcrops, Marvine conjectured them to be remnants of surface flows.

THE SURFACE FLOWS OF TABLE MOUNTAIN.

The form of Table Mountain, which is implied by its name, may be clearly understood by referring to the map and to Pl. VII, its relations to plains and foothills being exhibited by the latter. It is caused by a capping sheet of basalt which has protected soft sediments from erosion. The stream of Clear Creek has cut a gorge several hundred feet deep directly through the mesa, dividing it into two parts, distinguished as North and South Table mountains.

THE BASALTIC CAPPING.

General description.—The protecting basalt sheet of Table Mountain consists for the greater part of two flows with no sedimentary rock between them. Upon North Table Mountain the two are everywhere distinguishable, and the total thickness of basalt is much greater than upon South Table Mountain, where over a large area but one thin flow exists.

The structure of the capping where two flows are present is quite uniform, and for North Table Mountain, at least, the following detailed description of the cliffs midway between the two large gulches on the south side will be found to have a general application at almost any part.

The contact with the soft tuffaceous strata is irregular on a small scale, the lower surface of the flow appearing rudely mammillar wherever exposed by the crumbling away of the tuff or by excavations, as in tunnels driven in on the contact, for water. For 1 or 2 feet above the contact the basalt is black and very vesicular, the cavities being small and distorted in shape through the movements of the half solidified mass. The rock of the next 70 feet upward is compact and uniform in appearance. Then begins an amygdaloidal zone 45 feet in thickness, in the lower portion of which the cavities are usually small, seldom exceeding 2 inches across, while in the central part they sometimes reach a horizontal diameter of 6 to 8 feet by a height of 2 or 3 feet, and in the upper portion are commonly small and of very distorted shapes. At about 115 feet above the tuff the upper limit of the lower sheet is reached. The rock is here exceedingly porous, or even scoriaceous, and the surface of the flow is rough and jagged, resembling markedly that of many modern lava streams. Resting immediately upon this rough surface is a second sheet of basalt, identical with the first in all respects so far as can be known. There could have been but a short interval between the two flows, as no foreign substance appears between the sheets, and the jagged surface of the lower body shows no marks of erosion. The second flow was undoubtedly thicker and probably of greater lateral extent than the first, for, although as much as 140 feet of the second sheet may be seen in some portions of the cliffs, as at the southwest point of North Table Mountain, yet nothing corresponding to the amygdaloidal zone of the lower one remains.

The line between the two sheets is usually marked by more or less of a bench or break in the cliffs, specially noticeable along the southern face of North Table Mountain, a feature which makes the study of this zone practicable at numerous points. One of the best of these spots for the observation of the amygdaloidal zone is on the south face of the mountain, only a few yards west of the projecting point on the west side of the large gulch which here cuts into the table. The top of the débris slope here reaches up to a zone containing many large cavities partially filled with zeolites, and a small indentation in the cliff above makes it easy to examine the entire thickness of basalt here exposed. The greater number of the zeolites which have been described from this locality were obtained here, as earlier blasting had already opened many cavities in fresh rock.

On the little bench indicating the contact zone the upper portion of the lower sheet is seen to be a somewhat confused mixture of massive and porous material, similar to that shown on a much larger scale in Castle Rock, South Table Mountain. There are many angular cavities as well as the normal vesicles. The actual surface of the lower sheet is here quite scoriaceous. Resting upon this rough surface is the upper flow, which at the contact is also very porous and contains a few small cavities for 10 feet upward. A common feature of the porous semibrecciated portion of the lower sheet is the appearance in the cavities or fissures of a red zeolite in

SPHERICAL SUNDERING IN BASALT, NORTH TABLE MOUNTAIN.

small spheres, with a radiate structure, which are either loosely aggregated or form walls. They are sometimes embedded in another zeolite of similar color and granular structure. The former mineral proves to be thomsonite, the latter laumontite, with stilbite as a common associate. These zeolitic deposits are noteworthy because they frequently color this zone so that it is distinguishable at a considerable distance.

Débris of basalt accumulates at the base of the cliffs so that the lower contact is usually hidden, and the loose material may rise so that the foot of the bare cliff is at or near the top of the lower sheet. The débris piles consist of large blocks formed by the jointing, which is very pronounced. A good columnar structure characterizes the cliffs in many places, while the spherical sundering and other forms produced by weathering are also locally well developed. The photograph reproduced in Pl. XIV shows the perfection of the spherical sundering as exhibited on the south face of North Table Mountain near the main zeolite locality. The larger spheres are 2 or 3 feet in diameter.

North Table Mountain.—The upper surface of North Table Mountain is by no means so flat as it appears at a distance. Numerous shallow drains lead into the two large gulches and toward the minor indentations. There are, too, a few knolls rising to greater elevation than any point upon the cliff line. In one or two depressions are stagnant pools.

The highest point of the mountain, 6,599 feet, near its western edge, is a rather sharp knoll surrounded by minor points with connecting ridges, producing a series of semibasin-shaped areas, to which the fanciful name of "The Craters" has been locally given. Marvine, too, lends his support to the idea that they indicate the points at which the lava welled up and whence it spread out as a sheet.

In point of fact the area about this knoll represents the basalt of a higher horizon in the upper sheet than is now left at any other spot. The rock, which is here much bleached, is more coarsely crystalline than elsewhere, and the surface configuration, which alone suggested the term "crater," is due entirely to a peculiar development of jointing and to the manner in which a rock thus jointed is naturally affected by erosion. The accompanying illustration, Pl. XV, shows the structure about the highest point. Within certain large and rudely spherical spaces the basalt seems to have undergone a more perfect tabular jointing than in the areas between these spheres. The tablets of the spheres are smaller and thinner, and hence lighter and more easily removed than those of the intervening rock, and the result is that basin-shaped depressions are produced, separated by curved ridges that are sometimes quite narrow. None of these basins is entirely surrounded by a wall, as that would naturally prevent the removal of the rock fragments. Neither spherical sundering nor disintegration of the basalt occurs here, and the only visible reason for the "crater" forms lies in the variable jointing within and without these imperfectly spherical areas.

The basalt at this point is quite compact and contains no more small vesicles than may be found in the most massive parts of the lower flow. From analogy with the lower sheet this highest point must be at least 50 to 75 feet below what was formerly the upper surface of the flow, and it is probably 200 feet above the bottom.

The cliff at the southwest point of North Table Mountain shows fully 140 feet of the rock belonging to the upper flow. Ascending this cliff, through a crevice near the point, it will be noticed that the rude columnar structure prevailing in the lower parts passes by a horizontal fissuring of the columns into a tabular jointing which is most pronounced at the highest horizon remaining. The rock of the tablets is also much lighter in color and apparently coarser in grain than below, and thus approaches in character that found some 50 to 75 feet higher in the flow, at the points shown in Pl. XV.

South Table Mountain.—While the basaltic capping of South Table Mountain is, at some points along its northern face, resolvable into two flows, like those of North Table Mountain, this is by no means commonly the case. Instead of the regular structure described, there are many places along the cliffs of the northern, western, and eastern faces where the basalt from the tuff upward consists of solid and compact rock mixed most irregularly with very porous matter, producing a breccia-like structure. Sometimes uniformly compact rock appears above or below such brecciated material.

Castle Rock, the projecting point above the town of Golden, exhibits

TABULAR JOINTING IN BASALT, NORTH TABLE MOUNTAIN

this irregular structure very well, as will be seen from the illustration, Pl. XVI, taken from a photograph, which represents the composition of the southern face of this point. The high cliffs running east from Castle Rock are of quite massive rock until near the indentation at about the center of the northern face. For some distance east of this place the cliffs show a very irregular relation between compact and porous rock, and the fully normal status is not again shown on the northern face. This prominent northeast point of the mountain is likewise more or less irregular in its presentation of massive and porous rock.

The explanation of this structure consists in assuming that the earlier basalt sheet did not extend so far to the south as the northern line of South Table Mountain, but that it sent off arms or tongues of the common lava-like character, with high walls of rough, scoriaceous fragments cemented by parts of more compact rock. Over these arms and walls, filling the spaces between them, came the second sheet, itself broken and irregular in structure from the unevenness of the surface. The present cliff lines of the mountain give profiles across or parallel to these arms. The confused mingling of structures is most marked along the northern face of South Table Mountain.

The northern cliffs correspond nearly in height to the opposite ones of North Table Mountain, but the thickness of the capping decreases southward, until scarcely more than 10 feet remains in some places on the south line. This thinning is evidently in part due to erosion—for there is no amygdaloidal zone left when the basalt is very thin—but as this may be regarded as having been approximately equal over the whole mountain, it is plain that the lava itself thinned out. On the north slope of Green Mountain, 2 miles south from the southeast point of Table Mountain, there is a knoll, upon the summit of which loose, angular fragments of porous basalt lie in such quantity as to suggest that they represent a remnant of the sheet broken up in place. As no outcrops of basalt appear to the south, on the rising slopes of Green Mountain, it must be assumed that the lava did not extend so far in connected sheet form, but angular fragments strewn over the surface of several little benches of about the same elevation indicate the former presence of a thin sheet or of outlying arms of basalt.

THE EARLIEST BASALTIC OUTFLOW.

The capping sheets of Table Mountain do not represent the earliest surface flows of basalt in this region, for at various points on all sides of North Table Mountain, at a horizon which is quite uniformly 100 feet below the capping sheet, there appear typical streams of basalt. The present outcrops of these bodies form little cliffs on the edges of the benches occasioned by the presence of the eruptive rock, and all exposures seem to be sections of small streams. None of them reach as far south as South Table Mountain, and no dikes of exactly corresponding rock are known, for although a thorough examination of this type shows it to be petrographically identical with that of the more recent sheets, still it can always be recognized at once by its numerous augite crystals, which lie in a much darker and denser groundmass than is presented by the other type. The map shows the position and relative size of the six outcrops of this earlier rock that have been examined. By far the largest of these bodies appears below the high cliffs at the northeast extremity of North Table Mountain, forming itself a bench and minor cliff, distinguishable even from Denver. The southern end of this outcrop is well exposed by a gully which cuts across it. On the northern side of this small ravine the mass is shown as it rapidly thins out. The whole face here exposed is rough and very irregularly porous, with an almost scoriaceous crust of the same structure that is shown in the upper sheets. South of the gully a thin arm, 2 or 3 feet thick, consisting entirely of very vesicular lava, extends for some distance. To the north the body thickens rapidly and soon reaches a vertical thickness of 50 to 60 feet, which is maintained nearly to the extremity shown by the map on the north side of the mountain. When it reaches this thickness the mass has a structure much like that of the higher sheets. A porous zone adjoins the strata below, succeeded by massive rock in the center, and a thicker porous zone comes at the top. There are, however, no large cavities in these bodies, and they seldom contain other minerals than calcite and a green substance allied to delessite. There is a rude, vertical, columnar structure on the cliffs, and locally a spherical sundering.

On the western slope of the northeastern portion of the mountain is a small outcrop of similar character, whose extremities are covered by débris.

SOUTH FACE OF CASTLE ROCK, GOLDEN

The stream of the greatest extent after that first described occurs on the northwest slope of the mountain. It has caused a bench large enough to be indicated on the map. The eastern portion of this stream is thin and very lava-like in structure, with distorted and long-drawn-out pores. Under the bench its thickness increases somewhat, but probably does not reach that of the first mass, although an exact estimate is here impossible, owing to the débris. A small knoll north of the eastern end is capped by a remnant of this stream.

On the south slope of the mountain, between the two large gulches, are sections of two small streams, the western one being so exposed as to give a most excellent opportunity for the study of these masses. Approaching the outcrop from the west, on the same level, a thin sheet is first met with, consisting of very porous lava. This rapidly thickens eastward, and at its maximum the body is 50 feet thick. On the western side, where the mass is about 20 feet thick, the upper surface presents a mixture of scoriaceous basalt fragments with sand, and the whole structure reminds one most forcibly of the appearance of the walls of modern lava streams, which often consist of fragments of the quickly cooled crust broken and pushed along by the molten lava within, gathering up sand and foreign matter as the movement progresses. The eastern side of this section is covered by débris, but the mass certainly does not connect on the surface with a similar stream but a few hundred yards farther east. This latter body is not well exposed. The last stream to be mentioned occurs on the southeastern slope of the eastern point, and is of a size corresponding with the preceding. The body is a surface flow, as is shown very clearly in this case.

The structure of these simple lava streams has been repeatedly brought out in order that no doubt may arise, owing to incomplete statement, of their actual nature as surface flows, for this fact is important in explaining some problems in the geology of the district.

The structure of the lower lava streams and their uniform appearance at certain horizons may be affirmed as sufficient evidence of their nature as surface flows. They were covered by sediments of the same character and formation as those beneath them, and it is therefore quite probable that the streams were poured out upon a shallow sea bottom near the shore-line. As for the larger streams above, their structure is also emphatically that of surface flows, and no reason is known for objecting to the view that their time of eruption followed that of the lower streams by the period occupied in the deposition of the intervening 100 feet of Denver strata. It is true that there is nothing in the present position and appearance of the upper sheets of Table Mountain which might not be satisfactorily explained upon the supposition that the surface upon which the basalts were poured out corresponded to a comparatively recent surface of erosion. But when a lava of almost identical composition and so related in occurrence can be shown to be of the Denver epoch, there would seem to be no reason for claiming two widely separated periods of eruption of the same rock in the same small area. At least the burden of proof would seem to rest with any supposed advocates of the latter view. As a matter of fact, nothing is known incompatible with the former. The fact that the basalt sheets are not known in Green Mountain at a horizon corresponding to that of Table Mountain is simply explained by assuming the sheets to have been of very limited extent, an assumption also necessary in case the second view is adopted.

THE ZEOLITIC MINERALS OF TABLE MOUNTAIN.

General occurrence.—The minerals occurring in the amygdaloidal zone of the Table Mountain basalt have already been described in some detail by Dr. W. F. Hillebrand and the writer,[1] chiefly from the purely mineralogical standpoint. In this place some further facts of the mode of occurrence will be given, with suggestions as to the genesis of certain unusual varieties.

The list of species identified embraces the following: Analcite, apophyllite, chabazite, laumontite, levynite, mesolite, natrolite, scolecite, stilbite, thomsonite, calcite, and bole. All of these species except the bole appear in white or colorless crystals lining the various cavities in the basalt in more or less distinctly concentric layers, representing different periods of formation. Several of the species are often found together in

[1] Bull. U. S. Geol. Surv. No. 20, Contributions to the geology of the Rocky Mountains, p. 13, 1885; also, Am. Jour. Sci. (3), Vol. XXIII, pp. 452–458, Vol. XXIV, pp. 129–138, June and August, 1882.

one cavity, and with a general order of succession, to which, however, many exceptions may be noticed.

The species stilbite, laumontite, thomsonite, and calcite have another form of occurrence, in reddish or yellowish deposits whose characteristics will be specially discussed. The color of the minerals in these cases is due to ferric oxide in chemical combination in the silicates, and the deposits thus marked are older than the white or colorless varieties of the same species.

In regard to the occurrence of the white or colorless zeolitic species, nothing has been observed which appears to characterize this locality. They are found in greater or less abundance throughout the basaltic masses of both parts of Table Mountain in all kinds of cavities, but are best developed in the broad amygdaloidal zone of North Table Mountain. On all sides of the mountain the naturally exposed vesicles are found to contain zeolites in well-developed crystals, but on account of the blasting which has been done on the southern face of the mountain, near Golden, most of the described material has been obtained at this place, the crystals being fresher and cleaner than on weathered surfaces.

Nearly all of these species have a wide range throughout the mountain and also in the cavities of different portions of the basaltic masses. Scolecite and levynite have been clearly identified only at the main locality above referred to, and there only in the upper part of the amygdaloidal zone, in small pores, and usually with but few associates. Natrolite is also comparatively restricted in its occurrence, and appears to be most common on South Table Mountain.

For details concerning the development of individual species the reader must be referred to the publications cited above. Analcite, apophyllite, chabazite, stilbite, thomsonite, and calcite are found varying greatly in perfection and size. All but thomsonite occur in well-formed crystals in many places. Thomsonite is found only in radiate aggregates or spherules forming mammillary crusts. Scolecite is developed after the same manner as thomsonite, while natrolite occurs in long, acicular crystals more or less isolated. Levynite appears in crusts of small tablets set on edge. Mesolite is developed in minute spicules which form sponge-like masses or are woven into delicate films.

The general sequence of formation of the minerals is as follows: (1) Wine-yellow calcite, (2) stilbite and laumontite, (3) thomsonite in reddish spherules, (4) stilbite, (5) chabazite, (6) thomsonite, (7) analcite, (8) apophyllite, (9) mesolite. The first three of this series occur in the reddish deposits, described below; the others in the white or colorless series. No definite places can be assigned to levynite, scolecite, or natrolite.

Reddish deposits of the first period.—The colored minerals of the first period of zeolitic formation deserve some special description. They are found in the irregular cavities of the more or less broken, scoriaceous crust of the lower basalt sheet; in fissures leading down into the amygdaloidal zone, and in certain of the vesicles of this zone. They also appear to a less extent in some cracks and cavities of the earliest streams 100 feet below the main sheet. The character of this earlier zeolitic formation will be most clearly understood if the deposits of the vesicles are first described.

At almost any point of the circumference of North Table Mountain, within the zeolitic zone, it may be noticed that some of the cavities contain reddish-yellow deposits. The number of cavities containing such masses is relatively small, and while some of them may exhibit deposits a foot or more in thickness, directly adjoining pores are entirely free from anything resemblimg the formation in question. On examination of the deposit in some large cavity it is usually found to be characterized as follows:

In the first place, the mass is always found directly in contact with the basalt, no intervening mineral of earlier formation having been seen in any case. This deposit is therefore the first of the secondary mineral secretions.

Secondly, it is a striking characteristic that all these reddish zeolitic masses are horizontally bedded, and that when a cavity is but partially filled it is invariably the lower part which contains the mass, so that there remains a smooth, level floor to such a vesicle. In no case does the deposit of this period form concentric shells in the manner usual where there is a succession of zeolites in the pores of a volcanic rock.

Lastly, there is a sequence of species corresponding to the growth from below upward. Each stratum is quite uniform in composition, while successive ones may change materially.

In examining the mineralogical composition of the deposits found in different cavities a remarkable uniformity appears, and this is in strong contrast to the formations of the second period. The bottom of each mass is quite evenly granular, varying somewhat in density but usually compact, though resolvable with a good lens into a mixture of rude tablets and corresponding prisms which seldom, if ever, show a crystal termination. These two minerals were found to be, respectively, stilbite and laumontite. It is extremely rare that these two species are found in separate layers.

While the lower part of each deposit consists of the mixture above described, there may appear minute, isolated spherules of reddish thomsonite. At first few and far between, these spherules increase steadily in number upward in every deposit, and at last predominate strongly and even make up the entire upper layer. As the thomsonite increases it may frequently be observed that stilbite decreases, so that in the upper part of the mass it is not rare to find laumontite alone in the interstices between the thomsonite sperules.

Deposits similar to those just described occur in fissures which are not uncommon in the upper part of the basalt sheet and which reach a width of 1 or 2 inches. But the similarity is with the upper part of the stratified deposits in the round cavities, i. e., there is a development of thomsonite in a loose aggregate of spherules with laumontite or bole in subordinate quantity, and stilbite is usually wanting. Closely corresponding in composition to the filling of distinct fissures is that occurring in the more or less angular spaces at and near the crust of the sheet and on the actual upper surface of the flow when open spaces existed. As has been pointed out, the structure of the crust is due to the breaking and crumbling of the first-formed shell of a moving lava stream.

Genesis of the reddish deposits.—In consideration of all the above facts it seems to the writer that we may safely draw a number of conclusions concerning this earlier zeolitic formation. The appearance of the minerals deposited in stratified masses on the floor of amygdaloidal cavities, and the structure of the deposit itself, indicate that the solution out of which the minerals crystallized had comparatively easy access to the cavities, so that the liquid settled in the lower parts. The rate of crystallization was so rapid that the individuals of stilbite and laumontite mutually interfered with each other's growth, producing the even-grained mixture.

The fissures produced by contraction during the cooling of the mass would naturally furnish channels by which solutions from above might gain access to cavities in their courses, while excluded from others. And these very fissures are now indicated by veins filled with thomsonite spherules, laumontite, and bole. In the fact that the deposit in the fissure corresponds to the last layer in the cavities appears the explanation of the close of the period. When changing conditions caused the formation of thomsonite to succeed that of stilbite there began a deposition in the fissures themselves, and with the filling of the fissures the access of solutions to the cavities was cut off. As soon as this stoppage became complete the spaces remaining in the partly filled cavities were placed upon an equal footing with the other pores, and further deposition of zeolites could take place only in all alike through the slow penetration of the rock by the solutions. This is found to agree with the occurrence of species of the second period without reference to the presence of an earlier deposit.

It has been brought out earlier in this chapter that the sheet of basalt now yielding these zeolites was quickly followed by a second flow, and also that both sheets were probably covered by strata of the Denver formation, after the manner of the earlier basalts of the mountain. If these lava flows were poured out upon a sea-bottom we can suppose the resulting conditions to have been exceedingly favorable to the formation of zeolites such as are actually found. The porous zone between the flows would afford a channel for the comparatively ready circulation of sea water which would become highly heated from the half solidified lava. To these exceptional circumstances may be plausibly attributed the constant presence of ferric oxide, chemically combined, in all the silicate minerals of the first period.

AUGITE-SYENITE.

This rock is known only in a few small, irregular masses in gneiss, at a point west of the head of the north fork of Turkey Creek, and about $4\frac{1}{2}$ miles W. 20° S. of Morrison. It occurs in apparently irregular-shaped masses, forming small knolls, whose outlines can not be accurately determined owing to the heavily wooded ground which conceals the outcrops.

QUARTZ-PORPHYRY.

Some very limited dike occurrences of a quartz-porphyry in the vicinity of Boulder have been described by Prof. C. S. Palmer.[1] They were not observed in the field work for this report, and are too small to be represented upon the map.

SECTION II.—PETROGRAPHICAL DESCRIPTION.

INTRODUCTORY REMARKS.

It is the intention to present in the following sections petrographical descriptions of the more important and interesting rocks of the district. The more common sedimentary rocks and the Archean schists and gneisses are omitted from consideration, the former because their character has been sufficiently brought out in the discussions of formations, the latter because it was not within the scope of this report to study the mountain area, and the types of these rocks that have been observed are so simple and common that there is no necessity for detailed description.

The strata of the Denver formation are of peculiar interest both geologically and petrographically. The recognition of this important formation was originally due to its lithological character, and the materials of its sediments afford the only known evidence of a period of remarkable volcanic eruptions from a center not far distant. These rocks are therefore described in detail sufficient to demonstrate their peculiar character. The massive eruptive rocks naturally require description to bring out their characteristics.

BASALT.

The various masses of basalt occurring in the Denver Basin represent the structural modifications which have resulted from the differences in the conditions attending the consolidation of a certain magma.

The large dike of doleritic basalt at Valmont represents the magma cooling in the eruptive channel, probably 2,000 feet or more from the surface of the time of eruption. The Ralston and adjacent dikes and masses must have cooled under approximately the same circumstances as the Valmont rock. In the capping sheets of Table Mountain is seen the

[1] The quartz-porphyry of Flagstaff Hill, Boulder, Colo.: Proc. Colo. Sci. Soc., Vol. III, p. 351, 1891.

basalt of surface flows, each more than 100 feet in thickness and but 1 or 2 miles from the vent. The smaller streams of Table Mountain seem to represent the product of the first eruption of the magma, which was on a much smaller scale than the latter ones. With this relationship in mind the following descriptions will, to say the least, be of greater interest than they otherwise would be.

BASALT OF THE VALMONT DIKE.

Occurrence.—A description of the physiographic features of the Valmont dike has been given in Section I of this chapter, and it is here necessary only to repeat a few particulars. This dike is situated 3 miles east of Boulder and is about 2 miles long, with an average width of 20 to 40 feet. The rock is clearly shown in vertical position as it cuts the horizontal, friable, sandy shales of the Fox Hills Cretaceous formation.

Conditions attending the consolidation.—On the natural assumption that the very great similarity between the Valmont and Table Mountain basalts implies a practically contemporaneous origin of the two rocks, we must suppose the Valmont dike to have been formed during the early part of the Denver epoch. Through analogy we may infer that this dike represents a channel through which lavas corresponding to the Table Mountain flows were poured out upon the surface of that time, though these particular flows may more naturally be supposed to come from the nearer dikes on Ralston Creek. Between the horizon in the Valmont dike represented by the present outcrops and the land surface of the time of eruption there was a space filled by the upper strata of the Fox Hills, the entire thickness of the Laramie, and probably the Arapahoe formation, with perhaps a part of the Denver beds. Erosion has now entirely removed all but the first formation, but we have no evidence to show that the other deposits did not extend northward beyond the point in question.

The rock of the Valmont dike which is to be described was probably formed under the following conditions: The magma was in an eruptive channel 20 to 40 feet wide, at a distance from the surface of several hundred, or perhaps 2,000, feet. Its walls were of loose, sandy shales. When the magma became stationary the walls were presumably already heated from the passage of the lava, and the consolidation thus took place under considerable pressure, and where the cooling must have been very slow and uniform for all parts of the dike now visible.

Description.—The basalt of the Valmont dike is a dark greenish-gray rock with a porphyritic structure, occasioned chiefly by the prominence of black augite prisms, which reach a length of 1 cm. by a breadth of 0.5 cm. Close examination reveals some augites, and indistinct plagioclase tablets. A hand lens shows the mass of the rock to consist of plagioclase tablets quite irregularly arranged, and the dark color is partly due to minute black and green specks disseminated abundantly through the whole. Colorless olivine crystals appear to have a brilliant black, metallic luster through total reflection from curved fissure planes.

Microscopical investigation shows the rock to consist chiefly of plagioclase, augite, and olivine, while orthoclase and biotite are also important constituents, and magnetite and apatite play the usual accessory rôles.

The augite has a dull greenish-gray color and its phenocrysts possess the usual characteristics as to form and inclusions. The minute green grains visible with a hand lens are also augite, of the same properties as the large crystals. They are irregular in shape, and vary between 0.05 mm. and 0.20 mm. in diameter. They seem to be of a later generation than the large crystals, but it also appears that in this second period of growth the phenocrysts received local additions, causing the outlines of the most perfect prisms to become microscopically irregular.

Olivine is developed in normal form and abundance. It is quite fresh as a rule, but shows very beautifully in some crystals the process of serpentinization, the product being golden-yellow or sometimes greenish fibers normal to the fissures. There are many minute olivine grains corresponding in size to those of augite, but it is not evident that these are of a second generation, for there is an almost perfect gradation in size between these particles and the large crystals.

The main mass of the rock is feldspathic and its structure is visible only in polarized light. There are numerous narrow pinacoidal tablets of plagioclase 1 mm. to 3 mm. long, with fine laminæ twinned according to the albite law, and with further twinning after the Carlsbad and pericline laws in some cases. Extinction in the zone normal to the albitic twinning plane reaches an observed maximum of more than 35°, which indicates that the larger tablets are labradorite, or possibly a variety still richer in lime.

There are many smaller tablets or staves of plagioclase, with simpler twinning and a smaller extinction angle, and both these varieties are embedded in a feldspathic mass of irregular individuals formed in the last stage of consolidation. This last product is often added to the earlier crystals with coincident orientation, and a part of it is plagioclase, but there is so much of it free from polysynthetic twinning that in the light of the chemical analysis one is justified in assuming a still larger part to be orthoclase. Some plagioclase tablets are surrounded by feldspar extinguishing uniformly parallel to the twinning plane of the tablet. It is this added growth of plagioclase or orthoclase which makes it difficult to distinguish the larger labradorite tablets megascopically.

Biotite occurs abundantly and very regularly distributed throughout the rock in little, greenish-brown leaves, which are particularly associated with magnetite and olivine. Some flakes of biotite are included in augite and olivine, but the greater part seems to have developed after those minerals.

The accessory minerals magnetite and apatite need no special mention. Neither zircon nor titanium minerals have been noticed.

The structure of this basalt is somewhat unusual, in that the constituents formed during the period of consolidation in the dike do not form a groundmass sharply distinguishable from the phenocrysts brought up in the magma from below. The large augite crystals and the olivines are products of the first period of crystallization, and some of the plagioclase crystals also, but the latter grade so gradually into the series of crystals belonging to the second generation that the line between them can not be at all clearly drawn. The study of the other basalts to be described shows that a small number of the plagioclase crystals were in those magmas at eruption. Had the mass of the Valmont dike cooled a little slower it is probable that the resulting rock would have had a nearly typical granular structure, and the presence of crystals of two generations would have been especially hard to detect because of the irregular form exhibited by the old augite crystals, owing to resorption. Instances of granular diorites in which there were two periods of consolidation are known to the writer, and many other granular rocks may have had a similar history. It is therefore not essentially the contrast between the products of the first and second periods of consolidation which makes the porphyritic structure; nor is the uniformity of mineral development characteristic of the granular structure necessarily caused by consolidation within a single period.

Chemical composition.—The composition of the Valmont dolerite is given under I, and that of the augite from it under II. Both analyses are by L. G. Eakins.

Analyses of dolerite and augite from Valmont, Colo.

	I.	II.
SiO_2	48.25	49.10
TiO_2	.89	....
Al_2O_3	16.73	7.95
Fe_2O_3	3.99	....
FeO	6.28	8.30
CaO	8.32	22.51
BaO	.013	....
MgO	5.77	12.37
K_2O	4.08	Trace.
Na_2O	3.24	Trace.
P_2O_5	.68	....
Cl	.08	....
SO_3	.12	....
H_2O	1.72	....
	100.163	100.26

The rock analysis shows a normal composition excepting for the alkalies, but the predominance of potash over soda confirms the determination of orthoclase and explains its presence. This relationship of the alkalies is also found in the other basalts to be described, and is the leading characteristic of these rocks. The occurrence of orthoclase in basalt has occasionally been announced, but not often with chemical evidence sustaining the determination. In the present case it is entirely natural that the last substance to crystallize should be rich in potash. It seems probable that the abundance of biotite in these basalts is also connected with this higher percentage of potash.

The augite is seen to have the normal composition for basaltic augite. Titanic acid was unfortunately not tested for, as its presence in the rock was not ascertained until after the augite had been analyzed. As no titanium minerals are visible in the rock, it is probable that the augite contains the greater part of the amount of titanic acid found.

BASALT OF THE RALSTON DIKE AND THE ADJACENT MASSES.

Occurrence.—Referring to the first section of this chapter for any details not germane to the present discussion, the reader is requested to note the form, number, and relative positions of these basaltic masses as shown upon the map. The main dike runs north and south approximately on the line of the Fox Hills and Pierre formations, which are here folded to nearly vertical position. Adjacent to the south end of the dike are a number of large and small masses with irregular rounded outlines, which appear at various horizons of the Fox Hills. One mile to the southward is the northern edge of Table Mountain, capped by a sheet of basalt whose average elevation is about equal to that of the higher portions of the Ralston dike.

Conditions of consolidation.—From the evidence already given in this chapter, the age of the Table Mountain basalt sheets is referred to the Denver epoch, and they are supposed to have come from the vents indicated by the Ralston dike and adjacent masses. But this assumption, together with the age of eruption, requires the supposition that the relative horizons of the present outcrops have changed materially since the eruption, in a manner which has resulted in bringing the surface flows down to a level with a portion of the eruptive channel that was once far below the surface. The folding of the Arapahoe and Denver beds displayed to the southward supplies the easy and natural explanation of this change of level, and also explains the otherwise obscure relations of the basaltic masses to the peculiar fault in the area north of Table Mountain. This connection of the basalt with the folding movement and displacement is here reviewed to explain the fact that while the magma of the dike and masses under discussion consolidated at perhaps 1,000 feet from the surface, its surface lavas are now seen at approximately the same horizon. The conditions of cooling and final crystallization of these masses were nearly the same as for the Valmont rock, and the product is naturally a similar one.

It is probable that the Cretaceous shales traversed by these dikes were much fractured by the folding between the Laramie and Arapahoe epochs, and that to this fact is due the large number of small conduits represented by the irregular dikes and plugs. No doubt these all unite with the main dike at no great distance from the present surface. The ramifications of the eruptive channel must have caused the adjacent shale to be highly and uniformily heated, leading to a quite uniform rate of cooling for the magma.

Description.—The Ralston dike rock is similar to that from Valmont, but seems at first glance less distinctly porphyritic, because its augite crystals are smaller, and the darker, fine-grained mass of the rock obscures them. On closer examination, however, the structure is seen to be more nearly the normal porphyritic than in the first case, for augite, olivine, and a considerable number of plagioclase tablets are distinct phenocrysts in an evidently crystalline but megascopically unresolvable groundmass. The largest phenocrysts are tablets of labradorite 0.5 cm. across.

By microscopical study it is found that the Ralston dike rock has the same mineralogical constitution as the Valmont dolerite, and the difference between them lies chiefly in the development of the plagioclase. Here there is a decided contrast between the phenocrysts of probable labradorite and the smaller crystals of the groundmass. The latter are short and stout, and nearly all have an irregular zone of apparent orthoclase about them. This is much more distinct than in the Valmont rock and its identification as orthoclase seems unquestionable. There are many irregular grains of orthoclase independent of the plagioclase.

The augite phenocrysts are very irregular in form, and seem either to have suffered resorption which destroyed their symmetry or they never possessed sharp crystallographic boundaries. There are many very small irregular grains, as in the preceding rock.

Reddish-brown biotite shows a very strong tendency to form a ragged fringe about magnetite. Apatite has a phenocrystic development in large, short, more or less rounded prisms with axial inclusions, and also in clear needles of later formation.

TABLE MOUNTAIN BASALT; CAPPING SHEETS.

Occurrence.—The basaltic flows of the capping sheet of Table Mountain rest upon Denver strata, and they are believed to have been poured out upon the sea-bottom at a time in the Denver epoch corresponding to their present horizon in that formation. The reasons for this conclusion have been given in full, the most weighty of the considerations being the existence of the earlier smaller basalt bodies which are undeniably of Denver age. The capping is made up of two flows, the lower of which has a maximum thickness of about 125 feet, while the upper one has been so subject to erosion that its former thickness can not now be estimated, though from the remnant on North Table Mountain it can safely be considered to have been much greater than that of the lower flow. In the lower sheet may be found almost all the structural phases of basaltic lava flows, and the upper body corresponds to the same standard as far as can be seen. The upper surface of the lower flow is very porous, or even scoriaceous, with a cracked and broken appearance in places. For 40 feet below the surface the rock is vesicular, some cavities being several feet in diameter. The central portion is uniformly massive and compact, while a narrow porous zone is found adjoining the lower contact.

Conditions of consolidation.—It is not deemed of great importance to the present discussion to know whether these basaltic lavas were poured out into shallow seas or not. The water could not have had great influence upon the course of consolidation after a firm crust was formed, though the pressure of confined steam assists in explaining the occurrence of very large vesicles at rare intervals among the smaller ones. Whether cooling in water or not, the earlier flow was certainly covered by the lava from a second eruption before its jagged surface was appreciably modified by erosion and before either sediments or otherwise-formed deposits could lodge upon it. The identity of lavas and their juxtaposition suggest that very possibly the first lava was covered by the second before complete consolidation. In such a case the rate of cooling in the two bodies was mutually affected to some degree. In any case it is certain that the crust formed upon a basic lava stream of such thickness could effectually retard the consolidation of the interior portion and give time for the formation of a highly crystalline mass.

Description.—The constituents of the Table Mountain basalt are the same as of the rocks above described, but there is naturally a great difference in their development in different parts of the sheets. Porphyritic structure is more pronounced than in the dike rocks, yet the interior parts of both flows are highly crystalline. The grain of the groundmass produces the chief difference in outward appearance. In the central portions of both sheets the groundmass is clearly a crystalline mass of dark-gray color. Approaching the surface the rock is darker and the groundmass becomes aphanitic. In the inner parts of the vesicular zone a lens still shows a fine crystalline groundmass, and it is only in the outer, more or less scoriaceous crust that the microscope reveals a globulitic, glassy base.

The phenocrysts of these surface flows are nearly the same in development in all parts of the masses—plausible evidence that they existed in the magma at the time of eruption. They are also very similar to those of the dike rocks. Olivine is less abundant, and its crystals are now almost wholly decomposed, yielding a dark-green serpentine. Augite has usually a very well-developed crystal form, a fact which seems to indicate that the phenocrysts of the Ralston dike became irregular through resorption. Plagioclase tablets like those of the dike rocks are present here, but less abundantly. Biotite appears in the vesicles of the lower sheet in hexagonal leaves attached by the edges and inclosed by zeolitic deposits.

The groundmass minerals of these sheets are plagioclase, orthoclase, augite, magnetite, and apatite. Plagioclase occurs in stout little crystals or staves. In the coarser-grained parts orthoclase is found in an irregular oriented zone about many plagioclase crystals, as well as in irregular grains. With a decrease in size of the plagioclase staves the oriented growth diminishes, and in the denser parts one can only see that a colorless, apparently feldspathic substance occupies the main space between staves of plagioclase. Irregular grains of augite and a magnetite dust are sprinkled abundantly through the feldspathic mass. This magnetite dust and the clear apatite prisms are plainly later in formation than the larger grains and prisms which are often included in the augite phenocrysts.

The rock of the highest point on North Table Mountain represents the inner part of the upper, thicker sheet. Its constitution is not very different from that of the Ralston dike rock. By a kind of oxidizing process to which it has been subjected all iron-bearing minerals—magnetite, biotite, the alteration product of olivine, the small grains of augite, and even the outer zone of the augite phenocrysts—have been changed into an opaque, dark, reddish-brown substance (limonite), and this gives the rock a reddish tinge in mass.

At Castle Rock was found a dark nodule in the basalt, about 1½ inches in diameter, which is an irregular aggregate of imperfect augite prisms similar to the phenocrysts of the rock but of a decided green color, with very little magnetite and plagioclase. This mass seems to be a segregation of augite in the magma before eruption, and bears a significant resemblance to the common olivine nodules in basalt, or to those of amphibole in diorite or andesite.

Chemical composition.—The typical massive rock of the lower sheet was subjected to analysis by Dr. W. F. Hillebrand, with the following result:

Analysis of basalt from Table Mountain, Colorado.

SiO_2	52.59
TiO_2	.84
Al_2O_3	17.91
Fe_2O_3	3.81
FeO	5.18
MnO	Trace.
CaO	7.24
MgO	4.11
K_2O	3.83
Na_2O	2.94
P_2O_5	.14
Cl	.05
H_2O	1.24
	99.88

Sp. gr. 2.83 at 22½° C.

This composition is so nearly that of the Valmont dolerite that little discussion is necessary. The unusual ratio of the alkalis is the important fact, pointing to the probable existence of orthoclase in the rock, which has already been asserted from microscopical examination.

TABLE MOUNTAIN BASALT; EARLIEST LAVAS.

Occurrence.—On North Table Mountain, at a horizon which is about 100 feet below the capping sheet, there are exposed a number of comparatively small masses of basalt. They possess the typical features of surface flows, as minutely described above, and the exposures must be considered as sections of lava streams from the first eruption of basalt in this region, the quantity erupted being insufficient to form a continuous sheet as in the later outbreaks. These streams are of a maximum thickness of 50 feet, and they exhibit the same structure as the larger one above them on the mountain.

Conditions of consolidation.—As these streams were at once covered after eruption by sandy material like that upon which they rest, it is most natural to suppose them to have been poured out into the sea, for there are no visible reasons for supposing the eruption to have occurred during an interval in which no sediments were laid down. The smaller mass of these streams makes the conclusion necessary that their consolidation was somewhat more quickly completed than in the case of the larger masses described. As the first outbreak in a series from a common source, it is not strange that the bulk analysis shows a slightly different magma.

Description.—The basalt of these early streams is a dense, black rock characterized by many augite and olivine phenocrysts, lying in a denser, darker groundmass than is shown by any part of the upper sheets. Phenocrysts of plagioclase are present, but they are megascopically very inconspicuous.

The microscope shows the augite to have a pleochroism from yellowish to greenish shades, and the crystals are both larger and better formed than in any of the rocks previously described. Olivine, too, is developed in larger crystals than common, and is very fresh as a rule. The few plagioclase phenocrysts are filled with a cloud of minute inclusions excepting in a clear outer zone. The rounded forms of the parts rich in inclusions suggest a period of resorption.

The groundmass is composed chiefly of plagioclase microlites with a great deal of apparent orthoclase in irregular particles between them, and sometimes forming a zone about the larger crystals. A positive identification of the orthoclase is naturally impossible, but the chemical analysis shows that its development is probable. Augite grains, magnetite, and needles of apatite appear as in the rocks above described. Biotite is but sparingly present.

No glass base now exists in the stream, unless in the contact zones. But chlorite occurs in many angular spaces between microlites without presenting evidence as to its origin.

Chemical composition.—The following analysis, by Mr. L. G. Eakins, is of very fresh rock from the western body exposed on the southern slope of North Table Mountain between the large gulches.

Analysis of basalt from Table Mountain, Colorado.

SiO_2	49.69
TiO_2	.85
Al_2O_3	18.06
Fe_2O_3	2.64
FeO	6.19
MnO	.13
CaO	8.24
MgO	5.73
K_2O	3.90
Na_2O	2.99
P_2O_5	.81
Cl	.13
H_2O	.91
	100.27

A comparison of the analyses of the three basalts shows them to be very similar, even to the abnormal ratio of the alkalis, and this fact is used elsewhere as strong evidence that all belong to the same period of eruption.

AUGITE-MICA-SYENITE.

This rock occurs in small, irregular masses in the Archean near the head of the north fork of Turkey Creek, Jefferson County.

Description.—The rock is dark-brown in color, quite compact on the outer edges of the masses, while in the inner parts it is sometimes rather coarse-grained. In the latter case brown biotite leaves and green augite prisms are quite easily distinguished by the naked eye. The feldspar is of a gray or bluish tint, and except where the cleavage faces show distinctly it is scarcely recognizable. Biotite and augite seem about equal in quantity, and their predominance gives character to the mass, which has macroscopically a decided resemblance to some minettes. In the compacter parts of the mass the augite is much restrained in its development, while biotite is still prominent in minute flakes.

Microscopical examination of both coarse-grained and fine-grained types shows them to possess the mineralogical composition shown by many European "minettes" or "augite-syenites." The more important constituents are orthoclase, augite, and biotite, with rhombic pyroxene, hornblende, plagioclase, quartz, apatite, and magnetite. The structure of the coarser type is granular, while the more compact form shows something of an approach to porphyritic structure through the prominence of the pyroxene crystals.

Orthoclase, the most abundant mineral, is developed in irregular grains, which in the coarser rock are quite uniformly of a pale, smoky-brown tint, owing to a cloud of extremely minute inclusions, the character of which could not be determined with a power of 1,200 diameters. They do not seem to be fluid, however. These dust-like particles are often so evenly distributed that the tone of the entire individual is uniform, while in other cases they seem to be arranged in more or less parallel rows or streams, as though on certain planes of growth; and certain portions, usually the outer borders of each grain, are clear. Minute fluid inclusions and particles of other minerals are common. Carlsbad twinning is frequent. In the coarser rocks no plagioclase is visible, but in the finer-grained there are some small stave-like crystals, of many laminæ, which are probably oligoclase.

Augite, the next constituent of importance, occurs in numerous crystals and in small, round grains. The crystals in the coarser type are 1 to 3 mm. in length, and reach 1 mm. in thickness. In color they are pale-green and perfectly nonpleochroic. They usually swarm with inclusions of magnetite, biotite, and especially apatite. There is also some glass. In form and in abundance of mineral inclusions these augites resemble very closely the crystals commonly found in the minettes of Germany. In the finer-grained rock augite is less frequently developed in good crystals, and there especially is the appearance of a rhombic pyroxene noticeable. The latter is faintly but distinctly pleochroic, exhibits parallel extinction, possesses pinacoidal as well as prismatic cleavage and cross-fissures from which a fibrous alteration product extends, and is more nearly free from inclusions than the accompanying augite. The rhombic mineral is not abundant in any case. It is presumably less rich in iron than the hypersthene of the andesites, and is hence to be considered as bronzite. Green hornblende occurs in small, irregular grains in the compact rock and also intergrown with augite in the outer zone of a few crystals. Occasionally it surrounds the augite.

The biotite is of dark-brown color and occurs in small, irregular leaves often attached to pyroxene grains and containing many inclusions of magnetite.

Apatite is very abundant. Its prisms included in augite and the stouter free crystals are decidedly pinkish in color, with distinct pleochroism. The smaller prisms are often colorless. Magnetite is present in small amount in the usual grains. Quartz appears only in the finer-grained rock, in very small, angular particles as the last product of consolidation, and in very insignificant quantity.

Chemical composition.—The compact rock, in quite fresh condition, was analyzed by Mr. L. G. Eakins, with the following result:

Analysis of augite-mica-syenite from the north fork of Turkey Creek, Jefferson County, Colo.

SiO_2	56.90
TiO_2	.19
Al_2O_3	18.50
Fe_2O_3	.17
FeO	4.61
MnO	Trace.
CaO	6.17
MgO	5.10
K_2O	4.14
Na_2O	2.99
H_2O	.51
P_2O_5	.79
Cl	Trace.
	100.07

Sp. gr. at 29.5° C., 2.857.

This composition corresponds closely to what might be expected from the mineralogical constitution. It seems as if the orthoclase must be rich in soda, as there is little determinable plagioclase present. It is worthy of note that by exchanging 6 per cent of silica for iron oxide this analysis becomes very nearly like the analyses of the Table Mountain basalt. No positive evidence is known, however, indicating any close relationship in origin between the two rocks.

ROCKS OF THE DENVER FORMATION.

General statement.—The sediments of this formation are to be classed as clays, tuffs, sandstones, grits, and conglomerates, with intermediate members illustrating transitions in every direction. In Chapter III, Section II, will be found descriptions of the field relations of these types and data as to their distribution and local occurrence.

The present description has a twofold object. On the one hand, the rock names and characterizations found in the geological descriptions are to be explained and justified, in so far as they are based upon the results of a petrographical examination. This applies to rocks called tuffs, or sandstones, that are said to be made up almost entirely of the débris of volcanic rocks, a fact by no means obvious in many cases. On the other hand, the conglomerates contain certain andesitic pebbles, which anyone at all acquainted with the outer appearance of volcanic rocks would at once recognize as such. A concise petrographical description of these pebbles is given, to prove the great and interesting diversity claimed. The sources of these rocks are not known; hence detailed descriptions are not called for.

VOLCANIC TUFF.

General character.—The term tuff is here applied to a stratified rock composed of angular mineral or rock particles nearly all of which are of some volcanic source. This does not necessarily imply that these particles fell into the sea as ashes ejected from some neighboring vent. They may have been washed into the ocean from land regions where they fell as ashes, or they may have come from rapid disintegration of a lava. It is simply intended to characterize certain sediments in distinction from others containing a predominant amount of worn and rounded grains derived from various rocks, the latter strata being called sandstones. The tuff is a sediment of rapid formation, the material being chiefly derived from some single source; and as in this case the constituent particles are largely crystallized minerals, the whole may be supposed to approximate to the composition of the rock or magma from which the particles come. The purity or homogeneity of the tuff probably corresponds closely to the rapidity of its accumulation, for while a sandstone of identical composition is conceivable, the larger time involved in its deposition makes the admixture of material from other sources and of different character highly probable.

Transition stages would naturally arise as the period of tuff formation was succeeded by one in which a greater and greater admixture of sand or clay entered into the sediments. Such a change may be seen in the beds on South Table Mountain at the northeastern extremity, where the most typical tuff is succeeded by sediments in which clay and sand enter until they are predominant. Then comes again a stratum of coarse grain but with decided admixture of sand particles different in character from those of the tuff, and often this is a fine conglomerate containing small pebbles of various rocks along with rounded grains of a rock resembling the tuff in general composition.

Rocks which are pure tuffs in the above sense are rare in the Denver series. There are, however, numerous transition deposits which partake of the characteristics of both tuff and sandstone, as they will now be described for the more typical cases.

THE TYPICAL TUFF.

Occurrence.—The purest tuff known occurs at a horizon from 35 to 60 feet below the basaltic capping sheet of Table Mountain. It seems to have a somewhat local development, for although found all along the northern and eastern slopes of South Table Mountain, and locally identified on North Table Mountain, it is not found on the slopes of Green Mountain, where its peculiar character would seem to render outcrops probable. In the section at the northeastern point of South Table Mountain, and also at the southeastern extremity of the same mountain, this tuff is very well shown. Beds 5 and 6 of the section of the former locality exhibit the rock in its purest condition, and the specimens particularly described come from these beds. In the series included under (3) of the same section there are some layers agreeing nearly with the same description, but even the purest of these contain enough rounded grains of different character to cause their classification rather with the transition strata.

Plant remains are sparingly present in the tuff, and show the sedimentary character in cases where there might be some doubt from mere megascopical examination whether certain rounded masses were massive andesite or tuff of similar composition.

Description.—The pure andesitic tuff particularly mentioned above is very light gray or straw-colored, finely, evenly grained, and rather friable as exposed in the outcrops. A few black ore grains and some few particles of biotite, hornblende, or green augite may be distinguished in the light-colored mass, which consists chiefly of glassy feldspar fragments.

The sedimentary character of this tuff is usually plain, through the more or less banded structure produced by the varying amounts of darker constituents in different layers. Leaves and stems of plants are scattered through the mass, though never very abundantly.

As was mentioned in describing the section at the locality in question, the lower part of this tuff bed resembles a conglomerate in that there are pebble-like masses lying in a matrix of somewhat different appearance. The rounded masses are pebbles of tuff, and the matrix in which they lie is finer-grained material of the same kind. These pebbles represent a layer of tuff broken up during a turbulent period and redeposited partly as pebbles and partly as sand.

Microscopical study of this tuff shows it to be predominantly made up of plagioclase, with some augite, hornblende, biotite, and magnetite. The particles are sharply angular and fresh, and are identical in character, the presence of inclusions of glass, apatite, etc., with the constituents of andesites represented in the pebbles of some adjacent conglomerates. In this special layer the constituents are present in about the normal proportion for a massive andesite. No foreign matter, such as quartz or feldspar from Archean rocks, is present. Some particles have apparent glass attached to them.

The cementing substance of this tuff is composed chiefly of a web of minute, clear needles of unknown composition, which act feebly upon polarized light and seem to extinguish parallel to the vertical or prismatic axis. These needles are not visibly attacked by strong hot hydrochloric acid, and are therefore probably not zeolitic in nature.

As this tuff is composed so largely of clear plagioclase grains the Thoulet solution was used to isolate the predominant mineral for analysis. The result shows that but one feldspar could be separated in any purity, and that one isolated was found to be andesine, with composition as follows (analyst, Dr. W. F. Hillebrand):

Analysis of typical tuff from Table Mountain, Colorado.

SiO_2	59.35
Al_2O_3 / Fe_2O_3	25.33
CaO	8.83
Na_2O	3.06
K_2O	1.59

There are small quantities of MgO, H_2O, etc. The tuff, as a whole, contains SiO_2, 58.45; Na_2O, 1.69; K_2O, 0.66.

TUFFACEOUS BEDS IN GENERAL.

Those beds in which rounded particles appear in very small quantity are naturally of almost identical habit with the type described, and there is nothing new in them excepting the particles of andesitic rocks, usually reddish or brownish in color, and often quite decomposed. The cementing substance seems, in many cases, to be identical with that already referred to.

Many beds deserving the name of tuff are coarser-grained than the above type, and consist of fragments and worn particles in about equal parts. In many of them the eruptive character of the material is obscured by decomposition, and especially by the hydrated iron oxide to which the beds owe their distinctive yellowish-brown color.

The cementing material of various tuffaceous beds has been found to be zeolitic, as might be expected, and from frequent occurrence of heulandite in many places it seems probable that this species is more commonly the cement than any other substance. By tests made upon brown semituff from various places on the plains, it appears that a very large amount is sometimes soluble in hydrochloric acid, with gelatinization indicating the zeolitic character of the main substance dissolved. In one case 54.59 per cent was dissolved.

ANDESITIC PEBBLES OF CONGLOMERATES.

The eruptive materials of the Denver beds represented by tuffs and by pebbles of conglomerates form one of the most characteristic features of that formation. It has been shown that a large part of the series is almost exclusively made up of these materials, and they clearly represent a very large amount of rock destroyed. The source of these pebbles is not known, and they give the only known clues as to the events of one of the important epochs in the geological history of this region.

As pebbles of unknown origin, they are not worthy of detailed description, but it is desirable to record their character with some definiteness, because this information makes evident the extent of the volcanic eruptions of the time between the Arapahoe and Denver epochs, a period which seems to have been characterized by similar outbursts along the whole Rocky Mountain region from New Mexico to Montana.

Mineralogical composition.—Examination of hundreds of pebbles in the Denver beds, from the bottom to the top of the section, has not definitely revealed the presence of any other eruptive rock type than andesite, but the members of this large family are nearly all represented. At the siliceous end of the series is a light-colored rock, with sparing phenocrysts of augite and plagioclase in a microlitic groundmass of thoroughly trachytic habit. It is possible that this rock might properly be called a trachyte, but only a single pebble was observed.

Mica-andesite, generally rich in tridymite or quartz, is abundant in the lower beds of Table Mountain. These and some of the more siliceous hornblende-mica rocks may be called dacites.

Hornblende and mica are present in varying amounts in many pebbles, and augite is often associated with them in subordinate degree. Classifying andesites by the relative abundance of the constituents biotite, hornblende, and pyroxene, there are all manner of varieties to be found in the pebbles, the transition stages being those familiar to students of general petrography.

With the increase in augite comes greater basicity in general, and the extreme is a rock closely allied to the basalts, though none distinctly referable to the latter type was found. Apparently magnesia was not strong in these lavas, for while augitic varieties are so numerous, hypersthene was found in but one typical pyroxene-andesite from the summit of Green Mountain. This also explains why basalts are not found. The basalt-flows of Table Mountain are apparently contemporaneous with the Denver beds, and it is therefore probable that some basalt exists in the conglomerates. No especially interesting mineralogical types were observed.

Structure.—All of the rocks are porphyritic, and possess the further characteristics of lavas rather than of intrusive masses. Plagioclase and augite phenocrysts commonly contain abundant glass inclusions, and a zonal optical structure is frequent in the former. Hornblende and biotite are ordinarily much resorbed, and augite sometimes shows the same action.

The groundmass naturally varies very much, but is usually to be described as microlitic, with fluidal structure in most cases. In the hornblende- and mica-andesites the groundmass is often cryptocrystalline or partly isotropic, with yellow or brownish globulites and patches of tridymite. In the more basic rocks minute feldspar microlites are often found in a dark base, usually obscured by hydration of the iron oxide. None of the structures observed are such as are found, according to the writer's experience, in intrusive rocks.

Texture.—The great majority of the pebbles are naturally dense, but in the coarser conglomerates there are vesicular pebbles in great variety, representing nearly every observed massive rock type. In some of the pores are zeolites.

One rock, an augite-andesite, was found in many places in angular fragments, from apparently a single horizon, and of all textures, from the compact to the extremely vesicular. The porous modifications of this rock contain heulandite and the new zeolitic species ptilolite.[1] The angularity of the fragments and the various textures seem to indicate a local source for this rock.

[1] On ptilolite, a new mineral, by Whitman Cross and L. G. Eakins: Am. Jour. Sci., 3d series, Vol. XXXII, 1886, pp. 117–121.

CHAPTER VI.

ECONOMIC GEOLOGY.

BY GEORGE H. ELDRIDGE.

SECTION I.—COAL.

DEVELOPMENT OF THE BASIN.

The date of the discovery of coal in Colorado can not be authenticated, but it was probably prior to 1860, actual mining operations having been traced back to this year. The location[1] is said to have been on Coal (upper Sand) Creek, in T. 4 S., R. 65 W., at a prominent lignite outcrop still visible in the north bank of the creek between 1 and 2 miles above the mouth of Murphy Creek.

Among the earliest producers were the Marshall mines, in operation in 1863, assuming importance in 1865; the Murphy mine, on Ralston Creek; and the mines at Golden, discovered in 1861–62. The product of these mines for the years 1864–1869, inclusive—the earliest record attainable—is reported as follows:

Coal product of Marshall, Murphy, and Golden mines, Colorado, 1861–1869.

	Short tons.
1864	500
1865	1,200
1866	6,400
1867	17,000
1868	10,500
1869	8,000

[1] Geol. Survey of the Territories, F. V. Hayden, Report for 1873, p. 121.

The increase for the years 1867 and 1868 and the subsequent decrease is attributable to temporary activity in metallic mining and milling during those years.

In the summer of 1870, upon the completion of the Denver Pacific Railroad from Cheyenne to Denver, the Kansas Pacific, and the Colorado Central from Denver to Golden, the demand upon the mines of the foothills in Jefferson and Boulder counties largely and permanently increased, their annual production for 1870 and 1871 being respectively 13,500 and 15,860 tons.

In 1872 the completion of the Boulder Valley Railroad from Brighton to Boulder brought into market the product of the mines—already well developed—at Erie and Canfield. In consequence of this accession the coal production for the Denver fields for the seven years 1872–1878 rose to the following figures:

Coal product of the Denver fields, 1872–1878.

Year.	Foothill region.	Erie and Canfield.	Total.
	Short tons.	*Short tons.*	*Short tons.*
1872	14, 200	54, 340	68, 540
1873	14, 000	43, 790	57, 790
1874	15, 000	44, 280	59, 280
1875	23, 700	59, 860	83, 560
1876	28, 750	68, 600	97, 350
1877			130, 000?
1878			87, 825

The rapidly increasing demands of railways, furnaces, mines, mills, towns, and cities in 1879—the year of great mining excitement at Leadville and Silver Cliff—caused another notable increase in the coal product of Colorado, the output of the Denver Basin at this time amounting to 182,630 tons. This constituted the bulk of the increase for the entire State, the mines of southern Colorado being the only others that showed advance, and these rather in the line of development than owing to conditions of trade. From 1879, however, the latter mines largely increased their capacity and output, while the mines of the Denver Basin temporarily fell off in product, owing to diminished demand for their coal. For the next few years the product of the Denver Basin stood as follows:

Coal product of Denver fields, 1880–1884.

	Short tons.
1880	123,518
1881	156,126
1882	300,000
1883	215,403
1884	262,282

In 1884 strikes among the coal miners, extending from August 4 to the end of the year, greatly lessened the coal production of the entire State. Although the yield of the Denver Basin showed an increase over that of the preceding year, it fell far below what it should have been, considering the growth of Denver and of railway and manufacturing interests generally at that time.

In 1885 the production of the Denver Basin amounted to 244,346 short tons, and in 1886 it reached 260,145 short tons.

Coal product since 1887 of counties included within the Denver Basin.

County.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.
	Short tons.	*Short tons.*	*Short tons.*	*Short tons.*	*Short tons.*	*Short tons.*	*Short tons.*	*Short tons.*
Boulder	297,338	315,155	323,096	425,701	498,491	515,563	663,220	419,731
Weld	39,281	28,054	28,628	46,417	22,551	2,205	35,355	42,818
Arapahoe	16,000	1,700	823	700	1,273	654	633	559
Jefferson	12,000	9,000	10,790	10,984	17,910	21,219	1,895	34,108
Douglas	3,500	400	260	700	....	200	200	....

The increase in the yield of the mines of the Denver Basin in 1887 is largely traceable to the opening of new mines in the Erie-Canfield district, and to the prosecution of mining in all districts, particularly the Marshall, on a more extensive scale and with greater energy than had hitherto been shown. The increased output was required to meet the domestic and manufacturing demands created by the particularly rapid growth of Denver at this time. In the other fields of Colorado there was likewise a large increase in the output of this year, the product being consumed both within the State itself and beyond, along the lines of the great railroads to the east of the Rocky Mountains as far as the Missouri River.

In the fall of 1888 still another area of coal was opened up, in the valley of Coal Creek, 2½ miles below Louisville and 17 miles north-northwest of Denver. The output of this district for that year was 11,726 tons, of which the Simpson, which began operations in September, yielded 11,126 tons. The town of Lafayette is now located here. In this year, also, the Standard mine, in the Erie district, was put in condition to produce heavily, and late in the season the old Welch mine at Louisville, after a long period of comparative idleness, was reopened by a new slope about 800 yards to the southeast of the old shaft. Since then several new mines have been opened in both the Lafayette and Louisville districts.

List of mines in the Denver Basin, including worked and abandoned.

Name.	Location.	Condition.[1]
Sand Creek	T. 4 S., R. 65 W	Abandoned. Said to have been first discovery of coal in Colorado.
Two shafts	T. 3 S., R. 65 W., sec. 28. Tonsland.	Abandoned prior to 1872.
Scranton	Scranton	Produced prior to 1889. Since abandoned.
Platteville	T. 3 N., R. 66 W., secs. 17–20	Worked occasionally for local demands.
Stoner, Hopkins and others.	Near Platteville	Abandoned.
Excelsior	Near Evans	For local demand.
Eaton	Near Eaton	Do.
Brown		Do.
Brown		Do.
McKissic	T. 2 N., R. 67 W., secs. 18 and 19	Worked intermittently.
Briggs	T. 1 N., R. 68 W., secs. 7 and 8	Abandoned in 1883.
Boulder Valley		Abandoned in 1885.
New Boulder Valley	East of Erie	Opened in 1890. Since closed.
Dietz		Abandoned. Record of this mine for 1878, in Fossett's Colorado.
Superior	?	Abandoned in 1883.
Northrup	Near Canfield	Closed in 1884.
Star	do	Worked.

[1] Some of the mines noticed as worked may be at present temporarily closed.

List of mines in the Denver Basin, including worked and abandoned—Continued.

Name.	Location.	Condition.[1]
Progress	Near Canfield	Opened in 1884 (?); idle in 1886 and 1887; produced in 1888; since refitted.
Standard	do	
Jackson	do	Worked.
Northwestern		
Longs Peak		
Garfield, 1 and 2	Southwest of Erie	Worked
Stewart	do	Do.
McGregor	do	Do.
Cleveland	do	Do.
Mitchell	do	Do.
New Mitchell	do	Do.
Eulner		Abandoned (a prospect).
Chessey		Abandoned.
Baker	East of Lafayette 1½ miles	Worked.
Hornsville		
Excelsior	Near Lafayette	Opened in 1889 and 1890. Worked.
Gladstone	do	Do.
Ottis	do	Do.
Spencer	do	Do.
Simpson, 1 and 2	do	Opened September, 1888.
Cannon	do	Opened in 1888.
Marshall Consolidated	East of Louisville	New mine in 1888.
Marshall slope	Near Louisville	New slope in 1888.
Caledonia	do	Opened in 1890.
Welch (old)	do	Formerly large producer; heavy decrease in 1888. Abandoned.
Acme	do	Opened in 1889 and 1890.
Ajax (Leader)	do	Do.
Hecla, Nos. 1 and 2	do	Do.
Excelsior (Superior)	NW. of Louisville 2 miles	Abandoned.
Davidson	NW. of Louisville 3 miles	An old opening, worked intermittently for local trade.
Dunn	do	Worked for local trade in 1886.
Allen (Alan, Marvin)	do	Abandoned.
Allen-Bond	do	Opened in January, 1890. Worked.
White Rock	North of White Rock Station 2 miles.	Abandoned. Production was noted in 1879 by Fossett.
Barber	T. 1 S., R. 70 W., sec. 15	Abandoned.
Old Fox slope	East of Marshall	Do.
Fox	Marshall	Worked.

[1] Some of the mines noticed as worked may be at present temporarily closed.

List of mines in the Denver Basin, including worked and abandoned—Continued.

Name.	Location.	Condition.[1]
Marshall, Nos. 1 and 2.	Marshall	Not worked.
Marshall No. 3	do	Worked.
Marshall No. 5	do	Opened early in 1886 or late in 1885.
Old Marshall slope	do	
Black Diamond and one or two other openings.	do (?)	Abandoned. Probably the mine worked in 1863. Was working in 1883.
Fullerton	T. 1 S., R. 70 W., sec. 21	Abandoned.
Sweeney	Upper Coal Creek	Do.
Eggleston	do	Do.
122 mine	do	Abandoned. Worked many years ago for local use.
Coal Creek mines	T. 1 S., R. 70 W., sec. 33	Opened in 1860. Abandoned.
Loveland (Marvine) 3.	T. 2 S., R. 70 W., sec. 4	Abandoned.
Leyden	T. 2 S., R. 70 W., sec. 28	Abandoned sometime prior to 1870.
Murphy	T. 2 S., R. 70 W., sec. 33	Was working in 1879; since abandoned.
Church	Near Ralston Station	Abandoned (a prospect).
Ralston	do	Abandoned in 1887.
Colorado	North of Golden 2 to 3 miles.	Mentioned by Fossett as yielding in 1879. Long closed. Rocky Mountain 1 and 2 reopened in 1890.
Pittsburg		
Rocky Mountain 1 and 2.		
Prout		
Mineral Land Company's mines.	North of Golden 2 miles	Abandoned.
Golden Star	North of Golden 1 mile	Opened in 1884. Worked.
New White Ash	One-half mile north of Clear Creek.	Opened in 1890. Worked.
Loveland	Golden; immediately north of Clear Creek.	Abandoned.
White Ash	Golden	Abandoned about August 20, 1889. Cut into water of old workings. Discovered in 1861–62.
Johnson	T. 4 S., R. 70 W., sec. 3	Abandoned. Worked in 1873.
Welch and Loveland mine.	do	Abandoned. Hayden refers to it in 1873 Report.
Wheeler mine	T. 4 S., R. 70 W., sec. 14	Abandoned. "Has been worked; coal not very good." Hayden in 1873 Report.
Rowe or Roe (Rooney).	T. 4 S., R. 70 W., sec. 23	Opened prior to 1868. Abandoned in 1872.
Mann	T. 4 S., R. 70 W., sec. 24	Abandoned many years ago.

[1] Some of the mines noticed as worked may be at present temporarily closed.

List of mines in the Denver Basin, including worked and abandoned—Continued.

Name.	Location.	Condition.[1]
Pratt		Abandoned. Opened in 1882 or 1883 by slope, and some coal taken out.
Wilson	T. 4 S., R. 69 W., sec. 31	Abandoned prior to 1873.
Mount Carbon	Mount Carbon	Worked. Local trade. An old mine.
Wenrich (Gilpin)	T. 5 S., R. 69 W., sec. 9	Abandoned long since. May have been worked in 1873.
Jones	North of Deer Creek between 1 and 2 miles.	Abandoned long since. Worked in 1873.
Deer Creek (mouth of).	West of Platte	Opened in 1866 (?). Abandoned.
Archer	A prospect on east side of Platte, opposite Archer.	Coal shipped to Denver in the seventies. Hayden's Report gives 1866 as date of opening. Abandoned.
Weightman	Willow Creek	Abandoned several years ago.
Douglas (Cannon, Pearl Ash, Lehigh).	West of Sedalia 4 miles	Worked. Development commenced in 1883. Production variable.

[1] Some of the mines noticed as worked may be at present temporarily closed.

GEOLOGICAL OCCURRENCE OF THE COAL.

With the exception of the coal on the eastern border of the basin, in the vicinity of Scranton and Coal Creek, which is upper Laramie, the workable beds of the several fields about Denver are confined to the series of sandstones and shales that constitute the lower 200 feet of the formation. They probably attain their maximum depth of about 2,300 feet on the line of Section V, shallowing north and south of this. They are sharply upturned along their western border; along the northwestern, dipping gently to the southeast; while beneath the prairies they are probably thrown into a great number of minor folds and faults. The transverse sections of the field show the general configuration of the coal horizon to be that of an unsymmetrical shallow basin, the western and northern limits clearly defined, the southern and eastern indefinite.

The coal beds of the Denver Basin occur under three different conditions: (*a*) That in which the beds belong to the lower division of the Laramie and are steeply inclined along the foothills of the Colorado range; (*b*) that in which the beds are also of the lower Laramie but occupy an approximately horizontal position beneath the prairie; and (*c*) that in which the beds are horizontal but belong to the upper Laramie, occurring well up in the series of clays, a single locality presenting this condition, the Scranton area, 20 miles northeast of Denver.

The workable coal beds, whether of the upper or lower division of the Laramie, occur as deposits of irregular outline and distribution from one to several miles in area and of a thickness of from 3 to 14 feet. Their presence or absence, even in localities where the measures have been subjected to combined structural and erosive influences, as along the northwestern edge of the formation, depends upon original conditions of deposition, and in consequence of the uncertainty of these, actual coal-bearing areas at depths beneath the prairies obviously can not be determined except by exploration with drills. That such areas exist can not be doubted, for their presence along the exposed margin of the coal measures is repeatedly proved, and the sequence of events and the conditions of deposition must have varied but slightly for any part of the basin.

Along the western rim of the basin the coal measures suffer no visible interruption by reason of dynamic agencies, though the continuity of the beds is frequently broken by nondeposition. In the northern portion of the basin, where the measures occur at comparatively shallow depths and for a zone of 5 or 6 miles within the periphery of the Laramie are within easy reach of the surface, combined disturbance and erosion have caused great irregularity of occurrence.

The coal of the lower Laramie belongs eminently to a period of sandstone deposition; that of the upper Laramie to a period of clays with but slight association of sandstone. The heavy sandstones that do occur just above the Scranton seam are not of Cretaceous but of Tertiary age, and lie unconformably upon the coal and other beds of the Laramie.

Coal occurs at eight or ten horizons within the 200 feet of strata constituting the lower Laramie coal measures, but of these five is the maximum number showing a workable thickness in any one locality in the basin, the usual number being two or three. On account of the covered outcrop and the variability of the measures above the basal sandstones, both in number of seams and character of sedimentation, the identity of a seam can not ordinarily be determined beyond the comparatively limited area in which it is specially developed. The basal sandstones, A and B, and the bed of oysters, about 12 feet above their summit, are the chief horizons of reference in the series.

Notwithstanding the indefinite position of the coal seams in the lower Laramie, their occurrence for the basin in general points to certain horizons at which a workable thickness seems to be more frequently developed than at others. These horizons are: Between sandstones A and B, immediately above sandstone B, just below sandstone C, and at one or two points between the two last mentioned. Those most commonly developed lie in the shaly beds between the B and C sandstones.

The productive area of coal depends upon the thickness of the seam and the purity of the coal. Either of these varies independently of the other. In thickness the beds occur from a knife-edge to 14 feet without parting. In quality the coal may pass from the state of the highest purity for the field to one in which there is a large proportion of earthy matter, to a carbonaceous shale, or even to a shale wholly argillaceous. A combination of the two methods of variation is of frequent occurrence.

Partings of a more or less carbonaceous clay or quartzose sand-rock, varying from a line to a foot or two in thickness, are frequently present and may extend through an entire district. Nearly all carry plant remains—leaves, bark, etc.

COAL AREAS.

INTRODUCTION.

The coal fields of the Denver Basin are the Foothill, Marshall, Davidson, Louisville, Lafayette, Baker, Erie (embracing the Canfield and Mitchell), White Rock, and Scranton. Beyond the basin as mapped are the McKissic and Platteville banks, several miles to the north, and the Douglas or Lehigh bank, 6 miles southeast of Platte Canyon.

With the exception of the Scranton the areas are all geologically related, but have become distinct from one another through faulting, folding, and erosion. The mines of the Foothill region lie along the upturned portions of the measures. The Marshall district adjoins the northern end of the foothill area, its mines confined to the region of gentle dip immediately east of the latter. The Louisville, Lafayette, and Baker areas are faulted from one another, and the Canfield and Mitchell areas are separated by the eroded crest of an anticlinal fold or by a local cross-fault. Faults and folds separate the Davidson from the Louisville and Marshall districts, and the White Rock is severed from the others by erosion and a succession of faults. The Scranton is geologically distinct from all others by its higher horizon. Structurally the coal areas may be grouped under the Foothill region, the Davidson syncline, the Coal Creek syncline, the area east of the Coal Creek syncline, the White Rock field, and the Scranton field.

FOOTHILL AREA.

EXTENT.

The foothill area includes the highly inclined strata of coal measures along the base of the Colorado Range, and extends from the Marshall area in the north, with which it is continuous, to the vicinity of Wildcat Mountain in the south, 10 miles beyond the limit of the basin as mapped. South of this latter point no coal is opened or known to exist in workable thickness until the vicinity of Colorado Springs is reached, a distance of nearly 50 miles; north of the basin openings occur here and there as far as Greeley, 50 miles from Denver; in both directions, however, the beds are nearly horizontal and belong to the prairie class. East and west the foothill area is limited, if the outcrop alone is considered, by the confines of the Laramie—indeed, by the confines of its basal series of sandstones, coals, and shales, which is alone productive in this portion of the basin. The width of the area is therefore only about 250 feet. The beds doubtless extend beneath the prairie upon reaching the flexure in which the measures are involved, but they then lie too deep—at least 1,200 to 1,500 feet—for present profitable mining.

PRODUCTIVE LOCALITIES.

Following is a list of mines and prospects opened at various times on the vertical beds of the foothills:

Mines in the foothill area of the Denver Basin.

Name.	Locality.
The Coal Creek mines *a*	Upper Coal Creek.
The Leyden mine *a*	T. 2 S., R. 70 W., sec. 28.
Murphy mine *a*	T. 2 S., R. 70 W., sec. 33.
Church prospect *a*	Near Ralston Station.
Ralston mine *b*	Do.
Colorado mine *a*	
Pittsburg mine *a*	North of Golden 2 to 3 miles.
Rocky Mountain, No. 1	North of Golden 2 to 3 miles.
Rocky Mountain, No. 2	North of Golden 2 to 3 miles.
Prout *a*	
Mineral Land Co.'s mines *a*	North of Golden 2 miles.
Golden Star	North of Golden 1 mile.
New White Ash	Half mile north of Clear Creek.
Loveland *a*	Golden, north of Clear Creek.
White Ash *b*	Golden, south of Clear Creek.
Johnson *a*	T. 4 S., R. 70 W., sec. 3.
Welch and Loveland mine *a*	Do.
Wheeler mine *a*	T. 4 S., R. 70 W., sec. 14.
Rowe, Roe, or Rooney *a*	T. 4 S., R. 70 W., sec. 23.
Mann *a*	T. 4 S., R. 70 W., sec. 24.
Pratt *a*	
Wilson *a*	T. 4 S., R. 69 W., sec. 31.
Mount Carbon	Mount Carbon.
Wenrich (Gilpin) *a*	T. 5 S., R. 69 W., sec. 9.
Jones *a*	North of Deer Creek.
Deer Creek *a*	Mouth of Deer Creek.
Archer *a*	East of Platte, opposite Archer.
Weightman *a*	Willow Creek.
Douglas (Cannon, Pearl Ash, Lehigh)	West of Sedalia 4 miles.

a Now abandoned, January 1, 1890.
b Abandoned since the study of this field was begun.

Of the above openings the Douglas, Mount Carbon, New White Ash, Golden Star, and Rocky Mountain Nos. 1 and 2 are still (October, 1890) in operation; the Old White Ash and Ralston mines have been closed since the inauguration of this work; the Murphy and Loveland were originally important producers, but have long been idle; and the remainder, idle and never important, varied from pits with an annual output of a few hundred tons to mere prospects. The history of these mines and the extent to which they have been worked are, in a measure, indicative of the conditions of the beds in their respective regions, but abandonment of mines once well established does not signify that they have been worked out, but rather that they can no longer produce economically in competition with the mines of the prairies, where the coal is horizontal and within a comparatively short distance of the surface.

For much of the distance along the foothills the coal measures are barren, and the extent of the productive portion can be determined only by most careful prospecting; and it must always be borne in mind that, through the irregularity of outline of the original deposit, a bed continuous in outcrop for a considerable distance may extend to but slight depth, or vice versa. Thus far, continuity in depth has been found to exceed the limits of economic working.

STRIKES AND DIPS.

The strike of the coal measures in the foothill region is, with the exception of the portion included within the area of the unconformity about Golden, parallel with the range (N. 15° to 18° W.) in the southern portion of the field, and north or a little west of north in the northern. Between Bear and Coal creeks, however, the coal measures lie in a broad, westward-sweeping curve, without crumple or fracture of importance.

The dip of the beds varies from 10° to 15° on either side of vertical. The depth at which the dip of the overturned beds becomes vertical and then normal (easterly) varies from point to point, but in the lower levels of the White Ash mine at Golden between 700 and 850 feet would constitute approximately their vertical portion. Below this the eastward dip may generally be expected, and at 1,200 or 1,400 feet the shallow dip characteristic of the prairie occurs.

The curve from overturn to normal is of such a long radius that probably but slight fracturing of the coal seams has resulted. The seams of workable thickness along the foothills are apparently wholly confined to the series of strata between sandstones B and C, that between A and B being nowhere with certainty recognized as important.

SEDALIA DISTRICT.

The Douglas mine.—This is opened on a small creek about 6 miles southeast of Platte Canyon and 4 or 5 west of Sedalia. Two coal seams are mined, the linear extent of which is undefined, but, from their thickness and strong development in the pit, there is probably at least one-half or three-fourths of a mile of workable coal. In depth it doubtless extends far beyond economic mining limits.

The measures here have a strike N. 24° W., with an easterly dip of about 73°.

The horizon of the two coal seams is probably between sandstones B and C. The upper, easternmost seam is 8 or 9 feet thick where opened; the other, 4 feet; a heavy sandstone, varying from 10 to 20 feet in thickness, separating them. (Fig. A, Pl. XVIII.) The seams were clear of partings and bone within the limits of work at the time of examination. The coal is jet-black, lustrous, hard, square-jointed or nearly so, and of good resistance to atmospheric influences. Its structure and friability have been but little influenced by the bending to which the strata were subjected in the general uplift of the range. A slight amount of pyrite and resin is scattered through it.

SEDALIA DISTRICT TO MOUNT CARBON.

Various coal openings have been made between the Douglas mine and Mount Carbon, the locality next north now worked. These are, in succession, the Weightman, Archer, Deer Creek, Jones, and Wenrich or Gilpin, all of which are reported as having occasionally yielded a slight product, chiefly between the years 1870 and 1880. All are now caved and beyond examination. The horizon, thickness, or character of the coals can not be given. The strike of the measures included within this distance is N. 15° to 18° W., or with the trend of the range, and their dip is from 75° east to overturned.

MOUNT CARBON DISTRICT.

This designation applies to a short stretch of coal measures within a half mile north and south of Bear Creek, including the prominent flat-topped hill known as Mount Carbon. The valley of Bear Creek is here a third of a mile wide and is bordered by bluffs 50 feet high. The confluence of Turkey and Bear creeks is in the middle of the bottom lands northwest of Mount Carbon, upon Laramie beds. Mount Carbon is a remnant of the early terraced bench lands now separated by the valley of Turkey Creek and adjacent lowlands from the main body of uplands nearer the foothills. Its altitude above the creek is between 300 and 350 feet. The shape is elliptical, the longer axis east and west. South of Mount Carbon the conglomerates at the base of the Arapahoe form a line of prominent combs from which the distance to the coal measures, about 900 feet, may be closely laid off—the basal sandstones of the Laramie forming no outcrop along here. North of Bear Creek the prairie is cut by a number of shallow coulées, one of which enters the creek valley along the base of the Laramie, the coal having been opened both in this coulée and upon the prairie to the east.

In the northern face of Mount Carbon is an excellent exposure, in section, of the great fold along the front of the Colorado Range. The vertical portion of the beds appears in the coal-measure sandstones and the heavy sandstones and conglomerates at the base of the Arapahoe, and occupies the western half of the hill; the eastern half of the hill exposes the remainder of the Arapahoe and the basal members of the Denver formation, the latter forming a conspicuous knoll of gently dipping strata a little northeast of the main elevation. The fold itself shows in section in the eastern third of the hill, and is traceable by occasional visible outcrops of the more resisting beds and by a searching examination in the slightly covered strata by means of the pick. This structure continues both north and south of Mount Carbon, but the actual flexure is no longer visible owing to the planing down of the prairies and the comparatively insignificant height of the bluffs bordering the streams.

Both the prairies to the north of Bear Creek and the cap of Mount Carbon consist of a light but uniformly distributed Quaternary gravel, of rather coarse material, through which the harder beds of the vertical portions of the underlying formations occasionally outcrop.

The strike of the beds in the Mount Carbon region is a gently varying curve from N. 20° W. 2 miles south of Bear Creek to N. 60° W. immediately north of the creek, the region lying just within the southern confines of the great unconformity extending northward past Golden to Coal Creek. The dip of the highly inclined strata is between 75° and 90° eastward, that of the beds of gentle inclination, near the eastern base of Mount Carbon about 15°, shallowing still further to the east of this.

A cross-section of the more important part of the coal measures, taken on the northern face of Mount Carbon, is given in Fig. B, Pl. XVIII. Four seams are moderately developed, only the eastern two being of workable thickness. All lie in the horizon between sandstones B and C, the sketch involving about 43 feet of strata. This series of coal beds, from indications afforded by old workings and prospects along their outcrop, may extend with short interruptions for a mile and a half both north and south, but that any single bed holds its width for this distance is extremely doubtful. The depth to which they maintain their surface width is entirely a matter of conjecture; it may be less than in the regions of more strongly developed beds, as, for instance, the Douglas; or, on the other hand, their width may increase with depth, the present outcrops being perhaps near the periphery of the original deposits.

The coal of the Mount Carbon mine, so far as exposed at the time of examination, was quite free from partings; a single narrow but persistent streak of bony material occurred in one seam about 6 inches from the top, in the other at the top. The coal is, like other foothill coals, bright, jet-black, comparatively little fractured in the upheaval of the range, square-jointed, and is said to contain very little sulphur, in the form of pyrite, and but a slight amount of resin, which is uniformly distributed. The present opening upon the coal is by drift, about 125 feet below the top of the hill.

Leaves, bark, and other vegetable débris occur in abundance in this locality.

Considerable coal was formerly shipped from a shaft at the foot of Mount Carbon and from the Wilson shaft immediately north of Bear Creek, both mines having been equipped with primitive hoisting plants.

MOUNT CARBON TO GOLDEN.

Northward from the Mount Carbon district occur, in the order named, the abandoned mines—Mann, Roe, Wheeler, Welch and Loveland, and Johnson. The Roe mine lies at the western base of Green Mountain, about

3 miles north of Bear Creek. Following is a summarized account of this opening, taken from the reports of Hayden[1] and Marvine.[2]

The entrance to the mine is by a slope of 45°, 170 feet in length, through 141 feet of sandstone. The strata are here nearly vertical in position, though at neighboring points often with an easterly dip of between 70° and 80°. There are three seams of coal, 4 feet each, with 3½ feet of clay intervening. Below the coal there is a bed of clay 5 feet thick, and above 3½ feet of arenaceous clay. The coal is compact, makes an excellent fuel, and leaves a white ash. The mine had shipped 250 tons up to 1868 and was abandoned in 1872 for want of good communication.

The Wheeler mine,[3] 1 mile north of the Roe, was formerly worked to a depth of 40 feet, furnishing coal of inferior quality; thickness of seam, 7 feet.

The Roe and Wheeler openings are still visible, but the surface in their vicinity affords no ready section of the coal measures.

A section of the measures at the Welch and Loveland mine,[4] by Captain Berthoud, C. E., from notes on an open cut, follows:

	Feet.
Coal, No. 5, easternmost bed[5]	5
Sandstone and clay	16
Coal, No. 4[6]	1
Sandstone	6½
Fire-clay	3
Coal, No. 3[6]	3
Sandstone	6½
Fire-clay	4
Coal, No. 2[6]	2
Fire-clay	5
Coal, No. 1, westernmost bed[6]	3
Shale and sandstone	5

The general strike of the measures in the vicinity of the above mine is N. 30° to 32° W., with a dip westward (overturned) of 70° to 80°.

At the Johnson mine, one-fourth of a mile north of the Welch and Loveland, the coal is said by Mr. Marvine to be from 7 to 9 feet thick. It

[1] U. S. Geol. Survey of the Territories, Report on Colorado and New Mexico, 1869, p. 35.
[2] U. S. Geol. Survey of the Territories, Report an Colorado, 1873, p. 127.
[3] U. S. Geol. and Geog. Survey of the Territories, Report on Colorado, 1873, p. 127.
[4] U. S. Geol. and Geog. Survey of the Territories, F. V. Hayden, 1873, p. 127.
[5] Mined.
[6] Not mined.

strikes about N. 31° W., and dips to the westward (overturned) about 80°. It was opened by a shaft 90 feet deep. The mine has long been abandoned.

Between the Mount Carbon and Golden coal districts the Laramie measures lie in the southern half of the great inward-sweeping arch resulting from the Golden unconformities. Although the strains to which the strata, both here and along the northern half of the arch, were subjected in the general uplift of the range and the concomitant adjustment of the beds were doubtless considerable, but slight fracturing resulted. The coal horizon may easily be traced from surface particles and from the frequent comb-like outcrops of either the Laramie sandstones themselves or the conglomerates and sandstones at the base of the Arapahoe a few hundred feet to the east. From the succession of strata and from the thickness and character of the sandstones occurring west of the coal, it is probable that the seams formerly opened along here belong to the horizon between sandstones B and C.

Leaves and other plant remains occur in abundance.

GOLDEN DISTRICT.

General description.—This district includes the Old White Ash, Loveland, New White Ash, Golden Star, Excelsior, and Rocky Mountain 1 and 2 mines. It occupies the valley of Clear Creek and its tributaries directly west of the Table Mountains. The strike, for a long distance south of Clear Creek, is N. 30° to 35° W.; north of the creek it rapidly curves to N. 7° 30′ E., increasing to N. 17° E. in the vicinity of the Ralston mine. The measures have a dip at the surface of between 65° and 80° westward, reaching vertical at a depth of between 700 and 900 feet. Below this depth their dip is eastward, lessening in amount until probably between 1,200 and 1,500 feet the beds have assumed the gentle dip underlying the eastern portion of the valley and the Table Mountains.

The distance on the trend of the strata for which the measures are productive is difficult of approximation, but, with short interruptions, is probably 1 mile south of Clear Creek and 3 miles north of it, reaching in the latter direction to the disturbed area just north of Van Bibber Creek. In depth, the beds undoubtedly hold their width far beyond the limits of economic mining.

The general stratigraphy of the region about Golden is given in the preceding chapters. The details of the coal measures are shown in figs. C to F, inclusive, of Pl. XVIII, and in the following section.[1]

Section, in part, of coal measures at Golden.

No.	Nature of strata.	Thickness in feet.
1	Sandstone at top	6
2	Coal	2
3	Clay	8
4	Coal	2
5	Clay	2
6	Sandstone	3
7	Clay	4
8	Black slate	3
9	Clay	8
10	Sandstone	7
11	Clay	3
12	Sandstone	12
13	Coal	2
14	Sandstone	4
15	Clay	4
	Total to main coal bed	70

Much variability is shown in these sections, not only by the measures themselves but by the coal beds as well; it is therefore impossible to identify the seams in the several mines without exploration of the entire width of measures at each shaft. From the character and succession of the exposed strata, however, it is probable that the coals are those between sandstones B and C.

The fossil flora of the Golden coal measures is abundant, though of little variety. Oysters also were discovered by Captain Berthoud, of Golden, in the vicinity of the coal beds, though no note was taken of the precise horizon.

The Old White Ash mine.—This is in the south bluff of Clear Creek at the upper edge of the town of Golden. It was among the first worked in

[1] From Annual Report of the U. S. Geol. and Geog. Surv. of the Territories, F. V. Hayden, Vol. VII, On the Geology of Colorado, 1873, p. 126.

Colorado and was abandoned about August 20, 1889, by reason of accidental flooding, supposedly from the Loveland mine to the north.[1]

A longitudinal cross-section of the Old White Ash mine at the date of abandonment is given in C, Pl. XVIII. The collar of the shaft is 135 feet west of the main worked seam, and at the 600-foot level is still 39 feet to the west. Below this the strata become vertical, with indications of an easterly turn, so that the shaft will nowhere cut the main seam. The seam is opened from the shaft by cross-cuts, levels being driven from these. A second seam, 3 feet thick, lies from 10 to 20 feet west of that worked. This has been found to vary considerably in thickness, but has never fallen below workable limits.

The floor and roof of the large seam is either a black or gray slate or clay, or a gray sandstone, the former more commonly occurring. The entire seam is generally free from partings, and the coal from below the 200-foot level is extremely hard and bright.

The Loveland mine.—This is just north of Clear Creek, on the same seam as the Old White Ash. The width of the seam is reported between 9 and 10 feet, with occasional partings. The coal ranks with that of the Old White Ash. The smaller seam, west of that worked in the Old White Ash mine, again appears here with a thickness of 4 feet.

The New White Ash mine.—(Fig. O, Pl. XX.) This mine, opened in 1890, is located about a half mile north of Clear Creek. There are two workable seams, 32 feet apart, having in the portion opened a N. 7° W. strike, and a dip of 75° to 80° west (overturned). The strike gradually changes to north as distance in this direction is gained, while the dip slowly approaches the vertical in depth. The west seam is 3 feet 6 inches to 4 feet wide; the east 4 feet, but indicating an increase below present levels. Both seams are worked from the same shaft, which, in October, 1890, had reached a depth of 317 feet, with cross-cuts to the beds at 173, 245, and 317 feet.

[1] "Recently a fatal accident occurred, causing the death of ten men who were working at the end of the lowest level of the White Ash mine in the direction of the Loveland mine. The latter mine has for years been full of water. One of the upper levels of the White Ash, which if protracted would have made connection with the lowest level of the Loveland, has for a long time been on fire, and it is supposed that this at last burned through into the Loveland, letting in the water, which ran down the White Ash shaft and drowned the men working in the levels below. The bodies of the men have not been recovered, and the mine has been closed down since the accident." (Ann. Report Golden School of Mines for 1889, p. 60.)

The collar of the shaft is 25 feet west of the outcrop of the western seam, but at the 245-foot level the shaft is 4 feet east of the seam, and at the 317-foot level, 12 feet. Sandstone forms the west wall of the western seam. Slate with sandstone forms the eastern. The eastern seam was but little exploited at the time the mine was examined in the fall of 1890.

The Golden Star mine.—This is located about a mile north of Clear Creek, a half mile distant from the New White Ash mine. Two seams are worked, the shaft, which is sunk to the depth of 160 feet, cutting the western at 30 feet and at the 130-foot level standing about 15 feet east of it, the distance between the seams being about 33 feet. Fig. F, Pl. XVIII, gives the relation of the beds to each other. The strike here averages N. 8° E., with some very slight local deviations, the dip being 80° west (overturned). The walls are of slate or a kind of fire-clay, and sandstone. Both beds are said to occur in the nearer abandoned mine to the north of the Golden Star, but to be entirely wanting opposite the end of the Dakota hogback, a few hundred yards still farther north.

The coal of the Golden Star mine is clear, hard, and bright; it is rectangular jointed and shows but a slight amount of pyrite or resin.

The Rocky Mountain mines Nos. 1 and 2.—(Fig. P, Pl. XX.) These shafts are 950 feet apart, No. 1 being the southernmost and located on the northern slopes of the divide between Clear and Ralston creeks, a few hundred feet east of the Dakota hogback. Two coal seams are present, their strike being about N. 7° E., their dip 80° to 85° west in No. 1 and 85° to 87° east in No. 2, both observations being taken on the 175-foot level. The east vein in No. 1 shows 3 feet of clear coal in one body, the west 4 feet, the distance between the two being 29 feet. In the No. 2 mine, to the north, the east vein is between 3 and 4 feet wide, the west 6 to 7 feet, both of clear coal. In this mine but 7 feet of rock separates the two seams, while in the old Pittsburg shaft—700 feet to the north of No. 2—the two seams are reported to come together, forming one of 11 to 12 feet without parting.

The coal of these mines is very clean and bright, and but slightly fractured.

RALSTON CREEK DISTRICT.

Ralston Springs mine.—This is located in the valley of Van Bibber Creek, and until recently was a large producer. The shaft lies immediately north of a sharp Laramie knoll in the middle of the valley, and is sunk to the west of the overturned strata. The strike of the measures along here is very constantly N. 17° E., the dip being 65° and 80° westward, becoming vertical in depth. The seam is reported 8 feet thick and without partings. South of the shaft, in the vicinity of the Laramie knoll, the coal is said to be so interstratified with sand and clay as to be worthless. Northward it has been extensively developed and, it is stated, promises to hold width and quality to the end, at the east and west fault marking the southern line of the disturbed area about the Ralston dike.

The disturbed area east of Ralston dike.—The coal measures between the two east and west faults bounding this area have been horizontally displaced considerably over half a mile. Owing to this and the nonrecognition of the faults, early explorers were led to believe that the coal was Fox Hills, since characteristic Mactra had apparently been found above it. In reality, however, the Mactra occur in the dislocated beds north of the southern fault, beneath the coal, but east of an extended line of coal outcrop from the Ralston Springs mine; hence the error. The fault remained undiscovered until the present explorations. The coal measures of the disturbed area dip in a general way eastward, but where they have been exploited, at the southern end, are greatly fractured. North of the area, beyond the influence of disturbance, the region of the Ralston Creek mines is reached, these having been among the greatest producers in early times.

The Ralston Creek mines.—These embrace two shafts, one in the northern bluff of the valley, the other on the prairie a short distance to the south. They attained a depth of 112 feet below creek level, but have been closed for many years. There are said to be two workable coal seams: the western, near the base of the measures, 9 feet thick; the other, 25 feet to the east, from 14 to 18 feet thick.[1] The measures have a N. 4° W. strike, continuing between this and north for several miles northward, and to the south nearly to the fault along the northern edge of the disturbed area

[1] U. S. Geol. and Geog. Survey of the Territories, F. V. Hayden, Report on Colorado, 1873, p. 125.

east of the Ralston dike. The dip is vertical, or nearly so, for the entire distance given. The old Murphy shaft on the north side of the creek, said to be sunk on the eastern of the two workable seams, is about 125 feet east of the base of the Laramie, which would place the seams in the same general horizon as the others along the foothills; that is, in the zone between sandstones B and C. From surface relations between points along a gradually shallowing dip, from the thickness of the formation, and from the recognized horizons, it is estimated that the coal measures would be found under the region of slightly dipping strata, between a quarter and half a mile to the east of the old mines, at a depth of 1,200 feet beneath the creek level, the fold by which the beds are upturned being sharp and pronounced.

The extent of the productive measures of this locality can not be greater than half a mile to the south of Ralston Creek, while to the north it may extend with some interruptions as far as Leyden Gulch, a distance of about 2 miles. In depth the beds probably extend far below economically workable limits.

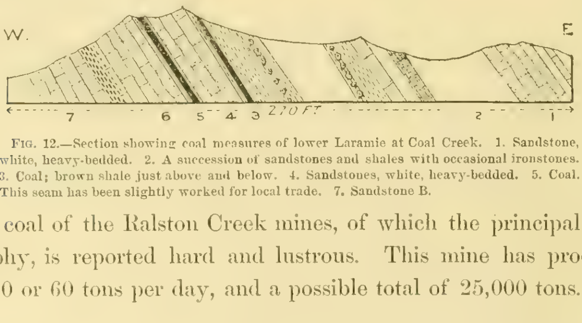


FIG. 12.—Section showing coal measures of lower Laramie at Coal Creek. 1. Sandstone, white, heavy-bedded. 2. A succession of sandstones and shales with occasional ironstones. 3. Coal; brown shale just above and below. 4. Sandstones, white, heavy-bedded. 5. Coal. This seam has been slightly worked for local trade. 7. Sandstone B.

The coal of the Ralston Creek mines, of which the principal one was the Murphy, is reported hard and lustrous. This mine has produced as high as 50 or 60 tons per day, and a possible total of 25,000 tons.

RALSTON CREEK TO MARSHALL.

The Leyden mine.—This is located in Leyden Gulch. It was originally a small producer, but has long been abandoned. From reports it is believed that the beds have changed in their character, forming, perhaps, the northern limit of the Ralston area.

From Leyden Gulch to Coal Creek the basal sandstones of the Laramie outcrop in low combs at a number of places. At Coal Creek the measures afford the above section (fig. 12).

The two coal seams now showing are: The upper, 2½ feet thick; the lower, 3½ feet. This statement differs from that of Marvine, in the Report on Colorado for 1873, page 124, in which six beds are mentioned; the one worked, of a thickness of 7 feet. The measures at the creek strike a little west of north and dip east about 50°, although north and south of this they become vertical.

It is probable that from Coal Creek northward the strata bordering the great fold on the east were considerably elevated, producing a gradual diminution in this direction in the depth at which the coal is to be found. The coal measures outcrop along the southern bluffs of South Boulder Creek, there being here only a slight southeasterly dip.

THE BOULDER COAL FIELD.

The entire coal field in the northwestern part of the Denver Basin is in the main confined to the two great synclines of the region; the one known as the Davidson lying diagonally across the Davidson and Lake mesas, its axis about a mile east of the town of Marshall; the other lying along the valley of Coal Creek, designated the Coal Creek syncline, and including the Louisville, Erie, and other subdivisions.

THE DAVIDSON SYNCLINE.

General features.—The Davidson syncline in its greatest extent embraces the Davidson-Lake mesa and its slopes from South Boulder Creek on the north to upper Coal Creek on the south. The areas mined at the time of examination were two, the Marshall and Davidson, but there are several long-abandoned openings and prospects scattered over other portions of the region. The western rim of the syncline as it appears in the Laramie formation coincides with the western line of outcrop of the basal sandstones; the eastern rim crosses the Davidson-Lake mesa in a northeast-and-southwest direction, very near the summit of the divide between Coal Creek and the drainage to the South Boulder through the town of Marshall. The southern end of the syncline is in the ridge separating Coal Creek from the Marshall Lake basin; the northern end lies midway between the fortieth parallel and Boulder Creek. The syncline is longitudinally crumpled by gentle yet clearly defined anticlinal rolls at two points, the region of the Burnt Knoll and the southern rim of the Marshall Lake basin; the axial extent of these rolls is between a half mile and a mile, the transverse extent about a half mile. The axis of the general syncline suffers the greatest depression between the Burnt Knoll and the southern side of the Lake basin, a maximum depth of 500 to 700 feet being attained by the coal measures.[1]

The continuity of the strata involved in the syncline is frequently interrupted by faulting. The outcrops of coal are broken and irregular, and the region is cut into small areas of various opposing portions of the Laramie and Fox Hills. Instead, therefore, of comparative geological simplicity there is great complexity, beds terminating abruptly beneath the surface or, by reason of gentle dip, having been brought into such positions that erosion has easily removed them in part or in whole.

The western rim.—Beginning at the vertical beds at the northern end of the foothill district, a little southwest of the town of Marshall, the exterior

FIG. 13.—Section of coal benches, Davidson mesa and northward, east of Marshall. A, B, C, Sandstones. F, F, Faults. X, Pleistocene cap of mesa. ▬ = coal.

periphery of the coal passes directly down the steep slopes of South Boulder Creek to the low line of bluffs immediately above the bottom lands. In this distance the strata change from their highly inclined position to one of gentle dip to the southeast. The outcrop of the coal beds follows the crest of the lower bluffs to a short distance east of Marshall, after which, gradually receding to a half mile from the valley bottom, it follows the low rise constituting the second terrace, the lower terrace along here being formed of the basal sandstone A of the Laramie, with occasionally a portion of the B stratum, the second terrace including the B sandstone and the overlying coal measures. The trend of the coal outcrop in the second

[1] In the test boring at the outlet of the Lake basin in the SW. ¼ sec. 14, T. 1 S., R. 70 W., Mr. R. C. Hills, of the Colorado Fuel Company, reports a depth reached of 615 feet, with the base of the Laramie still below. In drilling, one 3-foot coal seam was passed, and artesian water was obtained.

terrace is northeast. The second terrace disappears a half mile west of Burnt Knoll, the coal outcrop shortly passing into the northern or main branch of the Marshall fault system, which a little beyond occupies the bed of Dry Creek. Southeast of the fracture, for the greater portion of its length, beds of a much lower horizon, even the upper portion of the Fox Hills, occupy the surface of the country. Only near the western end of the fault has the coal on the south escaped erosion.

The coal of the interfault block, between the middle and southern branches of the fault system, rapidly rises from west to east, occupying the northern bluffs of the Davidson mesa as far as the steep-dipping portion of the syncline. Here its outcrop turns northward across the low country, paralleling the main Marshall fault at the distance of about a quarter of a mile. On this portion of the trend is opened the Allen-Bond mine.

The south branch of the Marshall fault system is also of especial importance in its influence upon the coal outcrop. In effect this fault has determined a line of bluffs to the south of a topographic depression at Marshall, lowering the beds on the north and leaving the outcrop of the coal in those to the south. The western end of the break probably lies in the main Marshall fault, at the point of the bluffs where the vertical dip becomes shallow, the outcrop of the coal here splitting, one portion passing into the lower bluffs along the periphery of the field, the other along the higher bluffs to the south of the Marshall depression. In the latter bluffs the coal outcrop extends eastward in a nearly horizontal line, midway their height, for nearly a mile, where, at the steeply dipping portion of the Davidson syncline on the eastern edge of the district, it turns down, crosses the gulch, and on the opposite side again rises, only to immediately sink in the depression which occurs on the northern side of the fault. The eastern end of this fault is in the fold just mentioned.

The possible bluff fault, a few hundred feet south of the foregoing, if present, is repetitive, the downthrow being on the north, the displacement slight.

The cross-fault at the west end of the Marshall mesa is also one of slight throw, appearing in cross-section in the north and south bluffs of the mesa.

In the vicinity of Burnt Knoll, which is the center of the slight anticlinal rise in the axis of the Davidson syncline, the trend of the coal outcrop becomes indefinite, but probably passes to the south of the knoll and thence onward to the region of the Davidson field just east, the old Allen opening lying a short distance south-southeast of the knoll.

At the northern or northwestern point of the Davidson mesa is a small flat in which lies the coal of the Dunn and Davidson mines.

The eastern rim.—Immediately east of the above mines the outcrop of the coal measures, as an effect of erosion combined with a rise of the beds against the southern arm of the Davidson fault, turns back upon itself, taking on its southward trend along the eastern rim of the syncline. The basal sandstones of the Laramie boldly outcrop a short distance southwest of the mines, in the northwestern face of the mesa, their general strike being N. 15° E., their dip 25° W. The coal outcrops a little to their west.

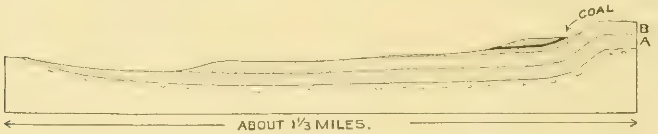


FIG. 14.—Section across coal benches of the Davidson mesa, Davidson district. A, B. Basal sandstones of Laramie. ▬ = coal.

A short distance southwest of the sandstone outcrops, on the eastern side of the syncline, borings, of depths unlearned, are said to have revealed the presence of 3, 4, and 5 foot seams of coal. From the above region the coal horizon enters the mesa on the eastern side of the broad indentation in its northern face, reappearing to the south, about the head of Marshall Gulch. The basal sandstones of the Laramie form strong horizontal outcrops in the railroad cuts and ditches just east of the divide in this vicinity, on the west slope assuming a western dip of 5° to 12°, which increases somewhat as the center of the syncline is approached. Together with the coal measures at the western end of the railroad cut, they now pass beneath the surface into the valley below.

In the ditches between the divide and Marshall Lake, in the eastern half of the distance, the basal sandstones of the Laramie repeatedly outcrop in practically horizontal position about 40 feet below the top of the mesa;

the western half of the distance is occupied by the coal measures, which dip to the NNW. 5° to 10°, occasionally returning to a horizontal position. Only traces of coal seams appear along here, and it is possible that the series entire is not present; on the other hand, the coal beds themselves may have decreased in thickness. Beneath Marshall Lake the strata are horizontal, but in a deeply cut ditch to the north they assume a southeasterly dip of 5° to 10°, with a general strike N. 30° E. Southeast of the lake, in the gentle rise of the mesa, the coal measures dip northwest. Along here the Ostrea bed is traceable for several hundred feet; it also appears flat in the bottom of the lake basin, the two outcrops, except for surface débris, being doubtless continuous. On the eastern side of the basin the northwesterly dip continues to the southern end of the depression, but, as will be shown beyond, the rim here becomes somewhat irregular in trend, and the trough itself is considerably modified.

From the horizontal outcrop of the Ostrea bed in the center of the Lake basin the measures rapidly steepen southward, entering the bluff southwest of the lake with a strike of S. 30° W. and a dip of 24° NW. The outcrop of the coal measures in the western walls of the basin constitutes the eastern rim of the Marshall coal area in this part of the field, the sharper and deeper portions of the syncline now lying entirely to the west, beneath the prairie uplands. The synclinal depression, except for the modification of its southeastern lip, is here, doubtless, at its narrowest point, since, at the head of a gulch entering the basin from the northwest, the beds have a southeasterly dip of 25° to 35°, their strike being N. 60° E. and the distance across the trough not over 1½ miles. The coal measures entering the steep slopes at the southwest corner of the basin pass through the mesa, to again outcrop in the bluffs on the north side of a short tributary of Coal Creek. Coal is here reported 3½ feet thick, but the drift is now closed, an outcrop of little promise alone showing. The strike is approximately N. 60° E., with a well-defined dip of about 6° NW. A short distance down the gulch, on the opposite side, the basal sandstones are seen, while above the higher coal-measure sandstones outcrop, succeeded in turn by the upper Laramie shales and ironstones. A strike N. 60° E. is of frequent occurrence in this portion of the field, and indicates a general change in direction for the southern end of the synclinal axis.

Southward from the tributary of Coal Creek mentioned the coal outcrop passes across the higher lands an undeterminable though probably short distance, when the southern extremity of the syncline is reached, the measures bending downward and passing beneath the prairie to their normal position.

Folds in the southeastern rim of the syncline.—The southeastern rim of the Davidson syncline, in the vicinity of the tributary of Coal Creek mentioned above and in the mesa separating it from the Lake basin, presents, in a number of longitudinal flexures, a structure that is the counterpart of the single fold in the region of Burnt Knoll in the northern part of the syncline; a crumpling in the trough or the sides of the syncline has been effected in both localities. In the area now under consideration, from the eastern edge of the main synclinal trough described above the strata bend gently over and downward to the east, rising a little beyond, prior to again assuming an easterly dip and becoming the western side of the shallow Eggleston trough which separates the Davidson from the Coal Creek syncline along their southern halves. The strata outcropping along the east side of the Lake basin are also crumpled, to become finally part of the system of folds to the south. The coal measures occupy the troughs of the several folds, but, in part at least, are eroded from the intervening anticlines. The foregoing structure may be observed in the southern walls of the Lake basin, and again, somewhat modified in the amplitude and number of the folds, along the tributary of Coal Creek to the south. In this latter locality there seems to be but a single strongly pronounced anticline, which, although dividing the general syncline into the two subordinate troughs, would, but for a gentle rise and drop to the east, directly separate the Davidson trough from the Eggleston depression. The anticline attains its maximum development about a low knoll just south of the gulch and a little below the abandoned coal-opening already referred to. The knoll is a dome-like outcrop of the basal sandstones of the Laramie, with an encircling rim of the coal measures dipping rather sharply away in the northwest and southeast directions and gently in the northeast and southwest. The coal itself nowhere presents an outcrop except at the abandoned mine already noted. East of the anticline the strata bend downward, and, beyond a second minor crumple in this portion of the rim and a long shallow curve, gradually rise again in the high bluffs on the northern side of Coal Creek, 1½ miles below, here a part of the Eggleston syncline.

It is possible that immediately east of the anticline just described, instead of part of the structure indicated, a break in the continuity of the strata may occur, the downthrow being on the east of the fault. Some ground for this supposition appears in the gulch entering Coal Creek; but for the possible presence of the fault or a very sharp downward flexure in this portion of the field, the distance between the sandstone knoll and the point at which the measures again begin their long, gentle rise to the east would be altogether too short to permit the presence of the higher Laramie beds that lie in the concavity of the syncline along the bluffs of the creek. The objection, however, to mapping faults without sufficient evidence has decided for sketching the geology as a succession of unbroken folds.

Productive areas.—Present productive localities in the Davidson syncline are the Marshall, Allen-Bond, and Davidson, the last of local importance only. Coal was formerly obtained at a number of points along the northern border of the field, but the openings have long been closed on account of limited area or narrowing seam. The heaviest coal seams—from 8 to 13 feet thick—occur in the Marshall and Allen-Bond areas, and a 3-foot seam may be found at several points about the rim of the syncline, as at the Davidson mines and the opening near Coal Creek, and possibly, also, underlying a large part of the deeper portion of the basin. The last occurrence is attested by three or four borings: one in Marshall Gulch at the exit of the Lake basin, which showed a 3-foot seam of coal at a considerable depth, the total depth drilled being 645 feet; and three a short distance north of the Davidson mesa, which afforded evidence of from 3 to 5 feet of coal. The latter coal is the continuation southward of the Allen-Bond and Davidson areas; the former, the continuation eastward of the Marshall.

THE MARSHALL DISTRICT.

A section of the lower Laramie sandstones and coal measures obtained in the bluff immediately east of the head-house of the Marshall No. 5 mine is given below. It comprises the entire series, and is as representative a section as can be obtained in a region showing so much variation in the composition of its beds.

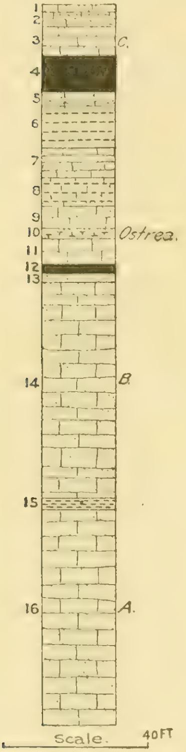


FIG. 15.—Section of coal measures, lower division of Laramie, Marshall district.

1. Sandstone; white; solid; forming top of hill south of Marshall No. 5 mine.
2. Sandstone; white; shaly.
3. Sandstone; white; moderately coarse grained; composed of quartz; designated throughout this report as "C" sandstone.
4. Workable coal bed of Marshall No. 5 mine. The outcrop of this bed at times is so weathered as to have the appearance of an extremely lignitic shale with a large portion of pure coaly layers threaded through it. It is possible that the coal may belong a little lower down than this.
5. Sandstone; solid, but inclined to shaly structure; slightly lignitic; of the quartz composition usual in the lower Laramie measures.
6. Shale; lignitic; often very brown, particularly in upper half.
7. Sandstone; white; fine-grained; quartzose; in 6 to 12 inch laminæ; some layers slightly ferruginous. Shades into 8.
8. Sandstone; fine-grained; white; stained brown with lignitic material; carries a few bands of lignitic shale.
9. Sandstone; white; quartzitic; resembles 14.
10. Ostrea bed; consists of calcareo-arenaceous shales; gray, yellow, or brown; abounds in Ostrea; varies in thickness from 3 to 6 feet. Occasionally becomes a solid sandstone.
11. Sandstone; white; fine-grained; contains a small amount of a black mineral with its black quartz.
12. Coal; locally workable, but not in the Marshall field. Here it is of the nature of lignitic shale. In its relation to sandstone B (No. 14) it forms an excellent reference horizon.
13. Shale; light-colored to white, with brown layers here and there.
14. Sandstone; white; heavy-bedded; composed wholly of quartz; thickness very persistent; designated in this report as sandstone B.
15. Shale; locally lignitic; occasionally a coal. Always present.
16. Sandstone; heavy-bedded; white; thickness persistent; designated in this report as sandstone A; 14 and 16 (sandstones B and A) are known as the basal sandstones of the Laramie.

Sandstone A is immediately underlain by the heavy bed of sandstone which everywhere forms the cap of the Fox Hills formation. At their line of junction, but in the lower sandstone, there is generally an abundance of characteristic Fox Hills mollusks.

In the locality affording this section there are two well-developed coal seams, also several beds of lignitic shale, any one of which might be elsewhere replaced by coal of workable thickness. The heavier coal seam lies a short distance below sandstone C and is from 8 to 10 feet thick; the thinner seam underlies the first by about 10 feet. A third seam, $2\frac{1}{2}$ feet thick, is often present in the district immediately over sandstone B.

East of the outcrop affording the above section, in the gulch leading down from the Marshall-Louisville divide, a portion of the series is several times repeated by reason of a number of slight fractures and displacements which were formed along the immediate rim of the deeper portion of the Davidson syncline at the time of folding. The reduplication thus effected has in the past led to overestimates of the number of beds prevailing in the region, the number having been stated by some geologists to be from 9 to 14.

The Marshall coal field is clearly defined on the north and west by the outcrop of its beds; on the east the limits of economic work are determined by the sharp fold constituting the rim of the deeper portion of the Davidson syncline and by the thinning of the beds in this direction; while to the south, beyond the bluff fault, although the productive measures may possibly extend for a considerable distance, evidence from openings well within the limits of the syncline again indicates thinning beyond workable size.

It is difficult to estimate the general depth at which the coal lies in the southern extension of this field, the exact form of the syncline being undeterminable. It is probably shallow, however, when compared with that at which the gently dipping beds usually lie along the foothills.

The mines of the Marshall district include the Marshall 1, 2, 3, and 5, the Fox (present mine), the old Fox Slope northeast of the main field, and a mine known as the old Marshall Slope at the western end of the field; besides these a number of unimportant openings, chiefly prospects, are scattered over the district in various directions. The mines latest worked are the Marshall Nos. 3 and 5 and the Fox; the others have long since been abandoned.

The Marshall No. 3 mine.—(Figs. J and K, Pl. XVIII.) This is opened in the lower bench of coal by a slope to the south, near the center of the depressed area north of the southern branch of the Marshall fault. The entrance to the slope is some distance south of the outcrop of the seam, the angle of descent being several degrees steeper than the dip of the beds, and the coal cut only at a considerable depth.[1]

Several hundred feet west of this slope is another, on the coal, having a southwest direction and uniting with the first at its foot.

The strike of the coal in the No. 3 mine is between N. 45° and 50° E.; the dip is 10° SE. in the upper levels of the mine, decreasing to 3° in the lower levels. In the lowest level of the mine the southern branch of the Marshall fault system was encountered. The fracture showed a N. 62° E. trend, with an inclination of its plane to the horizon of 45° SE.; the downthrow being on the northwest, the fault being of the reversed type. The coal in No. 3 mine varies in thickness from 8 to 9 feet. It is free from partings, is square-jointed, hard, bright, and contains but little pyrite and resin.

The Fox mine.—(Figs. G and H, Pl. XVIII.) This also is in the lower bench of coal. It is opened by a slope to the north—across the stratification—the entrance to which is on the north side of the valley, a half mile northeast of the Marshall No. 3 mine.

The general strike of the beds in this mine is N. 30° E., with a dip to southeast about 7°. At the time of the examination no faults had been encountered. The thickness of the seam varies but little from 9 feet. The coal lies very regular, is free from partings, but is divisible both in appearance and in quality into an upper and lower bench, 2 or 2½ feet and 6½ or 7 feet thick, respectively. The upper 2 inches of the top bench is in places a little bony. Generally the top coal is more fibrous, oily, and harder than the bottom coal, scaling off in slabs in working. The bottom coal, on the other hand, is dicy, has a bright luster and a conchoidal fracture; 2 feet from its top is a 12 to 18 inch band much harder than the remaining portion, and somewhat resembling the top bench. The top coal is reported to be a good steam coal, the bottom being better for domestic purposes.

The Marshall No. 1 mine.—Some doubt exists as to the identity of this mine, but it is probably that between the Marshall No. 3 and the Fox, now abandoned and on fire. It was opened by a drift (slope?) and worked to

[1] The custom of opening a mine by slope through barren rock instead of by shaft is an old one in Colorado. It has long been abandoned.

tne dip, southeast, a distance of between 400 and 500 feet, when a fault with a northeast trend is said to have been encountered—probably one of the branches of the Marshall fault system.

The old Fox slope.—This is located on the northeastern confines of the Marshall field, and is sunk in a southeasterly direction at a gentle angle through the overlying sandstones to the coal beneath. Its output was once important, but it has long been closed. Its coal is probably continuous with that of the Fox mine, but here shows considerable diminution in thickness.

The old Marshall slope.—This, lying in the very western part of the field, was sunk across the strata, toward the west, the dip of the beds being east. It evidently opened but a small area of coal, which was directly in the bow of the strata from their vertical position to that of gentle dip.

The Marshall No. 5.—(Fig. 1, Pl. XVIII.) This is the only mine lately worked on the upper coal bench of the Marshall field, that south of the southern branch of the general fault system. It was opened in 1886 by a horizontal drift beneath the coal, which cut the latter at a distance of about 240 feet from the entrance. The first cross-entry was then turned on the strike, nearly parallel with the outcrop. The strike is generally N. 60° E., the dip about 5° SSE. The coal at the breast of the cross-entry at the time of examination was 9 feet thick, a parting of half an inch occurring 2 feet from the top. At a distance of 200 feet back from the breast this parting began to increase perceptibly in thickness; 100 feet farther on toward the main entrance it showed a thickness of 1 foot, and in the next 50 feet became 4 feet thick. The parting thus continued increasing to the turn of the entry, at which point the upper coal was some little distance above the roof. A short distance beneath the lower member, in the main entry, a 1-foot coal bed was struck, which increases to 3 feet at the outcrop, several hundred yards west of the No. 5 mine. The coal of the No. 5 mine is very bright and resinous, contains a slight amount of pyrite, is of cubical structure, and has a conchoidal fracture. The top coal is the harder and more fibrous, and in general resembles the upper division of the Fox coal.

The upper coal bench has been well prospected along its outcrop by drifts extending into it from 10 to 50 yards. From some of these considerable coal has been taken, notably one a few hundred yards east of the Marshall No. 5 mine. It is also stated that the coal at a distance of 50 yards from the entrance of this opening abutted against a heavy sandstone, an occurrence which, with the topographical drop in the ground above and the position and succession of the strata in connection therewith, is strong evidence for the existence of the Bluff fault.

The Marshall No. 2.—This mine lies beneath the western slope of the Davidson mesa, in the partially depressed interfault block between the southern and middle branches of the Marshall fault system. It is opened by a drift from the gulch to the south, the seam dipping 10° to 15° SW. The area of coal workable from the mine is limited on the east by the natural thinning of the bed, by the crumpling at the crown of the arch on the western rim of the general syncline, and by the fracturing which was a concomitant feature of the folding. Aside from the numerous throws, which are all small, the coal seam, after passing the arch and assuming the high easterly dip of the syncline, crosses in outcrop to the southern side of the Marshall Gulch, there ascends the bluff in a westerly direction and unites with the coal of the upper bench, which has already been followed east to this point. In its western extension, within the interfault block itself, the coal of the No. 2 mine passes in its dip beyond the union of the middle and main branches of the system and becomes continuous with the coal opened in Marshall mines Nos. 1 and 3 and in the Fox mine. The link between the upper and lower benches of the Marshall field is thus completely established.

The coal of this mine is hard, bright, and solid, notwithstanding the fact that it has a cover of only 15 to 25 feet of sandstone (C) and shales. Its thickness in the central and western part of the mine is from 8 to 9 feet; at the eastern end, 4 feet. The mine has been extensively worked, but is now reduced to a minimum of production—perhaps abandoned altogether.

THE ALLEN-BOND DISTRICT.

The Allen-Bond mine.—(Fig. M, Pl. XX.) This is located on the western rim of the Davidson syncline, about 1 mile north of the Davidson mesa.

The mine was opened in January, 1890, and has become an important local producer. Two seams of excellent coal are present; an upper, 7½ to 9½ feet thick, and a lower, 4 feet thick, 32 inches of fire-clay and sandstone separating them. A slope on the coal and cross-entries afford access to the seam. The pitch of the beds is somewhat variable, but is usually below 30°. The general strike of the region is N. 20° E. The extent of the productive measures in this region has not been determined, the outcrop being covered and the amount of boring having been slight. While the seam may continue southward, even beneath the mesa, to the north it is soon limited by outcrop and erosion.

THE DAVIDSON DISTRICT.

This is of little importance. It consists merely of a small patch of coal, less than a square mile, that has escaped erosion on the northern slopes of the Davidson mesa. It occupies a projecting table or flat composed of coal measures on basal sandstones, the latter only extending beneath the main valley to the north. The structure of the area is that of a very gentle depression which occurs as a secondary and parallel flexure in the eastern rim of the main syncline to the west. The axis of the secondary trough lies in the eastern half of the district, near an old whim shaft. West of it the strata have a long and gentle dip of from 3° to 10° E., while east of the axis the dip is between 10° and 20° W., the latter degree that of the dip of the basal sandstones on the eastern edge of the area. The maximum depth of the coal along the axis of the syncline is about 60 feet. The area is connected with the main field to the southwest by a narrow band of coal measures along the eastern rim of the general syncline. The productive portion, except at this connection, is limited on all sides by the outcrop of the beds. A section visible for a short distance down one of the abandoned shafts shows the usual succession of beds, the clays and shales predominating. But one workable coal seam has been discovered, from 2 feet 8 inches to 3 feet thick. (Fig. C, Pl. XIX.) Its horizon can not be positively stated, but it probably overlies sandstone B, the upper seams, of the Marshall area, having been but slightly developed or altogether eroded.

The mines of the district are the Dunn and several unimportant and abandoned openings on the Davidson property. The Dunn, which affords the above section, is worked only periodically, to supply local demand.

THE EGGLESTON SYNCLINE.

This separates the southern ends of the two great synclines of this portion of the Denver Basin, the Davidson and Coal Creek. It is of limited area and lies almost wholly north of Coal Creek, in the southern and eastern portion of the Lake mesa. It is separated from the Davidson syncline by the anticline which crosses this mesa just east of the Lake basin, but is apparently united with the Coal Creek syncline by an open southern end. Its northern end is very shallow, the trough gradually deepening southward. The trend of the syncline is northeast to southwest. The northern end shows in a slight depression in the basal sandstones of the Laramie in the ditch at the eastern end of the Lake mesa. In this portion of the trough the coal measures barely escaped complete erosion in the wearing down of the region before the deposition of the Quaternary cap.

The outcrop of the coal horizon beneath the Quaternary probably joins that of the Davidson syncline, opposite to and near the southeast corner of the Lake basin; from here it passes eastward, then southward, and, after a somewhat tortuous trend, appears in the bluffs of Coal Creek near Sweeney's ranch, where the measures strike N. 30° E. and dip 15° to the northwest, forming here the eastern side of the syncline.

The coal horizon, exposed at Sweeney's, crosses Coal Creek half way between this and the Eggleston ranch to the west, where openings have been made in a low bluff bordering the bottom on the south side of the stream. The coal, according to report, for it could not be seen, here dips to the west, but it shortly takes on a southern dip, changing to southeast, and passes beneath the high mesas south of the creek. The center of the Eggleston syncline in the Lake mesa is occupied by the upper Laramie shales, but owing to the comparatively shallow depth of the trough only the lower beds of the series at present exist—in all, perhaps, 200 feet.

The thickness of the coal at the two openings in the Eggleston syncline is reported to be from 2 to 3 feet. But little has ever been mined, and this only for trial by farmers.

THE COAL CREEK SYNCLINE.

This syncline, which is a general depression embracing several subordinate troughs, occupies the valley of Coal Creek from a point a little west of the crossing of the Denver, Marshall and Boulder Railroad, several miles west of Louisville, to its confluence with the Boulder, a short distance below the town of Erie. The length of its longitudinal axis is thus a little over 12 miles, while the width of the trough from rim to rim will average about 3 miles. The syncline occupies the western side of the lower Coal Creek Valley, and trends diagonally across the upper valley, its axis lying a little nearer the north than the course of this portion of the creek.

STRUCTURE.

Western rim.—The western rim of the Coal Creek syncline lies in the bluffs on the southeastern side of the Lake and Davidson mesas and in the western slopes of the long ridge extending from the latter northeasterly to the vicinity of Erie and Canfield. In the continuity of this rim there is but one important break, that near the eastern end of the Davidson mesa, attributable to the Sand Gulch and Harper faults. The general position of this rim is clearly defined.

Rising from beneath the prairie to the south of upper Coal Creek, it first becomes distinctly recognizable to the north of the stream in the basal sandstones and coal measures of the lower Laramie, which occupy the bluffs at the eastern end of the Lake mesa. The position of the strata along here is locally somewhat undulating, as they lie in the very crown of the anticline separating the Eggleston and Coal Creek synclines They quickly assume a southeasterly dip of 10° to 15°, however, passing beneath the Quaternary wash of the valley. A short distance from the base of the bluffs the upper Laramie intervenes between coal measures and Quaternary, attaining a depth of 100 to 150 feet in portions of the bottom. Whether workable coal exists for any considerable distance along this portion of the rim has not been determined. A bed from 2 to 3 feet thick is exposed opposite the Sweeney and Eggleston ranches, but its extent is not established.

In the southern face of the Davidson mesa, a half mile west of the wagon road crossing to its northern side and $2\frac{1}{2}$ miles west of Louisville, the position of the rim is again clearly distinguishable in an outcrop of basal sandstones which dip 15° SE. and strike N. 52° 30′ E. The coal horizon enters the mesa a little east of this, though no outcrop of coal is visible; its presence in the vicinity is established by numerous drill holes put down for prospecting purposes. In crossing the Davidson mesa the rim of the syncline is concealed beneath the Quaternary cap, and it can only be conjectured that the coal measures gradually sink along the southern arm of the Davidson fault, to finally attain the position in which they are found north of the mesa at the abrupt turn in the Davidson ditch. In a cut at this point, 20 to 25 feet below the surface of the ground, are two or three narrow seams of coal, the thickest about 3 feet. These strike N. 30° E. and dip 5° to 10° to the southeast. At the Superior mine, a half mile east, the coal occurs at a depth of 90 feet, the collar of the shaft being between 5 and 10 feet higher than the coal at the head of the ditch. The southeasterly dip seems, therefore, to be general for this portion of the field. Along the periphery of the measures no outcrop of coal shows, its delineation being based on the general relations between topography and strata. and on the fact that in a drill hole near the railroad section-house 2 miles north of Louisville the basal sandstones of the Laramie were alone encountered, thus limiting the lower line of the coal series proper somewhere to the southwest of the boring. The coal horizon, where present, finally passes into the Sand Gulch fault. The strata along the southeastern edge of this severed area, in the immediate vicinity of Sand Gulch fault, have a decided dip to the northwest. This has been observed in drill holes and shallow prospects on the southeastern slopes of the mesa, a half mile northwest of Louisville.

This small coal area between the Davidson and Sand Gulch faults, which, from its chief opening, may be designated the Superior Area, has, therefore, a synclinal structure, the axis lying somewhat to the southeast of a median line and parallel to that of the main Coal Creek trough. The depression is slight, the highest beds in the mesa being the coal measures; in the bordering terraces, the basal sandstones only.

The southwestern end of the Sand Gulch fault is not clearly defined.

It is possible that instead of ending, as indicated on the map, in the Harper fault, it may continue on its trend across the valley of Coal Creek and enter the bluffs on the opposite side, at a point a little southeast of that at which the Denver, Marshall and Boulder Railroad crosses the creek, a marked irregularity in position and association of sandstones and shales in this vicinity suggesting this. In either case the strata southeast of the fracture have been raised, and, as the effect of subsequent erosion, the outcrop of the coal horizon has been carried to the east a considerable distance from the line of fracture.

From opposite Louisville eastward to the vicinity of Canfield the outcrop of the coal horizon lies either directly along the top of the ridge separating Sand Gulch and Coal Creek or just below the crest, on its western slope. In this distance the coal shows only in fine particles in the soil, or in an occasional drill hole or shaft, but this, with the exposures of Fox Hills and of the basal sandstones of the Laramie, is sufficient to define the horizon.

The strike along this portion of the rim is about N. 30° E., the dip from 5° to 15° ESE.

At the northern end of the ridge and beyond, in the valley of Boulder Creek, the outcrop is carried to the east into the flatter portion of the syncline, and the dip reaches its minimum. The coal horizon now passes beneath the Quaternary deposits in the forks of Boulder and Coal creeks, rounds the point of land between them, and reappears at water level in the latter creek near the railroad station at Erie. From this point northward it gradually rises to the level of the flood plain, and thence enters the bluffs on the east side of the valley about a mile below town. The outcrop then continues northward, rising to the general level of the prairie, whence it shortly passes into the lower Coal Creek fault. With this the western rim of the syncline is complete.

Eastern rim.—The eastern rim of the syncline in the northern half of the field is formed by the upward bend of the strata in the fold just west of the lower Coal Creek fault, in which fold the fault had its origin. The general features of the fold and fault are: The opposition of the Fox Hills and upper Laramie, on the west and east of the fracture, respectively; the relatively high inclination of the beds west of the fracture and the sharpness of their curve to horizontal; and the rapid succession in outcrop from Fox Hills to coal measures, the latter coming in at dips between 45° and 15°, usually nearer the latter.

A break in the continuity of the rim occurs opposite the town of Erie. Here, by displacement along the Erie fault—a cross fracture having a N. 64° E. trend with downthrow to the south—the upper beds of the Fox Hills and the coal measures have been brought in opposition, the former appearing on the north of the fracture, the latter on the south. The dip of the Fox Hills at the fracture is vertical; of the basal sandstones of the Laramie 200 feet to the north, 45°; of sandstone C, 100 feet still farther north, 10° to 15°, beyond which an approximately horizontal position is assumed. South of the fracture the beds are much less disturbed, the dip in the Old Boulder Valley mine being reported at 5° to 10° SE.

The southwestern extension of the fault is uncertain; it may be but little over a mile long, or may continue well toward the western rim of the syncline.

The foregoing structure has resulted in a line of outcrops as follows: From the point at which the coal measures first reach the surface along the western side of the Coal Creek fault a southern trend prevails to within 200 or 300 feet of the Erie fracture; at this point the line runs sharply west-southwest, paralleling the latter fault; its continuation in a southwest direction depends on the extent of the Erie fracture, but the measures, with their included coal seams, finally sink beneath the surface, and, upon the disappearance of the fracture, become continuous with their fellows on the opposite side. It is possible that this fault is the structural division between the Mitchell and Jackson subbasins, and that to the elevation of the strata on the north is due a large superficial area of sand. A gentle anticline in the measures has been already suggested as the alternative of this structure.

North of the Erie fault, immediately south of the deep railroad cut in the basal sandstones at the crest of the valley bluffs, there is possibly another fault, parallel to the Erie, though much shorter linearly, by which there may be a second indentation in the measures similar to the foregoing.

The coal to the south of the Erie fracture probably remains at nearly its normal depth beneath the surface until within the influence of the sharp flexure immediately west of the main Coal Creek fault, where it then rises to the surface, resumes its southward trend, crosses Coal Creek at the point indicated on the map, and is found in outcrop in the valley, on the west side of Coal Creek, east of the Mitchell mine.

The point next south of the Mitchell group of mines at which the coal is definitely located is a few hundred yards west of the trestle by which the old Denver, Utah and Pacific Railroad crosses Coal Creek. Coal 3 feet 10 inches thick is here reported at the bottom of a shaft 93 feet deep. The dip is 11° NW., approximately at right angles to the trend of the Coal Creek fault. On this dip the coal would reach the surface about 500 feet east of the shaft, a deduction with which surface observations coincide. A short distance south the displacement along the fracture apparently begins to diminish, and the coal sinks and gradually approaches that on the opposite or southeast side of the fault.

Opposite Louisville the southeastern rim of the syncline is again locally affected, here by the Louisville fault. This passes from the periphery of the general syncline diagonally across its trough beneath the valley of upper Coal Creek, separating it into the Lafayette and Louisville subbasins. The trend of the fault is approximately N. 45° E., the downthrow to the southeast, the maximum displacement at least 200 feet, and perhaps considerably greater.

The fault appears in the railroad cut in the southern bluffs of the valley just south of Louisville (fig. 9, p. 125), where the beds opposed are the lower members of the upper Laramie and sandstone B, or the top of A in the lower division. The succession of the strata northwest of the fracture is rapid, the dip being about 45° NW. The Fox Hills probably occupies a narrow belt beneath the Quaternary wash at the foot of the bluffs; then follow the several members of the Laramie in order. The linear extent of the fault is unknown. No trace of it appears in the bluffs north of the valley, and it is here probably completely reduced. The points at which the horizon of the coal reaches the surface on the west of the fault are unknown, but southeast of the Welsh mine at Louisville the outcrop is several hundred feet northwest of the fracture. For about a mile southwest of this the position of the coal may easily be traced across the bottom-lands by reference to the basal sandstones which are prominently exposed in the bluffs south of the valley. The latter, however, finally sink beneath the bottoms as distance up the valley is gained, and, with the exception of some irregular outcrops opposite the point where the Denver, Marshall and Boulder Railroad crosses Coal Creek, the bluffs for their entire length are here occupied by coal measures or upper Laramie strata. The coal in the upper valley is found at the depth of 160 feet in a shaft a short distance north of the rim of the syncline and near the point where the Boulder wagon road crosses the creek. It reaches the surface at some point southeast of this, passes into the bluffs, and then southwestward beneath the wash of the prairie until the western rim of the syncline is encountered or until, by the diminished displacement along the Louisville fault in this direction, it has sunk to meet the seam on the opposite side, leaving the surface rim of the syncline again open along here. Southeast of the Louisville fault, in the uplands between this and Rock Creek, the coal measures probably lie at a considerable depth beneath the surface, forming here also an open lip to the syncline.

Configuration of the interior of the syncline.—A transverse section of the Coal Creek syncline at almost any point would show it to be of gentle curvature and shallow depth. The greatest distance beneath the surface at which the coal occurs is probably in the region of the Lafayette mines, where the top of sandstone B is reached at an average depth of 260 feet. In the eastern mines of the Louisville group this horizon is reached at nearly the same depth, but west of the railroad a decrease to 170 feet has taken place, which is probably maintained nearly to the southwestern limit of the basin. In the Mitchell group of mines the seam most generally worked—probably that occurring immediately over sandstone B—lies at an average depth of about 100 feet below the surface of the valley bottom. South of the Lafayette-Louisville portion of the syncline, beyond the open rim of the basin, the depth probably increases considerably, there being thence an apparent southeasterly dip for the entire northwest portion of the Denver field. With the usual thickness of the coal measures, the foregoing depths will permit a general cover of from 50 to 200 feet of upper Laramie along the axis of the syncline, according to locality. East of the axis, along lower Coal Creek, the cover of upper Laramie rapidly diminishes, owing to the sharp rise of the strata toward the Coal Creek fault; west of the axis the decrease in depth of this series is more gradual, especially for the northern half of the syncline, where the beds have a very gentle southeast dip, but slightly greater than the slope of the hills. Regularity of structure and depth of the various measures have also been affected by the Louisville, Erie, Jackson-Star, and other, minor faults.

The structure of the extreme northern part of the syncline, from Erie north, is somewhat obscure, but the general depth of the coal measures may be locally estimated from outcrops in Coal Creek and from mines already opened. In the Boulder Valley and Erie mines the upper seam of coal developed is reported at 70 feet beneath the surface, and a second seam at a depth of 133 feet. Northward the cover of the coal decreases, both on account of erosion and because of a gradual rise of the strata. In the Star mine, near the northwestern rim of the syncline, this rise is 2 feet in 100.

Faults and rolls of roof and floor of minor importance occur in several mines of the Coal Creek syncline, but they are wholly local. They will be mentioned in the detailed description of the mines.

STRATIGRAPHY AND CORRELATION.

Introductory.—The strata involved in the Coal Creek syncline and exposed at various points within its confines include the sandstone cap of the Fox Hills, the basal sandstones and coal measures of the lower Laramie, and the lower third of the upper Laramie. All maintain their general lithological features, but the coal measures from point to point present important variations in the width of the individual beds composing them. This variability is particularly well illustrated in the actual union in the Lafayette-Louisville region of two beds of coal which in the Erie field are distinct and separated by a series of sandstones and shales of an average thickness of 25 feet, and their point of divergence may even be observed in the former area, the rate being about 1 foot in 50 or 60 until the general width between them is attained, several hundred feet to the north.

Recognition of the several coal beds and their relations to one another over the Denver field depends upon recognition of the associated beds of sandstone and shale and the horizon bearing the fossil Ostrea. Identification of the horizontal beds is easiest, and in the area of the Coal Creek syncline this has been definitely accomplished.

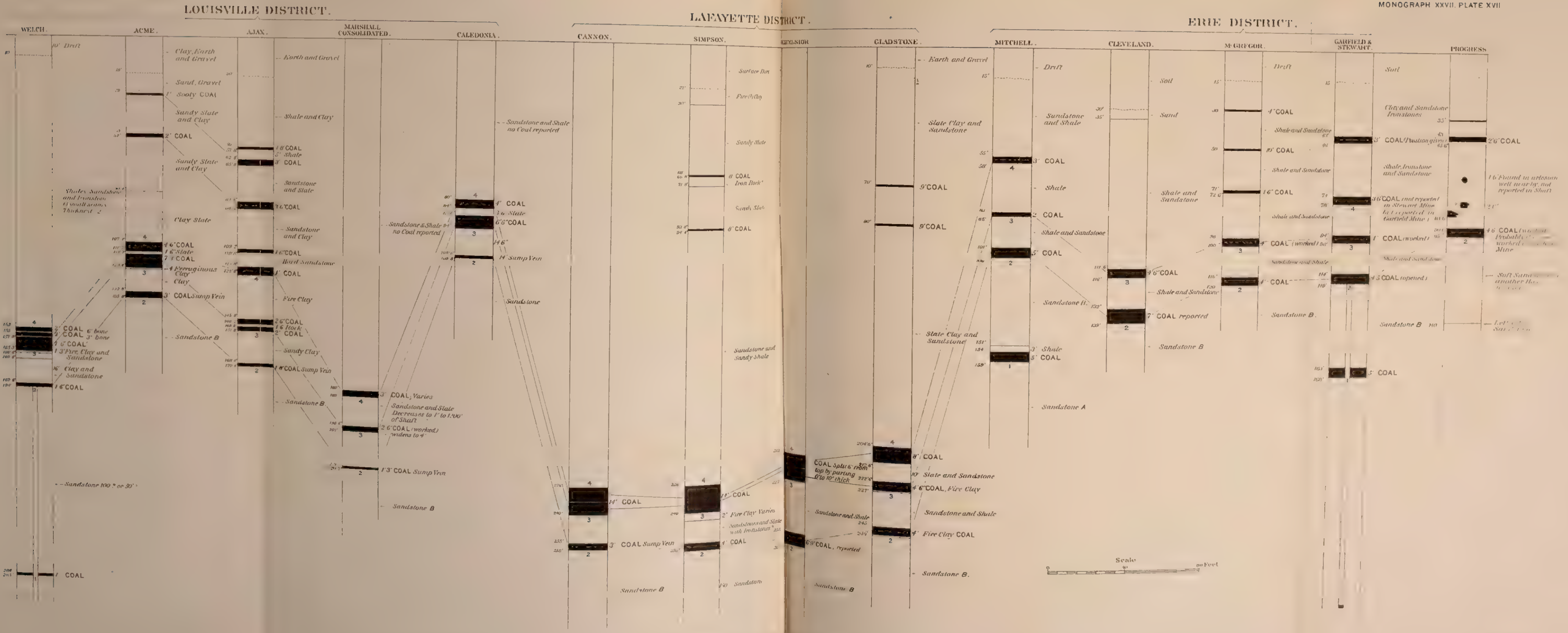
The seams present in the Coal Creek syncline may be conveniently numbered as follows: That which separates sandstones A and B, the lowest, as No. 1; that immediately overlying B, No. 2; the next, which occurs with regularity at the distance of 16 feet above the last, No. 3; and finally, as No. 4, the one, of constant presence and at the same time workable, 25 feet above No. 3. Above the No. 4 occur at various intervals several nonpersistent seams, from 1 to 3 feet in thickness, the lower being those more commonly present and also the better developed; but identification of these, except, perhaps, of No. 5, is impossible.

The shaft sections on Pl. XVII are chiefly from the records of superintendents, but they have been supplemented and verified by personal observation wherever possible, both in mines and at the surface.

The basis of identification of the beds of the Coal Creek syncline is the heavy sandstone B and the band of shales which separates seams Nos. 2 and 3, these seams being everywhere present and their relative distance from each other quite uniformly preserved.

Seam No. 1.—(Figs. G, H, J, Pl. XIX.) This has been exploited only in the Erie district. Its presence has been determined in the Stewart and Mitchell mines, and in the latter it has been worked. Near Louisville it is also reported, in a boring from the bottom of the shaft of the Old Welch mine (abandoned), but the data concerning its thickness and depth are unreliable. The presence or absence of this seam is an important consideration in estimating the value of coal lands, and should be one of the first points determined by mine owners. The coal, where opened, is usually free from partings and of excellent quality.

Seam No. 2.—This lies immediately above sandstone B. It preserves its identity throughout the entire Coal Creek syncline and is readily recognized by its position in the series of associated strata It has been proved of workable thickness in most of the mines in the Erie field and in the greater portion of the Lafayette district thus far explored, but in the Louisville



SUCCESSION OF STRATA IN THE SHAFTS OF THE LOUISVILLE, LAFAYETTE AND ERIE DISTRICTS.

area it is generally found too narrow to open, prospects nowhere showing a thickness greater than 3 feet 6 inches. The character of the seam is given in several of the sections of Pls. XIX and XX. It often carries a parting of variable width, which may, however, entirely disappear over extended areas—particularly the case in the Lafayette mines.

Seams Nos. 3 and 4.—These will be considered together on account of their union over certain parts of the Coal Creek syncline. The general character of each is shown in sections on Pls. XIX and XX. No 3 is that usually developed to a workable thickness, No. 4 being only occasionally so, except in the central portions of the syncline—in the Lafayette and a part of the Louisville fields—where it is united with No. 3 to the complete exclusion of the parting, the two forming a single bed of an average thickness of 14 feet. The approach and divergence of the seams to each other are distinctly shown in the Lafayette field. Along the axis of the syncline in the Simpson mine, and in the northern entries of the Cannon and the southern of the Excelsior, the two beds are united in a solid mass of coal; north and south of this, however, a parting of interbedded sand and clay appears, rapidly increasing, particularly to the north. In this direction the first appearance of the parting is at a point 223 feet north of the Excelsior shaft. From here the line of separation has an east-southeast trend—east of the shaft—the more southern the entry the farther the point from the main entry at which the appearance of the parting is encountered.

In the Gladstone shaft, 500 feet north-northeast of the Excelsior, the parting has increased to 10 feet and shows evidence of a continued gain until its normal thickness of 25 feet is attained. In this direction both seams, 3 and 4, hold to a clean condition, only occasional thin and nonpersistent partings showing in either. South of the axis the only opportunity of observation at the time of examination was in the south entries of the Cannon mine, where the parting had increased to 4 feet, and where, moreover, the lower seam, 3, had become so split with slate partings as to render it unprofitable for mining. This thickness of the main parting and the slate in the lower seam may increase or diminish to the south.

In the Louisville district there is neither the regularity in occurrence nor the freedom from partings in seams 3 and 4 and their resultant composite seam that there is in the Lafayette region. The individual seams, 3 and 4, are still generally identifiable by position, but vary in thickness from 1 foot to 3 feet and 3 feet to 6 feet, respectively, and this with rapidity and comparative frequency. The parting separating the two seams varies from 1 inch to its maximum width, 20 feet. A study of the sections of the Louisville district, Pl. XVII, clearly illustrates these features, for, from the nearest approach to the union of the seams—in the Acme, Caledonia, and Welch mines—and from a comparatively well-developed thickness, every gradation is observed to the opposite extremes, which occur in the vicinity of the Ajax and Marshall Consolidated shafts, where thickness of seams is reduced to a minimum and the mass of separating rock has increased to the maximum. It is a condition worthy of note in the mines of the Louisville and Lafayette districts that where the individual seams are no longer closely united in a mammoth seam they are inclined to become divided by partings, and that they are the more divided as separation of the primary seams increases.

The manner in which the component seams, 3 and 4, and their associated sandy and clayey beds sometimes vary is well illustrated in the Marshall Consolidated mine. (Figs. F, G, H, Pl. XX.) In passing from the shaft westward along the main entry, the lower seam is found to have widened from 2 feet 6 inches to 3 feet 6 inches in a distance of 1,200 feet; the upper seam, after a decrease from 3 feet to 1 foot, 400 feet west of the shaft, has again widened to 2 feet 6 inches at a point 1,200 feet west; while the intervening series of sandstone and slate, which is 20 feet thick at the shaft and without coal, has at a distance of 400 feet west decreased to a total width of about 3 feet 6 inches, with one or two impure coal streaks, and at 1,200 feet is only 1 inch thick.

Regarding the identity of the component seams in the Marshall Consolidated and Ajax mines, no question exists as to that of the lower; the correlation of the upper, however, is in places attended with some uncertainty on account of occasional partings that exist in the individual seams which can not be traced through from mine to mine, and so lead to a confusion between the beds. The Ajax presents the most serious difficulty in this respect.

An important consideration regarding the Nos. 3 and 4 seams in the Louisville-Lafayette field is the greater range in width of the lower, No. 3, and its tendency to maintain a superior thickness; the No. 4 seam rarely reaches a width greated than 4 feet, while the No. 3 frequently attains one of 6 feet, or even 7 feet 6 inches.

THE AVAILABLE COAL AREA OF THE COAL CREEK SYNCLINE.

It is impossible from surface and present mining data to estimate the productive area of the Coal Creek syncline, but the region is the most promising of the several coal areas of the Denver Basin, both in the thickness and in the continuity of its seams. A considerable tract at the northern end of the syncline in the vicinity of Erie, Canfield, and Mitchell has already proved of value; the region of Lafayette is now yielding from a large area, with evidence from drill holes of much greater extent; the vicinity of Louisville is rapidly developing still another valuable area of production. Southwest of Louisville about 2 miles, the syncline has again been prospected and, according to best accounts, proved to carry at least one seam of workable thickness. At several points in the outlying area northwest of the Harper and Sand Gulch faults there exists a seam which ranges from 3½ feet to 5 feet in thickness at depths varying from 48 to 154 feet. On the summit of the high ridge north of Coal Creek, near the old stage well on the Denver and Louisville wagon road, 6 feet 4 inches of coal is said to exist at a depth of 60 feet; and again, just west of the point where the former Denver, Utah and Pacific Railroad crossed Coal Creek, 3 feet 10 inches exists at a depth of 93 feet. These points of exploitation are well distributed and indicate for the syncline productive measures of broad extent and exceptional continuity. This, together with the number of seams which are of recognized workable thickness in one area or another renders the entire region one of great importance.

The mining areas within the Coal Creek syncline conform to the several subbasins described. There are five in all, the Superior, Louisville, Lafayette, Mitchell, and Canfield-Erie, though perhaps the area immediately about Erie may more properly belong to the Mitchell basin.

Following is a list of mines in the several districts, including both worked and abandoned. The names are those in existence at the time of the examination by the Survey, 1890. Changes have occurred with the advent of other owners, and so far as possible all later names are added in brackets.

Superior district.—Superior mine (abandoned).

Louisville district.—The Welch (abandoned), Marshall Consolidated, Marshall Slope, Caledonia, Acme, Ajax [Leader], Hecla Nos. 1 and 2.

Lafayette district.—The Cannon [Colorado Smokeless], Simpson Nos. 1 and 2, Spencer, Excelsior, Gladstone, Ottis.

Mitchell district.—The Mitchell, New Mitchell, Cleveland, McGregor, Stewart, Garfield Nos. 1 and 2, Longs Peak, Boulder Valley (abandoned), Northwestern.

Canfield-Erie district.—The Jackson [Chase], Star, Progress [Standard], Northrup (closed), New Boulder Valley, Superior (abandoned), Deitz (abandoned), Briggs (abandoned).

THE SUPERIOR DISTRICT.

This includes the portion of the field lying on the northwestern rim of the Coal Creek syncline, separated from the main body of coal to the east by the Harper and Sand Gulch faults.

The confines of the coal and the general geology were given in defining the syncline's rim. A single opening of importance, the Superior shaft, is located on the northern slopes of the Davidson mesa, a seam 3 feet 6 inches thick being reported as cut at a depth of 90 feet. The coal is said to be clear and hard. The mine has long been abandoned.

THE LOUISVILLE DISTRICT.

The structural limits of the Louisville district are the Louisville fault on the southeast and the rim of the syncline and the Harper fault on the northwest; southwest, also, it extends to the rim, while to the northeast it merges with the Lafayette area. That the entire district is underlain with coal of workable thickness is doubtful, but the distribution of the mines and prospects indicates that a large portion of it may become productive. The region varies widely, however, in the value of its lands for coal-mining purposes, for beneath a part certain of the beds are thick and consolidated, while beneath the remainder they are thin, separated, and considerably split by partings. These areas are not delineated, but from observation in the mines open at the time of examination it was inferred that the northwestern half of the syncline would prove the more important. Here the Nos. 3 and 4 seams locally approach within an inch of each other, and over a considerable area are sufficiently close to be mined together. Where separated the No. 3 was more commonly mined, although No. 4 might also be workable both at the same point and at others. The sections A and B, Pl. XIX, and F to L, inclusive, Pl. XX, afford a general view of the character and relations of the several beds.

The hollow of the Louisville syncline is apparently broad and gently rolling, with local faults of light throw, encountered in mining. In the northwestern half there is a gentle rise of the strata toward the rim, increasing from 1° or 2° to 10° or 15°. The rise to the southeast is much sharper, 15° to 20°, increasing locally to 25°, 30°, or even 40°. The heavier coal seams are quite free from dirt and the smaller layers of sand or clay, the only impurities of this nature being the partings of slate or bone from 1 to 6 inches or a foot thick, prevalent throughout the district. The coal is in the main bright, black, and square-jointed. Its texture is homogeneous, laminated, or fibrous, the last character being due to maintenance of the original wood structure in certain of the layers. It mines either in dicy blocks or with a conchoidal fracture in irregular lumps. The hardness varies, being perhaps the greater in the lower portions of the seams. With the exception of a single slope on the southeast outcrop of the coal, the seams are all worked from shafts.

THE LAFAYETTE DISTRICT.

This district includes the half of the Coal Creek syncline east of the Louisville fault. The precise limits are as yet undefined. To the northeast it is possibly continuous with the Mitchell area. On the northwest the line of demarcation is probably a little below the crest on the northwestern slope of the ridge separating Sand Gulch from Coal Creek, until the Louisville fault is reached, when this becomes its limit. To the southwest and south it probably continues beyond the rim of the syncline, although interruption may occur in this direction by the possible prolongation of the Baker fault from east of Coal Creek. On the east the Coal Creek fault cuts the field from the productive area of the Baker mine and the coal lying to the east-northeast.

The axis of the Lafayette trough lies a little south of the Simpson-Spencer shafts; the drainage being from the mines north and south to the Simpson-Spencer. The hollow of the trough is somewhat corrugated with minor flexures of gentle rise, but its general shape is broad and rather flat, the dip steepening only at the limits of the area now opened, on the northwest, very gradually. The mines show several faults with various inclinations for their planes, some of which are at a very acute angle with the planes of stratification. The throws rarely exceed 8 or 10 feet.

The coal of the Lafayette field is of the general character of the Erie coals. It is jointed and works in large blocks.

A woody structure of the coal is frequently encountered, as though carbonization had taken place in solid blocks, fiber for fiber. Silicified trunks of trees, knots, and branches are here and there found, but so far as observed they lie in no definite direction.

The mines are all opened by shafts. Sections of the two seams at several points in the district are shown in Figs. A to E, inclusive, Pl. XX.

MITCHELL DISTRICT.

The productive portion of the Mitchell area is defined on the west by the crest of the ridge separating Coal Creek and Sand Gulch, on the east by the sharp rise of the beds to the surface along the Coal Creek fault, and on the north by the Erie fault, against which the coal measures probably abut with little bending. To the south the field is apparently continuous with the Lafayette. The limits thus defined form the exterior periphery of the field. It is hardly possible that the coal seams should hold workable within the entire area, since their tendency to a rapid variation in thickness is well established. Their general relations are shown in the sections of shafts, and their structure in the plate of individual beds.

The coal of the area is bright, hard, and dicy. Both laminated and homogeneous varieties occur. "Mother of coal," pyrite, resin, and white sulphate of lime are present in variable but never high percentages.

The mines are all worked from shafts. Figs. E to J, Pl. XIX, show the general character of the seams.

THE CANFIELD-ERIE DISTRICT.

The western and northern limits of the Canfield-Erie district are the outcrop of the measures beneath the Quaternary of the Boulder Valley, contracted somewhat by the natural deterioration of the coal under decrease of cover, and perhaps also, at the northern end, by a thinning of the coal below workable thickness. The eastern limit of the field lies a few hundred feet west of the lower Coal Creek fault; the southern, a little north of the Erie fracture, the beds on this side of it being turned up against the plane. Near the western edge of the area, where this fault has apparently disappeared, the Canfield-Erie and Mitchell fields become continuous.

The disturbed condition of the strata in proximity to the faults has been noted in the preceding pages. In this portion of the district the measures lie in the gentlest possible curve consistent with a synclinal structure, approximating the horizontal over much of the area. Local flexures occur, and also faults of small throw. Of the latter the Jackson-Star is the most important thus far encountered. The throw is but 30 feet, however, not enough to have exposed any of the beds to the influence of erosion and so brought about their removal.

The stratigraphy of the Canfield-Erie region is somewhat less clearly defined than that of the Mitchell, chiefly because of the less satisfactory data afforded by the mines. The succession of strata in the Progress shaft (Pl. XVII) and in another prospect a short distance from this indicates that the seam worked in the former is the No. 2, or that above sandstone B. No reliable section of either the Star or Jackson shafts is attainable. From the depth of the Star, which is about that of the Progress shaft, it is probable that the same bed (No. 2) is worked in both. From the depth of the Jackson shaft, the difference in altitude between its collar and that of the Progress, and the dip of the beds in the latter mine, it is probable that the seam worked in the Jackson is likewise the No. 2. Whether the No. 2 or No. 1, could readily be decided by boring or by an examination of the strata in the shaft. In the old Boulder Valley mine, also, the seam worked was probably the No. 2.

The new Boulder Valley mine is located on the eastern edge of this field. At the time of examination, in the fall of 1890, it was too slightly developed to afford more than a section of the seam worked. (Pl. XX, Fig. N.) The measures were then reported to rise rapidly to the south and west, and the coal to deteriorate. The 5-foot layer was the only one worked. It lies at a depth of 70 feet below the collar of the shaft.

Regarding the Northrup and other abandoned mines no data are attainable.

The coal of the Canfield-Erie area resembles in every detail that of the Mitchell basin.

The sections of the seams worked in the Erie-Canfield district are shown in Figs. K, L, and M, Pl. XIX, and Fig. N, Pl, XX.

THE AREA EAST OF COAL CREEK.

General description.—The western slope of the high ridge between Coal and Dry creeks is underlain by strata that were at one time directly continuous with those of the Coal Creek syncline. The measures outcropping are the upper and lower Laramie and the highest layers of the Fox Hills. The area is one of gentle flexures, with a balance of dip to the east or southeast and a strike varying between north and northeast. Occasionally a curvature is sharp, but the displacement is always limited. The chief faults are the Coal Creek, which limits the area on the west, and the Baker, which passes just east of the Baker mine, with a trend N. 61° 35′ E. The cross-fault in the angle between the two is of little importance. Other faults may have been developed from some of the sharper folds, but they can not be detected at the surface.

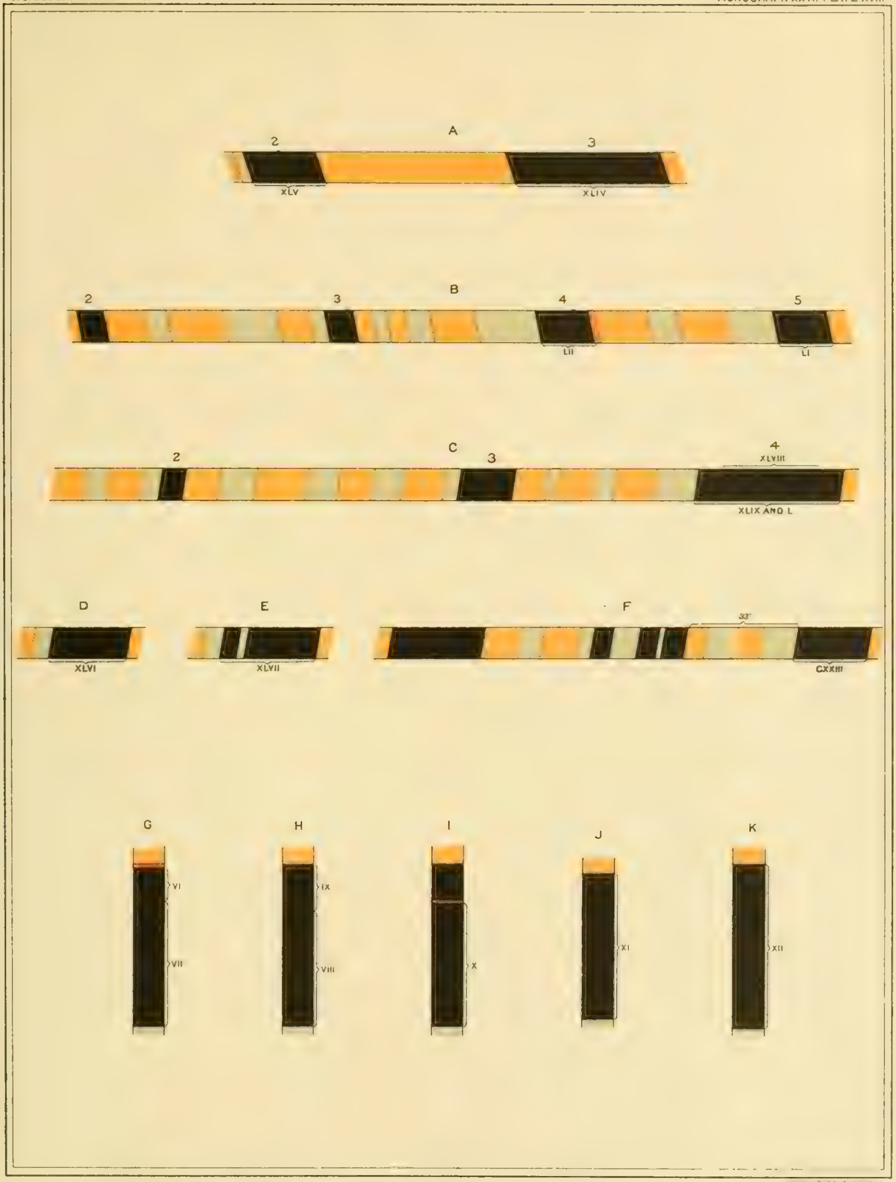
The coal measures extend northeast, east, and southeast an undetermined distance beyond the map limits. With the exception of an outcrop on the west side of the Baker fault, along its southwestern half they lie at a considerable depth beneath the surface. Along the Baker fault they rise in outcrop between 1½ and 2 miles northeast of the Baker mine, followed by the basal sandstones of the Laramie in a gulch but a mile north of the mine, these by the Fox Hills in one only half or three-fourths of a mile north. Between the last point and the mine the coal measures with the lower beds of the upper Laramie have escaped erosion and occupy the area westward to the Coal Creek fault. The maximum distance which the coal horizon has receded from the fault is about one-fourth mile. The strata on the northwest of the fracture dip 10° to 15° NNW.; on the southwest they have been but little disturbed. Along the short cross-fault west of the Baker mine the coal measures on its north dip 3° to 10° NNE.; they abut against upper Laramie on the south. The triangular interfault block, considerably fractured, is of no economic importance. Excepting at the Baker mine, the only outcrops of coal on the exposed line of coal measures are one mile northeast of the mine, immediately over sandstone B, where the thickness is apparently not over 2 feet, and several small seams in the bluffs of Coal Creek just west of the mine. East of the Baker fault the depth at which the coal measures lie is unknown.

The stratigraphy of the coal measures, as shown in outcrops in the vicinity of the Baker mine, is merely a variation of that in other regions—rapidly alternating sandstones, lignitic clays, and occasional narrow coal seams; low down in which, in this instance, is the heavy seam worked at the mine, the basal sandstones lying still beneath. A sandstone a short distance above the Baker seam is locally developed to a thickness of nearly 20 feet, and, according to Mr. Davis, the manager, in places lies directly on the coal. A thin bed of fire-clay usually underlies the coal.

The Baker mine.—(Fig. D, Pl. XIX.) This is located on the bench land east of Coal Creek, about three-fourths of a mile north-northeast of its confluence with Rock Creek. The mine is opened by a slope on the seam, the strike of which is about N. 37° E., the dip averaging 15° NW. The seam worked is probably either No. 2 or 3, possibly both, consolidated. The coal lies in two benches, the lower about 4 feet thick, the upper 7 feet, separated by 7 or 8 inches of slate, which is persistent throughout the mine. Of the lower bench the lower 36 inches is a fibrous coal, the 6 inches above a "curly" coal, while the remainder has a conchoidal fracture and is clear and bright. The upper bench carries rather more iron than the lower, and is a softer coal. The coal of both benches is of considerable solidity and works in large blocks.

DESCRIPTION OF PL. XVIII.

		Samples.
Fig. A.	Douglas (Lehigh) mine	XLIV, XLV
B.	Mount Carbon measures	LI, LII
C.	Old White Ash mine, 600, 650 feet	XLVIII, XLIX, L
D.	Golden Star mine (second level, N.), west vein	XLVI
E.	Golden Star mine (second level, S.), west vein	XLVII
F.	Golden Star mine, landing at 160-foot level, east vein	CXXII
G.	Fox mine	VI, VII
H.	Fox mine	IX, VIII
I.	Marshall No. 5	X
J.	Marshall No. 3, lowest level	XI
K.	Marshall No. 3, an upper level	XII



COAL SEAMS OF THE DENVER BASIN.

Figures A–F FOOTHILL COALS.
Figures G–K MARSHALL FIELD.

Other openings.—Other openings in this field, from which coal is said to have been shipped for local trade, are now abandoned. Of these, four are near the Baker mine, and two, the Eulner and Chessey, 2 or 3 miles northeast.

There are doubtless localities in this great area east of Coal Creek which carry in depth workable beds of coal, but they will remain unknown till the coal trade is far greater than at present and the more accessible areas already opened are well on toward exhaustion.

WHITE ROCK AREA.

The White Rock coal area lies just beyond the northern edge of the Denver field, on the northern side of Boulder Creek, about 6 miles west of Erie. At this point a prominent hill rises some 350 feet above the creek level, its southern and western slopes the steeper, its northern and eastern very gentle. The hill is composed almost entirely of the basal sandstones and coal measures of the Laramie, only the lowest beds of the upper Laramie underlying the heavy cap of Quaternary. Along the southern base of the hill the sandstones of the Fox Hills occur in local outcrops. The basal sandstones of the Laramie complete the bluffs, carrying the No. 1 seam, which is here but a succession of thin layers of coal, sand, and slate, in all 2 to 3 feet.

Above sandstones A and B are the coal measures, but they appear only in occasional outcrops. The coal occurs in a shaft (now long abandoned) near the summit of the hill; it is said to lie about 40 feet over sandstone B, and is therefore one of the higher seams of the series. It was regarded as of little value.

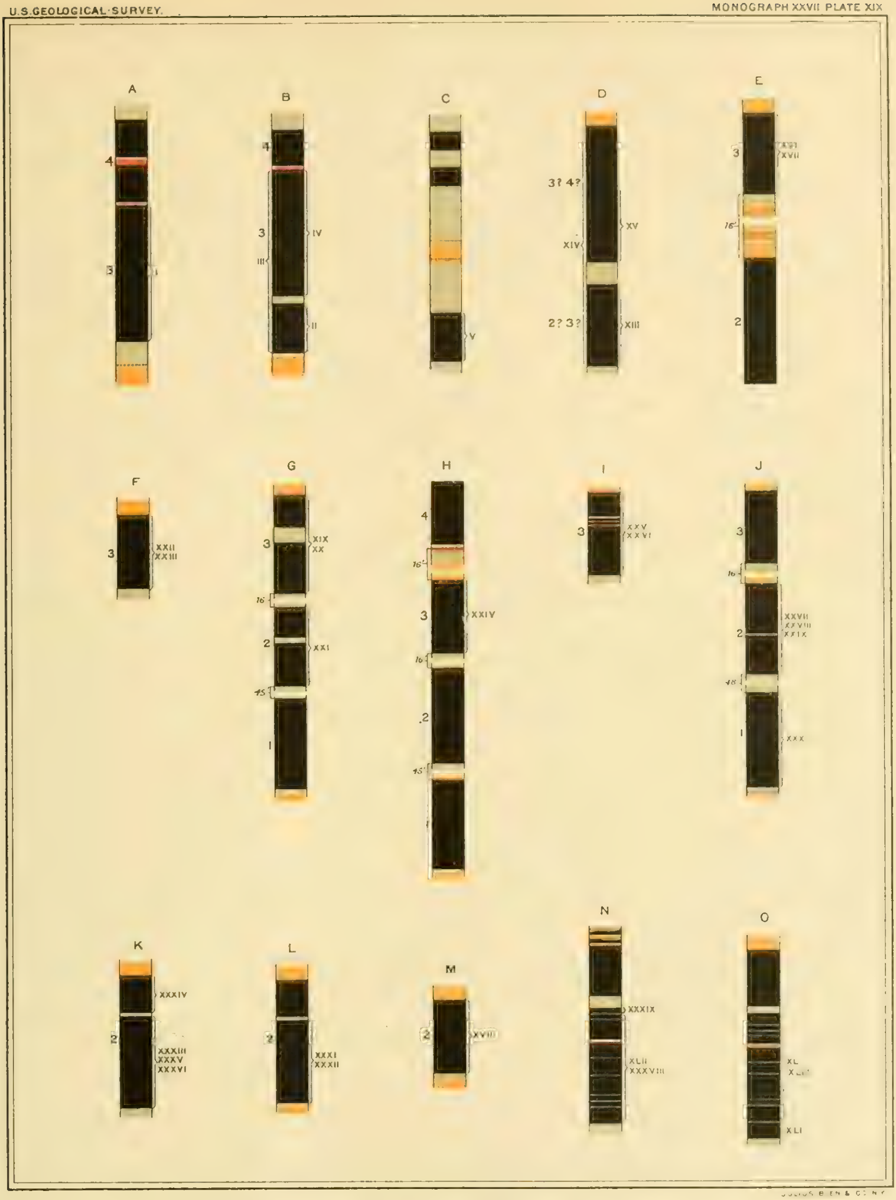
The strata of the area have a general N. to N. 20° E. strike, with an easterly or east-southeasterly dip of 5° to 10° over the more regular portions. The northern slope of the hill lies beyond the limits of the map and the details of its structure were not attempted.

OTHER MINE LOCALITIES OF THE LOWER LARAMIE COAL MEASURES IN THE VICINITY OF THE DENVER BASIN.

Several mines in the lower Laramie coal measures lying wholly north of the area defined for exploration have been periodically worked in the

DESCRIPTION OF PL. XIX.

	Samples.
FIG. A. Welch mine	I
B. Welch mine	II, III, IV
C. Dunn mine	V
D. Baker mine	XIII, XIV, XV
E. Cleveland mine	XVI, XVII
F. McGregor mine	XXII, XXIII
G. Stewart mine	XIX, XX, XXI
H. Garfield mine	XXIV
I. Garfield mine (specimen from Garfield mine for special analysis, XXXVII)	XXV, XXVI
J. Mitchell mine	XXVII, XXVIII, XXIX, XXX
K. Jackson mine	XXXIII, XXXIV, XXXV, XXXVI
L. Star mine	XXXI, XXXII
M. Progress mine	XVIII
N. Scranton mine	XXXVIII, XXXIX, XLII
O. Scranton mine	XL, XLI, XLIII



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COAL SEAMS OF THE DENVER BASIN.

Figures A – B LOUISVILLE FIELD. Figure D BAKER FIELD.
Figure C DAVIDSON FIELD. Figures E – M ERIE FIELD.
Figures N – O SCRANTON FIELD.

Scale
0 1' 2' 3' 4 5 6 7 8

COAL BONE SLATE SANDSTONE

past. Chief among these are the McKissic, about 10 miles northeast of Erie; the Platteville, near Platteville; the Excelsior, near Evans, and the Eaton and Brown, near Eaton, all stations on the Union Pacific Railroad, from 25 to 60 miles north of Denver. The measures are in direct continuation with those of the Denver field.

THE SCRANTON COAL FIELD.

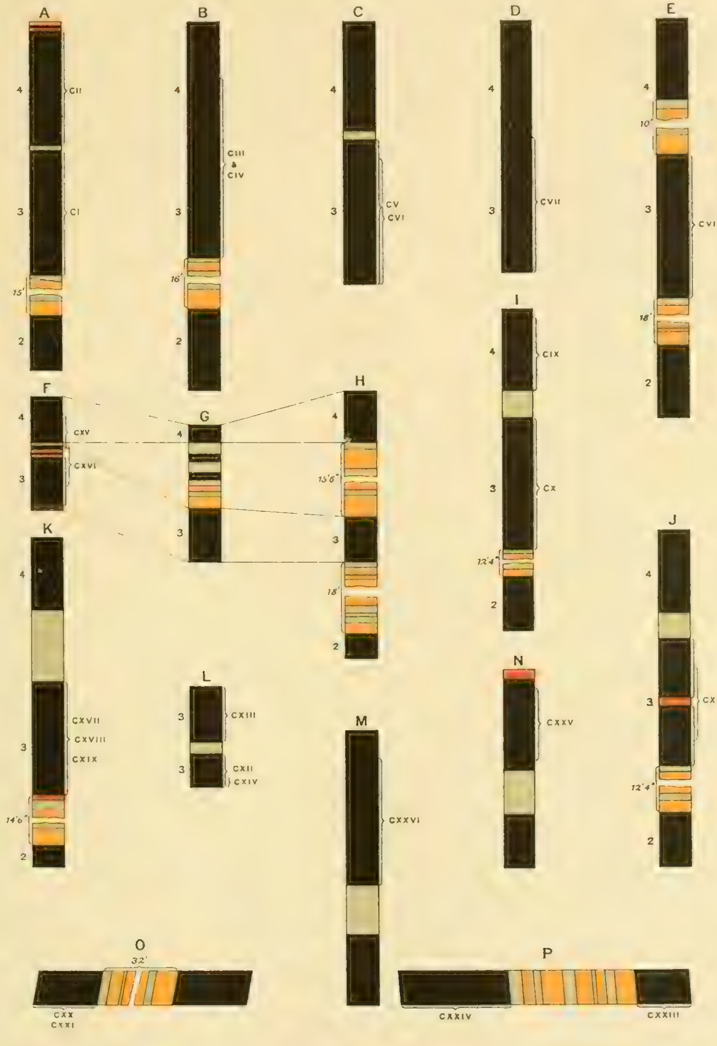
This field lies at the head of Second Creek, about 20 miles east of Denver, the meridian of 104° 40′ passing just east of the settlement. It is impossible from surface outcrops to define the limits of the field, but there is believed to be an area of at least 15 to 20 square miles over which a workable thickness of coal, except for local thinning, is likely to be found. A seam is opened at Scranton which has a thickness of over 10 feet, including partings; coal is also reported, 6 feet thick, at a depth of 90 feet, in a prospect shaft about 3 miles south-southwest of Scranton, just north of the Kansas Pacific Railroad; again, in two other shafts between the latter and the Scranton mines, of about the same thickness; in traces, also, about 3½ miles southwest of Scranton, three-fourths of a mile north of the railroad; and, finally, in the bluffs of Sand Creek, where a 6-foot bed may be seen in arenaceous clays and sandstones. In the last locality, 10 feet above the coal, is a heavy bed of Monument Creek sandstone, a marked line of unconformity showing between it and the underlying series. The Monument Creek formation is also found directly over the coal in the immediate vicinity of the Scranton mine. Eastward from these localities it extends far beyond the area mapped. The coal of this field is all of the upper, shaly division of the Laramie.

The structure of the Scranton coal field is apparently that of horizontal or slightly undulating strata for the area in general, with sharper folds and steeper dips in particular localities. Faults have not been detected, although it would be surprising if an area of this extent and character should be entirely devoid of them. The strike of the beds at the Scranton mine is N. 15° W., the dip 3° to 5° E.

The general character of the bed mined at Scranton and the strata with which it is associated are shown in the following section (fig. 16), reported

DESCRIPTION OF PL. XX.

		Samples.
FIG. A.	Cannon mine	CI, CII
B.	Simpson mine, No. 1	CIII
	Simpson mine, No. 2	CIV
C.	Excelsior mine	CV, CVI
D.	Excelsior mine	CVII
E.	Gladstone mine	CVIII
F.	Marshall Consolidated mine, 1,200′ W. of shaft	CXV, CXVI
G.	Marshall Consolidated mine, 400′ W. of shaft	
H.	Marshall Consolidated mine, at shaft	
I.	Acme mine	CIX, CX
J.	Acme mine	CXI
K.	Caledonia mine	CXVII, CXVIII, CXIX
L.	Ajax mine	CXII, CXIII, CXIV
M.	Allen-Bond mine	CXXVI
N.	New Boulder Valley mine	CXXV
O.	New White Ash mine	CXX, CXXI
P.	Rocky Mountain mine, No. 1	CXXIII
	Rocky Mountain mine, No. 2	CXXIV



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COAL SEAMS OF THE DENVER BASIN.

Figures A - E, LAFAYETTE FIELD Figures F - L, LOUISVILLE FIELD
Figure M ALLEN-BOND „ Figure N ERIE FIELD „
Figures O - P, FOOTHILL COALS

Scale
0' 1' 2' 3' 4' 5' 6' 7' 8'

COAL BONE SLATE SANDSTONE

from an old shaft of the mine, and in Figs. N and O of Pl. XIX, obtained in the mine at the time of examination.

The prevalence of clay partings in the coal is very noticeable, these and the bone about the middle of the bed being remarkably persistent. The bands of coal, clay, and sandstone, immediately above the seam, in fact forming a part of it, are irregular in occurrence, their lines of deposition rising or sinking, the individual strata thinning to a knife-edge or attaining almost the maximum thickness of the series.

The coal itself is a thoroughly representative type of the lignite of the plains; its streak is brown; it weathers rapidly and disintegrates completely; it contains 25 per cent water, yields a large amount of ash, and burns with evolution of comparatively little heat.

FIG. 16.—Section of coal measures of upper Laramie at Scranton.

THE COAL.

CHEMICAL ANALYSES OF INDIVIDUAL SAMPLES.

The analyses in Table I may be regarded as representative, both of the mines from which they were obtained and the areas in which the mines are. With the exception of Nos. 37, 127, 128, and 129, all are of commercial mine samples, but owing to the ease with which the slate or other partings are separated in mining, and the freedom of the coal itself from impurities, the analyses are available for scientific discussion of the coals as well as for their commercial comparison. The samples were taken directly across the seams from fresh surfaces cut for the purpose. Rooms long abandoned, and others newly opened, were sampled to show the degree of deterioration on long exposure underground or to illustrate possible variation in the physical and chemical conditions of the coal. Such portions of the bed as were excluded in shipping—partings, pyrite balls, silicified roots, and bone—were also excluded from the samples, but in all cases where feasible the coal ordinarily left for support to the roof was included. Whenever the coal appeared to show physical differences in its natural position in the mine, or where statements as to supposed or actual differences were made by the mine superintendent, separate samples were taken for purposes of study. To obtain a fair average the samples were equably distributed throughout the mine.

CHEMICAL ANALYSES OF THE COALS OF THE DENVER BASIN, ARRANGED ACCORDING TO MINING DISTRICTS.

TABLE I.—*Analyses of coals of the Denver Basin.*

District.	Number.	Mine.	Fixed carbon.	Volatile combustible.	Water.	Ash.	Sulphur.	Color of ash.	Specific gravity at degrees F.	Fuel ratio, $\frac{c}{v-c}$.
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Pr ct.*			
Erie-Canfield	125	New Boulder Valley.	42.34	37.81	14.90	4.95	0.49	Yellow-gray	1.35 @ 19.4	1.12
	18	Progress	44.73	33.57	16.64	4.51	.55	Light yellow	1.341 @ 13.0	1.33
	31	Star	43.86	32.10	18.54	4.99	.51	Yellow-white	1.336 @ 12.0	1.37
	32	do	44.51	32.51	17.03	5.35	.60	Reddish-white	1.335 @ 10.0	1.37
	33	Jackson	45.15	33.37	16.04	4.86	.58	White	1.350 @ 10.5	1.35
	34	do	44.69	32.34	17.61	4.70	.76	White, slight red tint.	1.336 @ 14.0	1.38
	35	do	45.55	33.01	16.42	4.25	.77	Yellow-white	1.333 @ 15.0	1.38
	36	do	44.62	31.35	17.75	5.53	.75	do	1.338 @ 17.5	1.42
Mitchell	37	Garfield	47.86	30.82	17.25	3.55	.52	Red	1.345 @ 12.0	1.55
	24	do	44.63	34.51	16.80	3.52	.54	Light yellow	1.331 @ 12.0	1.29
	25	do	43.89	34.14	17.03	4.53	.41	Yellow	1.336 @ 11.0	1.29
	26	do	44.68	34.59	17.66	3.25	.42	Red-yellow	1.336 @ 15.0	1.29
	19	Stewart	44.97	33.43	17.25	3.79	.56	Light yellow	1.328 @ 12.0	1.35
	20	do	45.62	34.54	15.44	3.76	.64	White	1.339 @ 12.0	1.32
	21	do	44.43	32.63	18.32	3.97	.65	Slightly reddish	1.331 @ 19.0	1.36
	22	McGregor	44.74	34.98	16.38	3.38	.52	Reddish	1.330 @ 19.0	1.28
	23	do	44.55	33.85	17.58	3.48	.54	do	1.334 @ 18.5	1.32
	16	Cleveland	43.77	33.84	18.07	3.84	.48	Reddish-white	1.331 @ 12.5	1.26
	17	do	45.30	33.81	16.76	3.60	.53	Light red	1.334 @ 14.0	1.34
	27	Mitchell	44.86	33.42	17.01	4.22	.49	Reddish	1.350 @ 12.0	1.34
	28	do	44.16	34.03	16.96	4.39	.46	Light red	1.335 @ 13.0	1.30
	29	do	45.26	33.80	17.01	3.52	.41	Red	1.339 @ 16.0	1.34
	30	do	43.06	32.53	16.84	6.47	1.10	Yellowish-gray	1.352 @ 13.0	1.32
Area east of Coal Creek.	13	Baker	44.08	33.28	18.38	3.72	.54	Reddish	1.324 @ 5.5	1.32
	14	do	45.05	34.67	16.38	3.46	.44	do	1.341 @ 8.0	1.30
	15	do	43.90	34.41	17.75	3.45	.49	Yellowish-white	1.329 @ 13.0	1.28
Lafayette	108	Gladstone	44.93	36.70	13.72	4.65	.36	Yellowish-gray		1.22
	105	Excelsior	45.10	37.82	13.42	3.66	.34	do	1.36 @ 21.2	1.19
	106	do	45.16	37.81	13.04	3.99	.46	do		1.19
	107	do	44.56	38.13	13.47	3.84	.53	do		1.17
	103	Simpson-Spencer	43.85	37.09	14.74	4.32	.61	Light gray	1.35 @ 19.4	1.18
	104	do	44.34	37.87	13.57	4.12	.38	do		1.17
	127	do	46.15	34.65	16.27	2.93	.29	Brown-gray	1.35 @ 17.5	1.33

TABLE I.—*Analyses of coals of the Denver Basin*—Continued.

District.	Number.	Mine.	Fixed carbon.	Volatile combustible.	Water.	Ash.	Sulphur.	Color of ash.	Specific gravity at degrees F.	Fuel ratio, $\frac{c}{v-c}$.
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Pr ct.*			
Lafayette	128	Simpson-Spencer	26.87	28.18	11.43	33.52	.55	Pink	1.61 @ 16.6	.95
	101	Cannon	44.14	37.78	13.26	4.82	.46	Light gray	1.36 @ 22.4	1.17
	102	....do	44.70	39.61	11.85	3.84	.46	....do	1.36 @ 20.2	1.13
Louisville	115	Marshall Consolidated.	43.72	37.05	14.53	4.70	.33	Yellowish-gray	....	1.18
	116	do	42.81	36.93	15.12	5.14	.71	Pale yellow	....	1.16
	117	Caledonia	45.19	37.29	12.87	4.65	.28	Dark gray	1.38 @ 18.9	1.21
	118	....do	43.62	38.09	13.93	4.36	.38	Gray	1.37 @ 19.3	1.15
	119	....do	43.65	37.59	14.28	4.48	.47	....do	....	1.16
	1	Welch	44.50	33.94	16.39	4.75	.42	....do	1.340 @ 23.5	1.31
	2	....do	44.00	33.99	17.04	4.35	.62	Light yellowish-gray.	1.329 @ 24.0	1.29
	3	....do	43.36	33.32	17.34	5.58	.40	Light gray	1.343 @ 23.0	1.30
	4	....do	44.47	33.44	16.73	5.11	.35	Yellowish	1.354 @ 23.0	1.33
	109	Acme	42.67	38.79	14.38	4.16	.29	Yellowish gray	1.355 @ 21.7	1.10
	110	....do	43.52	38.27	12.95	5.26	.37	Light gray	1.37 @ 16.8	1.14
	111	....do	42.95	37.88	14.07	5.10	.32	Reddish-yellow	....	1.13
	129	....do	46.46	35.30	15.63	2.61	.30	Red	1.34 @ 20.2	1.32
	112	Ajax	44.91	36.39	14.11	4.59	.34	Reddish-yellow	....	1.23
	113	....do	45.56	36.08	14.10	4.26	.34	....do	1.37 @ 19.6	1.26
	114	....do	40.85	38.08	15.81	5.26	.35	Yellow	1.35 @ 19.9	1.07
Davidson	5	Dunn	45.11	33.87	16.49	3.95	.58	Reddish-yellow	1.334 @ 24.0	1.33
Allen-Bond	126	Allen-Bond	45.13	37.57	12.45	4.85	.33	Reddish gray	1.38 @ 17.8	1.20
Marshall	6	Fox	46.62	32.60	16.24	3.68	.86	White	1.343 @ 22.0	1.43
	7	....do	47.91	33.85	14.37	3.20	.67	Very light yellow	1.344 @ 18.0	1.42
	8	....do	45.08	36.18	15.06	2.94	.74	Light yellow	1.315 @ 20.0	1.25
	9	....do	47.36	28.66	18.67	4.90	.41	Reddish-yellow	1.371 @ 24.0	1.65
	10	Marshall No. 5	43.08	35.44	16.12	4.67	.69	....do	1.341 @ 25.0	1.22
	11	Marshall No. 3	45.08	34.79	13.81	4.71	1.61	Gray	1.348 @ 25.0	1.30
	12	....do	45.03	36.10	14.79	3.07	1.01	....do	1.339 @ 16.0	1.25
Foothill	124	Rocky Mountain, No. 2.	41.26	37.87	14.40	6.47	.45	Dark gray	1.41 @ 21.4	1.09
	123	Rocky Mountain, No. 1.	38.89	36.65	14.13	10.33	.48	Reddish-gray	1.44 @ 21.6	1.06
	122	Golden Star	38.52	39.08	14.09	8.51	.98	Yellow-gray	1.41 @ 20.2	.98
	46	....do	39.97	34.44	19.46	5.71	.42	Slightly reddish	1.365 @ 11.0	1.16
	47	....do	37.13	34.70	20.95	6.36	.56	Greenish-gray	1.353 @ 4.0	1.07
	120	New White Ash	41.32	38.45	14.94	5.29	.28	Dark yellow-gray	1.40 @ 19.4	1.07
	121	....do	40.60	36.91	14.60	7.89	.31	Dark gray	....	1.10
	48	Old White Ash	42.62	35.48	18.36	3.14	.40	Gray	1.349 @ 10.0	1.20
	49	....do	42.74	34.11	19.02	3.68	.45	Greenish-gray	1.359 @ 16.0	1.25
	50	....do	43.42	33.60	19.17	3.92	.49	....do	1.362 @ 17.0	1.32
	51	Mount Carbon	36.09	33.36	24.27	5.81	.47	Reddish yellow	1.329 @ 18.5	1.08
	52	....do	35.85	34.84	22.93	5.87	.51	....do	1.329 @ 12.0	1.03
	44	Lehigh	35.54	35.53	22.94	4.92	1.07	Light gray	1.344 @ 13.0	1.00
	45	....do	34.74	32.95	22.15	8.48	1.68	White	1.388 @ 11.0	1.05
Scranton	38	Scranton	28.42	31.54	26.08	13.55	.41	Reddish-gray	1.365 @ 14.0	.90
	39	....do	32.29	33.25	26.37	7.57	.52	Gray	1.317 @ 13.5	.97
	40	....do	29.52	30.12	26.92	13.22	.42	Greenish-gray	1.321 @ 16.0	.97
	41	....do	30.37	32.56	27.81	8.79	.47	....do	1.345 @ 14.0	.93
	42	....do	31.10	31.32	28.25	8.90	.43	....do	1.330 @ 13.5	.99
	43	....do	30.84	31.72	23.90	13.01	.53	....do	1.369 @ 11.0	.97

The analyses given in the following table were derived from Table I:

TABLE II.—*Analyses of coals of the Denver Basin, arranged according to mining districts.*[1]

1	2	3	4	5	6	7	8	9	10	11
	Mines.		F. C.	V. C.	Water.	Ash.	S.	Sp. gr.	Aver-age of.	Fuel ratio, $\frac{c}{v\text{-}c.}$
I	New Boulder Valley	New	42.34	37.81	14.90	4.95	0.49	1.35	1	1.12
II	Erie-Canfield	Old	44.59	33.53	17.13	4.19	0.57	1.336	24	1.33
III	Lafayette-Louisville	New	44.07	37.64	13.78	4.50	0.41	1.364	20	1.17
IV	.....do	Old	44.27	33.71	16.80	4.75	0.47	1.338	5	1.31
V	Marshall	Old	45.74	33.95	15.58	3.88	0.86	1.341	7	1.35
VI	Golden	New	40.08	37.79	14.43	7.70	0.50	1.415	5	1.06
VII	.....do	Old	41.2[illegible]	34.35	19.39	4.56	0.46	1.358	5	1.20
VIII	Other Foothill	Old	35.55	34.17	23.07	6.27	0.93	1.347	4	1.04
IX	Scranton	Old	30.39	31.75	26.55	10.84	0.46	1.341	6	0.96

[1] The following data regarding the time of sampling and of making the analyses, the places in which the analyses were conducted, and the lapse of time between the two operations of sampling and analyzing, are here added with a view to affording a complete record of the coals represented above, and so presenting an appropriate basis for their discussion:

I. New Boulder Valley mine, 1½ miles east of Erie. Sampled in October, 1890. Analyzed in Washington, D. C., in March, 1891.

II. Erie-Canfield, Mitchell, Baker groups, sampled in September, 1886; analyzed in Denver in January, 1887.

III. Lafayette, Louisville, Davidson groups, sampled in September-October, 1890; analyzed in Washington in March, 1891. Samples crushed, quartered, and bottled some time between November 1 and December 31, 1890. Lafayette field not opened in 1886.

IV. Louisville, Davidson groups, sampled in August, 1886; analyzed in Denver in September-October (?), 1886.

V. Marshall field, sampled in August, 1886; analyzed in Denver in September-October (?), 1886.

VI. Golden group, sampled in October, 1890; analyzed in Washington in March, 1891. Samples crushed, quartered, and bottled some time between November 1 and December 31, 1890.

VII. Golden group, sampled in February, 1887; analyzed in Denver in February, 1887.

VIII. Carbon, Lehigh mines, sampled in February, 1887; analyzed in Denver in February, 1887.

IX. Scranton mines, sampled in January, 1887; analyzed in Denver in February, 1887.

PECULIARITIES PRESENTED IN THE FOREGOING TABLE.

Table II presents some striking peculiarities wholly unforeseen prior to its compilation. Among these are, first, the relations between volatile-combustible matter, water, and specific gravity in the more lately sampled coals, which were analyzed in Washington, and in those sampled in 1886–87, analyzed in Denver; and, second, the relations between the volatile-combustible matter and the fixed carbon of the foothill coals as compared with the more normal contents in the prairie coals.

In regard to the first of these peculiarities, upon reference to column 6 (water determinations) the percentage of moisture in the samples from the New Boulder Valley mine, the Lafayette-Louisville region, lately developed, and the newly opened mines of the Golden district, all of which were taken more recently and analyzed in Washington, is found to be considerably below that of other coals of adjoining or nearly related areas which were earlier sampled and analyzed in Denver, the difference amounting to between 3 and 5 per cent. At the same time the volatile-combustible matters are found to vary in the opposite direction, increasing in their per cents approximately as much as the water contents decrease. The specific gravities also vary inversely as the water contents and directly as the volatile-combustible matters.

At present it is impossible to suggest any satisfactory explanation of the above peculiarities. Such results were not anticipated, and, moreover, are not only opposed to what would be expected from physical laws, but are apparently opposed to one another. For instance, the natural inference based upon the hygroscopicity of coals would have been that the analyses in the very moist atmosphere of Washington as compared with the very dry one of Denver would have given the higher per cent of water at the former place. Instead of this, the coals analyzed at Denver parted with a much larger amount of moisture, notwithstanding many of the samples were exposed to the dry climate of the region for two or three months before analysis—a length of time ample to bring them to a stationary condition in the quantity of their water contents.

It would seem hardly possible that the volatile-combustible matters could be influenced either one way or the other by altitude above sea-level or the condition of the atmosphere. There is, however, a variation inversely as the water. So persistent is this in the coals from the various localities that it is highly probable that the figures of this column are directly dependent upon those of the water column, a possible inference being that in the Denver analyses some of the volatile matters may have escaped in the moisture determination, although the analyses were made in the same manner, by the same chemist, with the same care, and at the same temperature. It is a significant fact that the sum of the volatile-combustible and moisture contents is approximately the same for both suites of analyses—Washington and Denver.

Again, the specific gravities of the coals determined in Washington are considerably higher than those determined in the West. Under precisely similar conditions of manipulation, the higher results should have been obtained in the West, on account of the difference in barometric pressures. The specific gravities can not be considered in reference to the moisture contents of the coals, for the former determinations are invariably made upon saturated particles, which would, therefore, evidently present like conditions for determination in both localities.

An explanation of the inter-relations of the volatile-combustible and water contents of the coal may possibly be found in a striking peculiarity displayed by certain coals, of quickly taking up a large per cent of water under a moist condition of the atmosphere and of as readily parting with it under a drier condition.[1] The discovery of this peculiarity was made in 1884 in the course of investigations conducted at Newport, R. I., upon an anthracite from that State and upon a lignite from the Mouse River region in Dakota. In the case of the anthracite, upon which the investigations were more extended, the variation in the contents of water amounted to from 10 to 15 per cent, according to the hygrometric conditions of the atmosphere, one series of analyses being made during prevailing north and west winds, conducive to dry atmosphere, the other during southwest winds, which in Newport are frequently accompanied by fog. A piece of Pennsylvania anthracite, and also bituminous coals from the Cumberland field and from Montana, however, exhibited no such features.

Although a similar explanation of the difference in the water contents of the coals of the Denver field is possible, it is not altogether satisfactory, since it involves the reverse of the usual conditions of moisture and dryness in the East and West. In this instance there appears a considerable increase in the per cent of water in the coals analyzed in the dry atmosphere of the West over that of the determinations made in Washington.

The lapse of time between the sampling and analysis of the above coals probably had little or nothing to do with the hygroscopic peculiarities exhibited, for both in the East and the West this interval, in some cases, extended over a period of several months, more than ample for the full exertion of the phenomenon, since, in the special cases referred to above, both absorption and elimination of moisture were rapid, and practically reached their limits within twenty-four to eighty-five hours after exposure.

[1] Notes on Rhode Island and Massachusetts coals, Arthur B. Emmons: Trans. Am. Inst. Min. Eng., Vol. XIII, Sept., 1884, p. 510. Also Water in coals: idem, Vol. V, June, 1876, pp. 97–99.

The fact that the analyses are not all of coals from the same seam and locality has not induced the peculiarities in the water contents of the coal, since in both the earlier and the later analyses, inter se, there is no more variation than is everywhere recognized as likely to occur in samples of the same bed taken from sections even within a few feet of each other.

Other circumstances, such as the length of time a mine has been opened or the depth of the bed beneath the surface, have likewise been without influence, since under both conditions like results have frequently been obtained.

There is, then, apparently but the one cause—the hygrometric condition of the atmosphere—to which the pronounced variation in the water contents of the above coals can at present be ascribed. In the drier atmosphere of Denver, under less barometric pressure, they parted with a greater amount of moisture than it is possible to expel under the usual conditions of analysis in the more moist atmosphere and with the higher barometer of the East. But, it is observed, the effect of such varying hygroscopicity of coals is not confined to their moisture contents but extends to the estimation of the volatile-combustible matter, and through this to that of the economic value of the coal. Since it is a property of irregular occurrence and one remaining undetected under precautions hitherto supposed to be ample to obtain accurate results, it should be looked for in all coals and made the subject of special tests, the analyses themselves being conducted according to some standard method.

The second peculiarity presented in Table II, the relations in the foothill coals between the volatile-combustible contents and the fixed carbon, will appear more clearly in the consideration of these constituents in the general discussion that follows.

GENERAL DISCUSSION OF TABLE II.

Notwithstanding the peculiarities named in the foregoing pages, from the fact that the prairie coals are of the same general horizon (though in some instances of different seams), were laid down under like conditions, and have been subjected to practically the same geological and dynamic conditions, it is probable that throughout they are of approximately the same relative constitution, and a fair comparison may be instituted between them from either the earlier or the later set of analyses. The same method of comparison will for like reasons also hold for the foothill coals, inter se.

Fixed carbon.—Employing either the old or the new suite of analyses, the prairie coals of the lower Laramie closely approximate one another in the percentage of fixed carbon, those of the New Boulder Valley mine alone materially falling below the others. The foothill coals—excluding that from below the 600-foot level in the Old White Ash mine at Golden, which in its percentage of fixed carbon distinctly approaches the coal of the prairie regions—show among themselves a somewhat greater range in this constituent than is recognized in the prairie coals, and, in direct comparison with the latter coals, present a remarkable decrease in the fixed carbon. Such alteration as this last is readily explained by the very considerable depths at which weathering of vertical coal beds may proceed and by the easy infiltration, either mechanically or in solution, of foreign material into the interstices and joints of the seams; and a further factor in the decrease may be the actual breaking up of some of the more stable carbon compounds to supply the place of the more volatile hydrocarbons that are possibly given off in weathering.

A steady increase, however, in the fixed carbon of the coal of the vertical beds takes place as depth is gained. It is clearly perceptible in the mines about Golden, where careful sampling afforded the following sequence of percentages:

Fixed carbon.	Depth.
Per cent.	*Feet.*
38.32	130
38.70	160
40.07	175
40.96	245
42.68	600
43.42	650

Volatile-combustible matter.—The average percentages of the volatile hydrocarbons in the prairie and foothill coals of the lower Laramie, as shown in the older suite of analyses, are, respectively, 33.64 and 34.27; in the Scranton or upper Laramie coal, 31.75.

The percentage of volatile-combustible matter in the earlier samples of coal from the foothill mines varies but little from the other early percentages of the same column; it should, on the contrary, in view of the fixed carbon contents of these coals and a maintenance of the characteristics of the prairie seams, have been much lower. The dynamic influences to which the foothill coals have been subjected, resulting in flexure and incipient fracturing, would naturally be regarded as particularly favorable to the escape of volatile matter, and a considerable relative decrease in the percentage of volatile hydrocarbons from that in the normal prairie coals would have been expected. This would have accorded with experience in other and similarly placed fields in various parts of the world. Instead, however, of a decrease, a slight increase in volatile constituents is seen. In explanation of this peculiarity it is suggested that after the lighter hydrocarbons of the normal coal had been driven off by the increased pressure and heat that accompanied the folding of the strata, facilitated by such crushing as the beds underwent, their place was supplied by the partial breaking up of the heavier hydrocarbons left behind, the amount of carbon thus becoming diminished, while the volatile matter by increment remained the same.

In the Marshall group of mines the volatile-combustible matter shows a variation from 32.60 per cent to 36.10 per cent, with an average of 33.95 per cent. The workable area, however, is in close proximity to the general fold along the base of the range, is considerably faulted, and altogether presents greater opportunities for variation in the volatile constituents of its coal, by escape or otherwise, than the other regions of the Denver field.

Among the analyses of samples from the Marshall field, Nos. 8 and 9 afford an excellent illustration of the variation in the volatile-combustible contents of coal from two different layers of what is, in the locality sampled, a single seam, without parting. Of the two layers, one (No 9) is regarded as an excellent steam coal, the other (No. 8) as more adapted to domestic uses. The former, which constitutes the upper 2 feet 6 inches of a 9-foot seam, shows a fixed carbon content of 47.36 per cent with a volatile-combustible content of 28.66; it is more fibrous and oily looking, and harder than the bottom coal; in mining, it scales off in irregular fragments. The bottom coal, on the other hand, has a fixed carbon content of 45.08, and its volatile-combustible matter amounts to 36.18; it mines in blocks, and has a conchoidal fracture.

The Scranton coal is remarkably low in its percentage of volatile-combustible matter, the average lignite carrying about 40 per cent.

The remaining coals of the Denver field vary but slightly in their volatile hydrocarbons from the average for the areas in which they are found.

The water content of the coals.—The coals are readily comparable in regard to this constituent upon reference to the older suite of analyses. In the prairie coals of the lower Laramie the water amounts to 16.78 per cent, in the foothill coals of the lower Laramie to 21.025 per cent, and in the Scranton coal to 26.55 per cent. Of the coals of the lower Laramie those of the prairie may be regarded as containing the normal water content, since they are in the condition least disturbed and the nearest to that of original deposition. The foothill coals, on the other hand, are in a vertical position, and in the flexing to which they have been subjected have been considerably fractured; they have thus been brought into that position which most readily permits the passage of water along bedding planes and fractures opened up by folding, and are afforded opportunities for the absorption of moisture not presented by coal in a less disturbed region. The coal from the lower levels of the Old White Ash mine at Golden shows, however, a distinct tendency, both in water content and in other constituents, to revert to the normal prairie composition, these levels being within a comparatively short distance of the curve to the gentle dip which prevails beneath the prairies. The coal of the higher levels in all the foothill mines, in fact, distinctly shows an increase in water over that in coal from lower levels. This is not pit-water, but hygroscopic, which the coal is enabled to absorb in greater degree as it is brought under the more favoring conditions.

The water content of the Scranton mines, the coal of which is upper Laramie, is that of a typical lignite.

Ash.—The ash of the Denver coals presents no peculiarities, unless in those of the new Golden mines, where it has risen to 7.70 per cent, the seams being vertical or steep pitching, comparatively narrow, and divided by fine partings. The amount will very probably decrease in depth. The ash of the Scranton coal is about that of many prairie lignites.

The fuel ratio $\frac{c}{v-c}$.—This is, at the present time, the accepted basis of classification of coals in the United States. The average of the early fuel ratios of the Erie-Canfield region, the Lafayette-Louisville older mines, and the Marshall district is 1.33; that for the shallow mines of the foothill region, including two at Golden, is 1.07; excluding the Golden region, 1.04; this, however, would be raised to 1.13 if the analyses of the coals from the lower levels of the Old White Ash mine were included, the fuel ratio of these being 1.25—well up toward the ratios of the prairie coals, and again showing the transition in depth of the vertical coals to the composition normal for the undisturbed coals of the prairies. The fuel ratio of the Scranton coal is that of a typical lignite, 0.96.

CLASSIFICATION OF THE COALS.

The coals of the Denver Basin may be classified as shown in the following table:

TABLE III.—*Classification of the coals of the Denver Basin.*

Class.	Description.	Proximate analyses.						Percentage of constituents of fuel.		
		Fixed carbon.	Volatile matter.	Water.	Ash.	Sulphur.	Specific gravity.	Fixed carbon.	Volatile matter.	Fuel ratio, $\frac{c}{v-c}$.
	Lower horizon:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per ct.*				
I	Horizontal beds .	44.87	33.73	16.50	4.27	0.63	1.338	57.08	42.92	1.33
II	Vertical beds....	36.60	34.30	22.12	6.19	.79	1.351	51.62	48.38	1.07
III	Upper horizon.......	30.39	31.75	26.55	10.84	.46	1.341	48.90	51.10	.96

Based upon the ratio $\frac{c}{v-c}$, the coals of the Denver field fall into three distinct classes, each of which is confined to a certain portion of the field as at present developed, and, moreover, has for that portion a remarkable uniformity of chemical composition. Were it possible to make the corrections which are unquestionably required for the more recent analyses, the coals affording these would in all probability likewise fall into one or another of the three classes established upon the earlier analyses.

Class I $\left(\frac{c}{v-c}=1.33\right)$.—This embraces the prairie coals of the lower Laramie. They resemble in their physical appearance many bituminous coals of the East, and in their fuel ratio certain coals in the lower portion of the Pennsylvania bituminous series. Their proportionately great amount of water, however, and the fact that the total percentage of fuel constituents is much less than that universally present in the Eastern coals, prevent a close relationship between the two series. The coal of Class I withstands weathering well and is the highest of the coals about Denver in economic value.

Class II $\left(\frac{c}{v-c}=1.07\right)$.—This embraces the coals of the foothills to a depth of 300 feet. At greater depths they approach Class I.

Class III $\left(\frac{c}{v-c}=0.96\right)$.—This is characterized by the excess of volatile matter over the fixed carbon, by the extremely large proportion of water contained, and by the high percentage of ash. The coal of this class weathers most readily upon exposure to the atmosphere, its color becoming brown, its appearance earthy. It is a lignite, regarding this term as signifying a position above the peat and below a variety of coal commonly accepted as near the base of the bituminous series in the East. It is a class in which the fuel ratio oftener falls below than exceeds 1.

SPECIAL SAMPLES OF COAL.

The analyses of these coals are given in Table I. No. 37, from the Garfield mine, represents a hard, smooth, pitchy coal, somewhat resembling the higher bituminous and coking coals of the mountain regions. The analysis shows it to be somewhat higher in fixed carbon and lower in volatile-combustible matter than the general samples of the Erie-Canfield field. Its fuel ratio, 1.55, places it considerably above the associated coals. This variety is distributed without regularity through both the vertical and the horizontal extent of the seams, but does not enter prominently into their composition.

No. 127, from the Simpson mine, is a typical specimen of conchoidal coal. It is of frequent occurrence in the prairie coals of the bituminous variety, forming prominent layers from 2 to 8 inches in thickness. It resembles in its fixed carbon and volatile-combustible contents the run of the coal in the Denver field, and in its fuel ratio, 1.33, falls into the higher class.

No. 128, from the Simpson mine, is a typical specimen of "bone coal." Its fuel ratio is 0.95, approaching the lignites in this respect. Its ash amounts to 33.52 per cent. Its water content is 11.43 per cent.

No. 129, from the Acme mine, is a specimen of fibrous, woody, lustrous coal. It is low in ash, of medium range among the prairie coals in its water content, and has a fuel ratio of 1.31, showing it to be somewhat below the variety of which 127 is a sample.

SECTION II.—THE CLAYS OF THE DENVER BASIN.

The economic clays of the Denver Basin are derived from the Pleistocene, Denver, Laramie, Fox Hills, and Dakota formations, the Denver and Laramie, however, affording but a small proportion of the total yield. The clays of the Dakota are refractory and are employed in the manufacture of fire-brick, crucibles, and allied products; those of the other formations are of the ordinary type, and are manufactured into brick and tile for general architectural purposes.

FIRE-CLAY.

The fire-clay of the Dakota occurs in noncontinuous bands, 5 to 15 feet thick and several hundred in length, in the argillaceous shales which separate the two or three heavy layers of sandstone that constitute the bulk of the formation. Numerous openings have been made upon them in the vicinity of Clear, Bear, and Deer creeks, and at other, less accessible points along the foothills, within and beyond the confines of the Denver Basin. With the exception of those near Golden the openings are prospects.

The mines near Golden are in the hogback about 2 miles north of the town. Several bodies of fire-clay here occur immediately beneath the upper heavy sandstone, access being by tunnel through this.

On the next two pages analyses of several of the typical clays of this country and Europe are tabulated, together with the uses in which the clays are employed.

*Analyses of fire-clays from the Denver Basin and from other American and foreign localities for comparison.**

	Locality.	Silica (combined) (SiO_2).	Alumina (Al_2O_3).	Water (combined) (H_2O).	Per cent of the Kaolinite base.	Titanic acid (TiO_2).	Silica (quartz sand) (SiO_2).	Total sandy material.
1	Denver Fire Clay Co., Denver, Colo	39.134	33.64	11.75	84.524	0.80	11.216	12.016
2	William B. Dixon, Woodbridge, N. J	31.12	26.95	9.63	67.70	1.90	28.81	30.71
3	William H. Berry, Woodbridge, N. J	40.50	35.90	12.80	89.20	1.30	6.40	7.70
4	Loughridge & Powers, Woodbridge, N. J	42.23	39.53	13.59	95.35	1.40	.50	1.90
5	Crossman Clay and Manufacturing Co., Raritan River, N. J	37.85	35.75	12.30	85.90	1.60	10.50	12.10
6	E. F. Roberts, pits near Eagleswood, N. J	40.40	38.40	12.50	91.30	With Al_2O_3	5.20	5.20
7	J. D. Hylton's fire-clay, Pensauken Creek, N. J	17.50	18.11	5.50	41.11	With Al_2O_3	56.80	56.80
8	Mineral Point fire-clay, near Johnstown, Pa	44.95	38.84	12.50	96.29	1.55	.30	1.85
9	Mount Savage fire-clay, Mount Savage, Md	39.90	30.08	7.60	77.58	1.15	16.90	18.05
10	Scioto Star Fire Brick Co., Sciotoville, Ohio	52.36	33.34	12.28	97.98	....	With clay.	....
11	Portsmouth Fire Brick Co., Portsmouth, Ohio	50.95	39.49	9.18	99.62	....	With clay.	....
12	Fire-clay, Cheltenham, Mo	38.10	31.53	11.30	80.93	1.50	12.70	14.20
13	Glass-pot clay (strong), Stourbridge, Worcester County, England	30.50	22.52	8.30	61.32	1.00	33.65	34.65
14	Crucible fire-clay, Halifax, Yorkshire, England	39.45	32.19	11.80	83.44	....	11.80	11.80
15	Fire-clay, Frankenthal-on-Rhine, Germany	41.90	31.69	9.45	83.04	.90	8.10	9.00
16	Fire-clay, Bollène, Dept. de Vaucluse, France	38.20	28.19	10.50	76.89	1.15	14.95	16.10

* The fire-clays from localities other than the Denver Basin are taken chiefly from "Report on Clays," Geological Survey of New Jersey, 1878. Two, Nos. 10 and 11, are from Vol. V, Economic Geology, Geological Survey of Ohio.

1. Employed in manufacture of all refractory products—fire-brick, chemists' and assayers' supplies, furnaces, etc.
2. "Of special value for making crucibles, glass pots, and the more siliceous fire-brick."
3. "Used for making retorts."
4. For general refractory products.
5. Fire-brick and other highly refractory products.
6. For general refractory uses.
7. "Fire-brick, and for retorts and condensers in zinc furnaces."
8. For rolling-mill and blast-furnace brick. Best for steel works purposes cemented with Springfield kaolin.

Analyses of fire-clays from the Denver Basin and from other American and foreign localities for comparison—Continued.

	Locality.	Potash (K_2O).	Soda (Na_2O).	Lime (CaO).	Magnesia (MgO).	Sesqui-oxide of iron (Fe_2O_3).	Total deleterious impurity.	Water (hygroscopic) (H_2O).	Total.
1	Denver Fire Clay Co., Denver, Colo...	0.49	0.09	....	Trace.	0.75	1.33	2.13	100.00
2	William B. Dixon, Woodbridge, N.J..	Trace.	Trace.	....	0.07	1.24	1.31	.57	100.29
3	William H. Berry, Woodbridge, N.J..	.28	.16	....	....	1.10	1.54	1.50	99.94
4	Loughbridge & Powers, Woodbridge, N.J..............................	.41	.08	0.10	....	.50	1.09	1.21	99.55
5	Crossman Clay and Manufacturing Co., Raritan River, N.J.............	.37	....	....	Trace.	.95	1.32	1.00	100.32
6	E. F. Roberts, Pits near Eagleswood, N.J..............................	.59	....	.22	.25	1.20	2.26	1.30	100.16
7	J. D. Hylton's fire-clay, Pensauken Creek, N.J..........................	.76	.20	.11	....	1.09	2.16	.40	100.47
8	Mineral Point fire-clay, near Johnstown, Pa............................	.35	....	....	....	.91	1.26	.70	100.10
9	Mount Savage fire-clay, Mount Savage, Md..............................	2.30	....	....	....	1.67	3.97	.90	100.50
10	Scioto Star Fire Brick Co., Sciotoville, Ohio............................	1.00				1.02	2.02	....	100.00
11	Portsmouth Fire Brick Co., Portsmouth, Ohio..........................	.31	....	.30	.28	With Al_2O_3	.89	....	100.51
12	Fire-clay, Cheltenham, Mo............	.40	....	....	Trace.	1.92	2.32	2.50	99.95
13	Glass-pot clay (strong), Stourbridge, Worcester County, England........	.50	....	....	....	1.43	1.93	2.10	100.00
14	Crucible fire-clay, Halifax, Yorkshire, England..............................	.51	....	....	....	2.65	3.16	1.60	100.00
15	Fire-clay, Frankenthal-on-Rhine, Germany..............................	2.22	....	....	....	2.54	4.76	3.20	100.00
16	Fire-clay, Bollène, Dept. de Vaucluse, France................................	.40	....	....	....	2.76	3.16	3.60	99.75

9. Used for fire-brick and other refractory products.

10. Fire-brick.

11. Fire-brick.

12. "Very refractory; used in glass pots and crucibles."

13. Glass pots.

14. "High-class fire-brick, cupola linings, and Bessemer steel-makers' requirements. The bricks are excellent."

15. For high-class refractory products.

16. "Most noted and most sought after of French clays for manufacture of refractory materials. Used one-third crude and one-third burnt, with one-third quartz sand for tuyères of Bessemer converters and steel furnace hearths."

The fire-clays of the Dakota are bedded, delicately laminated, and locally jointed. They are hard, compact, and fine-grained, the purer varieties being almost free from grit. The color is either a dark, bluish gray or a lighter shade, passing into a drab. The darker varieties contain a greater amount of carbonaceous matter, which is distributed either uniformly and invisibly through the mass of the clay or in more or less extended patches of lignitic particles on the planes of lamination. The impurities are a fine sand in thin layers, or oxide of iron, the result of the decomposition of minute grains of pyrite. The latter imparts to the clay a characteristic spotted appearance, sufficient to determine its Dakota horizon where otherwise—as in the area of the unconformity at Golden—through proximity to the dark Benton shales, it might be wholly misinterpreted.

Following is an analysis[1] of an average specimen of Golden fire-clay, obtained from the mines north of the city:

	Per cent.
SiO_2	50.35
TiO_2	.80
Al_2O_3	33.64
Fe_2O_3	.75
MgO	Trace.
Na_2O	.09
K_2O	.49
H_2O and organic	13.88
	100.00

Much organic matter.

The composition of pure kaolinite is: SiO_2, 46.30 per cent; Al_2O_3, 39.80 per cent; H_2O, 13.90 per cent.

Computed on the basis of the kaolinite composition, the above analysis would become—

	Per cent.
SiO_2 combined	39.134
Al_2O_3	33.64
H_2O combined	11.75
TiO_2	.80
SiO_2 quartz	11.216
K_2O	.49
Na_2O	.09
MgO	Trace.
Fe_2O_3	.75
H_2O hygroscopic	2.13
	100.00

[1] Analysis by Dr. W. F. Hillebrand, U. S. Geological Survey.

The excellence of the Golden fire-clay as a refractory material is largely due to the small percentage of the bases, potash, soda, lime, magnesia, and iron, which, in the presence of quartz, readily form with it fusible silicates. The percentage of free quartz in the sample analyzed was estimated from the total silica on the basis of alumina present in pure kaolinite. The same method was employed in regard to the hygroscopic water. Of the bases the iron has the widest range in the quantity present, and requires special attention in hand-sorting the clays for the several uses for which they are employed. The mixing, tempering, and general treatment of the clays depend upon the product to be turned out; being matters beyond the scope of this work, they were not investigated.

The amount of fire-clay annually mined in the region about Golden rarely falls below 4,000 tons and often considerably exceeds this. From other portions of the field a possible output of 2,000 tons more is derived. A large amount of the clay is manufactured into crucibles, scorifiers, muffles, and furnaces, all of the very finest quality, while the remainder is consumed in the fire-brick industry.

Fire-clays also exist in the Laramie formation in connection with the coal, usually forming the floor of the bed, but they are of inferior quality and of too slight and irregular thickness to be of economic importance. They are frequently replaced by sandy beds.

CLAY FOR THE MANUFACTURE OF BUILDING MATERIALS.

The clays employed in the manufacture of general architectural materials are derived mainly from the upper half of the Fox Hills formation, especially from a zone 300 or 400 feet thick a short distance below the capping sandstones. The clays are slightly arenaceous, of marked homogeneity in constitution, and quite free from the concretionary limestones which are characteristic of lower horizons in the formation. Present developments are confined chiefly to the vicinity of Golden and Valmont, but there are many localities along the base of the foothills favorable for the establishment of brick industries. The high angle of inclination in this region is well calculated to secure for the clays prior to their conversion into bricks, and, therefore, for their resulting product, a uniformity of composition quite unattainable in regions of slight dip, where but a comparatively small thickness is mined at a time.

The manufactured product from the Fox Hills clays is a pressed brick of the finest quality and color. The machines in use and the process employed are practically those of other portions of the United States. The product is consumed in Colorado, chiefly in Denver.

The Pleistocene and Denver formations, in the vicinity of Denver, rank next to the Fox Hills in the importance of their yield and manufactured product. The latter is large, both in pressed and common brick.

Clay product of the Denver Basin for the year 1894.[1]

Product.	Number.	Value.
Brick (common and pressed)	19,629,000	$127,469
Fire-brick	....	38,393
Paving brick (vitrified)	1,688,000	16,880
Drain tile	....	500
Sewer pipe	....	50,000
Tile (building, roofing, floor, encaustic, art)	....	2,500
Other products (assayers' supplies, stoneware, etc.)	....	52,500
Total value	....	288,242

[1] From Mineral Resources of the United States, 1894, U. S. Geological Survey.

SECTION III.—BUILDING STONES.

INTRODUCTION.

Within the area of the Denver Basin but a single important quarry of building stone, that at Glencoe, has been opened. Beyond, however, both in the foothills and on the adjoining prairies, there are several, affording great variety in texture, hardness, color, and adaptability to architectural requirements. That considerable rock, of an excellent quality and well suited to many of the uses arising in the construction of buildings, does exist within the confines of the Denver Basin, and that the beds are of sufficient extent to afford a satisfactory and continued yield, together with a necessary economy in production, the observations of the present survey reasonably affirm. The nondevelopment within the basin is due in part to a difference in the character of the stone from that beyond, and in part to the early establishment of the industry at points remote and the subsequent more ready fulfillment of architectural demands from the quarries first opened. There has always been, moreover, a lack of systematic exploration within the Denver Basin, which has also acted as a deterrent.

The geological horizons of the building stones quarried along the eastern base of the Colorado Range are the white quartzites of the Silurian; the Red Beds and Creamy sandstone of the Lower Trias; an occasional bed in the Upper Trias; the Dakota, Fox Hills, and Laramie of the Cretaceous; and the rhyolitic tuff of Castle Rock, of Tertiary age.

SILURIAN BUILDING STONES.

The Silurian quartzites lie high on the mountain slopes in the vicinity of Manitou. They are pure white, of remarkably even and fine grain, and extremely hard. They outcrop in a ledge 15 feet thick, traceable for several hundred yards. At present they are but little quarried on account of comparative inaccessibility and excessive hardness, but they are destined sooner or later to enter in an important degree the list of constructive and ornamental materials of Western cities. No measures of Paleozoic age occur in the Denver Basin.

TRIASSIC BUILDING STONES.

The strata of the Trias—the "Red Beds" of the West, the Wyoming formation—yield at various points in Colorado building and other stones of great variety of shade, texture, and strength. East of the range these occur at a horizon not everywhere the same but usually within 500 feet of the top of the lower division of the formation—a zone which is generally of much finer material and more uniform in texture than the beds lower down. There are three varieties of stone from this general horizon, each well adapted to its own special uses: (*a*) a handsome light-red sandstone, frequently used in superstructures; (*b*) a hard, banded, comparatively thin-bedded variety, employed as flagging and in foundations on account of its great compressive strength (15,000 pounds to the square inch); and (*c*) a white quartzite, the homologue of the Creamy sandstone, used extensively west of the Mississippi River for curbing, flagging, and paving.

STONE FOR SUPERSTRUCTURE.

Manitou stone.—The first of the above varieties is known in the trade as Manitou stone, from the locality affording the chief supply. It is of a warm, light-red color and soft texture, but of somewhat varying compressive strength. This, however, rarely falls below the required degree for private residences, but in selecting the stone for tall office buildings a careful choice of quarries should be made. The stone is chiefly an aggregate of fine, well-rounded quartz grains, with a slight amount of feldspar and an occasional grain of magnetite, the whole impregnated with the sesquioxide of iron. The rock lies in beds from 5 to 15 feet thick, separated by occasional narrow seams of clay or shaly sandstones. Weathering has extended usually but a slight distance beneath the surface. The dip of the beds varies between 45° and 90° usually east—at the Manitou quarries between 80° and 90°—the strike being with the trend of the range, a few degrees off north. The jointing is on a large scale, permitting the quarrying of blocks of enormous size when necessary. At the quarries in operation the rift of the rock is not often utilized, the beds standing so nearly vertical and being usually of such thickness that simple channeling is advantageously employed. The Manitou stone works with great ease and is employed in various forms of architectural ornamentation as well as in the ordinary layers of superstructures. The capabilities of the stone are extensively illustrated in the architecture of Denver, in business blocks and private residences. It is among the most beautiful of the building materials of the United States. The geological position of the stone is about 400 feet below the top of the lower division of the Trias.

STONE FOR FOUNDATIONS, LOWER COURSES OF BUILDINGS, FLAGGING, CURBING, AND PAVING.

Stone used for foundations, flagging, curbing, and paving occurs at approximately the same horizon as the Manitou stone, and, also, from this to the summit of the Creamy sandstone. The quarries are located at Bellevue, Stout, Arkins, and Lyons, towns in the foothills from 25 to 40 miles northwest of Denver.

The strata along this portion of the range have undergone an incipient alteration from their original and normal condition of comparative softness, as displayed in the Manitou stone, to one of greatly increased hardness. This is probably due to compression, developed in the general folding "en échelon" of this region, and in a local, secondary folding and faulting, which is noticeable at the several points where the quarries have been opened. In the region about Bellevue, for instance, there is the unusual occurrence within the foothills of a well-developed secondary fold, which along a portion of its axis has quite possibly been relieved by faulting. Near Stout contorted strata again appear, and, although of minor importance, are positive evidence of the early existence of compression. At Arkins the quarries lie almost in the very axis of the synclinal portion of the general échelon fold of this region. At Lyons they are in close proximity to another of these folds. Within the region including the above quarries there is a tendency of the strata to thinner bedding than at many points along the foothills, although there is, also, marked variation in the thickness of individual beds.

The Bellevue quarries.—These are situated in the foothills about 9 miles due west of Fort Collins. Their product is distinctively a building stone, although suited to special rather than general uses. Beds of heavier stratification predominate. The hardness and compressive strength of this stone are greatly in excess of that of other building stones east of the range; its color is slightly deeper and more somber than that usual for the Trias of the foothills; and it is quarried with ease in blocks of any desired size, lifts of 4 and 6 feet being the more usual. It is composed chiefly of fine quartz grains, with an occasional accessory mineral, the mass being infiltrated with oxide of iron. Its texture is nearly uniform throughout. Such a stone, while excelled by others in the ease with which it is worked for ornamental building purposes, is nevertheless admirably adapted to use in the lower courses of superstructures, in sills and caps, and other portions of buildings requiring special strength, and in foundations. It offers a resistance to compressive strains far in excess of the ordinary building stone of the Red Bed series.

The Bellevue stone is geologically the lowest of the stones quarried in the northern portion of the field, occurring several hundred feet below the top of the Trias and at approximately the same horizon as the Manitou stone. The dip is east 30°, the strike with the trend of the range, nearly north. The beds form a bold outcrop to the west, 100 feet in height, the quarry being opened on their backs. The stone is weathered to a depth rarely greater than 3 to 6 feet.

Stout and vicinity.—The quarries at Stout and in its vicinity are opened in the upper portion of the homologue of the Creamy sandstone and extend at intervals along the trend of the ridge for 3 or 4 miles. The dip of the beds is 30° to 45° E. Compression has altered the original sandstone to hard quartzite, a resistance to crushing as high as 12,000 pounds to the square inch being attained. The rock is more distinctly and finely laminated and lies in much thinner beds than the normal white sandstone. The lifts of the stone as at present quarried vary in thickness from 1 to 2½ feet, and are in area 8 by 12 and 15 feet. The direction of the grain is definitely marked, rendering quarrying easy. End joints are usually present. The rock is normally a variable white, but is occasionally tinted a faint red. It is usually dotted with small spots of the hydrated oxide of iron, a characteristic of this horizon throughout the foothill region.

The stone is extensively employed in sidewalk construction, particularly in business portions of the city, where constant wear and possible weights demand great resistance and strength. For paving and curbing purposes it is dressed at the quarry into blocks of the required size, and its market in this product extends to the Missouri River. It is considered too hard for general building purposes, being used only for foundations and an occasional sill or cap.

Arkins.—The Arkins stone is said to be identical with the Stout, but a visit to these quarries was not made. They are located on the Buckhorn, in the synclinal half of the échelon fold immediately north of Big Thompson Creek. They are reached by a branch of the Union Pacific, Denver and Gulf Railroad from Loveland, about 8 miles in length.

Lyons.—Lyons and its quarries lie in the foothills, 12 miles west of Longmont, at the terminus of the Denver, Longmont and Lyons branch of the Burlington route. This, also, is a region of folding, and in consequence the strata have been subjected to considerable compression, resulting in hardening and increased resistance. The fold is of the échelon type, and lies just north of St. Vrains Creek. The quarries are located on the western leg of the compound flexure in the uppermost members of the Creamy sandstone, at the very top of the lower division of the Trias.

The sandstone is considerably modified from the normal by impregnation with iron, and a consequent reddening, and by a tendency to gradually pass into the lower beds of the upper division of the Trias, which are uniformly red and inclined to a shaly or more thinly bedded structure. It is quarried exclusively for flagging, curbing, and sills. To the first and last of these purposes it is admirably adapted, but it is a little soft for curbing. The laminæ vary in thickness from 1 to 12 inches, but the product of the quarries is chiefly the thinner plates, ranging in thickness from 1 to 4 inches, and in area up to 50 square feet. The stone is very homogeneous in texture and composition, and its durability has been well tested in a comparatively long period of use in Denver; in outcrop, also, the strata show but slight disintegration, and the amount of stripping requisite is light.

The physical properties of the above varieties of building and other stone are not completely determined, but their ratio of absorption is undoubtedly small, their compressive strength great, and their composition such as to render alteration through atmospheric agencies slight.

Glencoe quarries.—The Glencoe quarries are located on Ralston Creek, in the top of the Creamy sandstone. They have been worked at intervals, affording a handsome and durable stone.

CRETACEOUS BUILDING STONES.

The building stones of this age in the vicinity of the Denver Basin are at present derived from the summit of the Fox Hills formation. At various points in the West, however, the Laramie sandstones afford excellent structural material, and near Canyon extensive quarries have been developed. The quarries on the confines of the Denver Basin are located along the north bank of St. Vrains Creek about 3 miles east of Longmont and 28 miles north of Denver. The summit sandstones of the Fox Hills here form a bluff of 50 feet, capped at a distance from the face by a shell of the basal sandstone of the Laramie. The line of division between the two formations is marked by a strongly developed bed of the fossils characteristic of this horizon. The Fox Hills sandstone is divided into an upper and lower bench, both quarried and used in constantly increasing amounts in the construction of residences and office buildings in Denver. The upper bench is the familiar yellow sandstone, everywhere the cap of the formation. The lower is a bluish-gray sandstone, in texture much finer than the upper. Both sandstones are aggregates of quartz grains with mica or some other mineral in minute quantities. The bluish stone contains more clayey matter than the yellow, and in places is inclined to a shaly structure; below, it shades into the general mass of arenaceous shales composing the bulk of the formation. Other differences between the upper and lower sandstones are, greater quantity of iron oxide in the upper, to which it owes its yellow color; the comparative freedom of the lower from this salt, but the presence of an appreciable quantity of lime, producing hard nodular masses of calcareous sand, from 2 to 3 feet in diameter. Both benches, but more frequently the upper, show a few scattered fossils; the casts are not sufficiently numerous, however, to render the stone undesirable, although they must be considered in its selection. The beds occupy an approximately horizontal position, are crossed by few joints, and from their massive character may be quarried in any desired size. The upper sandstone is, indeed, a single bed, from 15 to 20 feet thick; the lower usually occurs in lifts of 6 or 8 feet, but may be still further divided, locally, by bands of shaly structure. The ratio of absorption has not been well determined for these sandstones, but it is somewhat higher than for those of Triassic age. Of the two varieties afforded by the Longmont quarry, the blue is stated by the quarrymen to be perceptibly more absorbent than the yellow. Both varieties are porous and in the dry atmosphere of the West quickly yield up their quarry water after removal from their beds. They are said not to reabsorb moisture to a detrimental degree after once having been seasoned. Quarrying is not carried on in the winter months. The yellow stone is used for residences and for tall business structures, but the blue is probably adapted for residences only.

THE CASTLE ROCK BUILDING STONE.

This is a rhyolitic tuff. It occurs as a bed of variable thickness—from a thin sheet to 200 feet—separating the two divisions of the Monument Creek formation. The deposit nowhere enters the limits of the Denver Basin as represented on the map, but lies wholly to the south, outcropping in isolated patches at various localities on the Arkansas divide. The stone is extensively quarried in the neighborhood of Castle Rock, 33 miles south of Denver, and has long been used in the construction of many of the more important buildings of Colorado.

The rock is a deposit of eruptive material of the composition of rhyolite. Its main constituents are in an extremely fine state of division and form a homogeneous rock mass, except for minute fragments of the crystals of glassy sanidine and small scales of biotite-mica which are scattered through it with comparative uniformity. The rock is rendered more or less porous by numerous cavities, of sizes up to that of a walnut, the result of a decomposition of some accessory mineral component which is distributed through the bed. This feature makes the stone undesirable for employment where great strength is required; for the superstructure of buildings of moderate height its compressive strength is, however, ample. In color there are two distinct varieties, a delicate shade of pink and a bluish-gray of equal depth. Either may be used alone, or they may be combined without order in the general structure, or one may be employed in ornamental relief to the other; they may also be effectively used in combination with the red Triassic stone from Manitou. The Castle Rock stone retains its color well, and from an artistic view forms one of the handsomest building stones of the West. The stone is usually dressed in the rough or rock finish, its fracture being distinctly conchoidal. The durability of the stone can only be judged from its condition in the outcrop. This is such as to warrant belief in a strong resistance to weathering, at least in the dry atmosphere of the West. The older buildings of this stone in Denver have had as yet but about eighteen years' existence.

OTHER STONES.

The other stones of the Denver Basin and the adjoining districts are of little importance at present, although in time they may be developed. This is particularly possible in the cases of the Dakota quartzite and the heavy band of pink sandstone locally present near the top of the upper division of the Trias. Both have already been used to a slight extent, the former for paving and foundation, the latter for building purposes. For superstructures the Dakota will probably never become a favorite, owing to the abundance of the softer and really handsomer stones already described.

Granite occurs in abundance in the mountains west of the Denver field, but no examination was attempted. Quarries have been opened, however, and the stone has been used for building purposes in Denver and other Western cities.

PRODUCT.

The value of the sandstone product from the localities and geologic horizons referred to in the foregoing account amounted in 1889 to \$1,142,457, distributed as follows: Boulder County, \$405,773; El Paso, \$377,800; Larimer, \$317,388, and Jefferson, \$41,496. The total value of sandstone quarried throughout the State was \$1,224,098. Of this, an amount valued at \$703,477 was devoted to general building purposes, while for street work the product used was valued at \$509,955, the remainder being devoted to bridge, dam, and railroad work.[1] The consumption in Denver has been very large, but both building stones and the material for street work are marketed in many of the more eastern cities. Since 1889 and 1890, owing to the general business depression, the product has steadily diminished, but the figures given show the possibilities of the Denver field and the adjoining regions.

The total output of granite for the State in 1889 was valued at \$314,673, of which Douglas County is credited with \$200,049; Clear Creek with \$75,000; Gunnison County, \$25,000, and the balance distributed among Chaffee, Larimer, and Boulder counties.[2]

[1] From Mineral Resources of the United States, U. S. Geol. Survey, 1889-90, p. 384.

[2] Idem, p. 383.

Value of the building-stone product of the Denver Basin and adjacent country for the years 1889–1891.a

Product.	1889.	1890.	1891.	1892.	1893.	1894.
Granite	b $285,000	....	$55,000	$11,250	$61,000	$38,302
Sandstone	1,142,000	....	228,177	239,986	74,451	78,182
Rhyolite	(c)	....	....	20,000	10,672	8,000
Total	1,427,000	....	283,177	271,236	146,123	124,484

a From Mineral Resources of the United States, U. S. Geol. Survey.
b Very nearly.
c No statement made regarding early outputs.

SECTION IV.—ARTESIAN WELLS.

HISTORY OF DEVELOPMENT.

EARLY ATTEMPTS.

The earliest exploration for artesian water in Colorado was at Kit Carson station on the Kansas Pacific Railroad, in the year 1870, under the direction of Gen. William J. Palmer. The well, according to best accounts, was sunk to a depth of about 1,300 feet without obtaining water and was then abandoned.

The next attempt to find artesian water was made in the vicinity of Denver in February, 1874, when a well located near the cemetery, on the highlands, east of the town, was drilled by private enterprise to a depth of 795 feet, but none of the three water-bearing strata cut yielded surface flows, the pressure being insufficient. In another account of this well, however, the date is given as 1871, and water is reported to have flowed at the surface from a depth of 670 feet; obstructions soon after caused a discontinuance of the work.

In the year 1879 a well was drilled for petroleum at South Pueblo, in the Arkansas Valley. At a depth of 1,180 feet a flow of mineral water (temperature 82° F.) was struck, yielding 160,000 gallons per twenty-four hours. Drilling was abandoned at a depth of 1,404 feet; cost, $5.16 per foot. This flow is from the Dakota sandstones. On December 1, 1888, the yield was 126,000 gallons per twenty-four hours.

In 1880 a well was bored for water on Coal Creek, Fremont County. A depth of 1,278 feet was reached without obtaining a surface flow, although from a depth of 350 feet water rose to within 15 feet of the surface; the quantity was slight.

In the same year (1880) several shallow wells—from 50 to 200 feet deep—were sunk near Greeley. None yielded water flowing at the surface.

In 1881 a second well was drilled at Pueblo for the South Pueblo Steel Works. Its location is on the mesa 125 feet above the Arkansas River. The depth attained was 1,200 feet. A fair flow of water resulted. In 1888 the supply was reported as 28,800 gallons per twenty-four hours. The strata passed were chiefly shales. The cost did not exceed $5 per foot.

At the same time that the above well was drilled an experimental attempt to secure artesian water was made under the auspices of the United States Department of Agriculture near Fort Lyon, 84 miles east of Pueblo, in the valley of the Arkansas. The result was unsatisfactory, a single flow of but 3 gallons per hour having been obtained at a depth of 430 feet, the expenditures to this point amounting to $18,353.55. A commission subsequently appointed by the Department reported unfavorably upon the location of the well, and this, with the unsatisfactory results obtained, led to its abandonment at a depth of 815 feet.

The commission then made a careful examination of the stratigraphy and structure of the prairie region of Colorado between the Arkansas and Platte rivers. Two sites were selected by them as favorable for further experimental boring, one at Akron, 112 miles east of Denver, on the Burlington and Missouri Railroad, the other at Cheyenne Wells, 117 miles southeast of Denver, near the Kansas Pacific Railroad. At neither point were the attempts successful, although at the former locality a depth of 1,260 feet was attained and at the latter 700 feet.

ACTIVITY IN THE DENVER BASIN.

The active prosecution of well-boring in the vicinity of Denver constitutes a second period in the history of the development of this industry in Colorado. In March, 1883, Mr. R. R. McCormick, who was boring for coal near St. Luke's Hospital, in North Denver, was forced to abandon the attempt on account of a large flow of water which rendered further progress with the tools in use impossible. This water was characterized by its extreme purity and its superiority over the water furnished by the Denver Water Company from the Platte, and the interest created by its discovery was very great. The question of its source was discussed at length, and it was due largely to the emphatic and, as later proved, correct assertion of Mr. Horace Beach, the United States commissioner in charge of the Government wells on the plains, that this water was artesian and not derived by seepage from artificial lakes near by, that confidence was established in these wells and boring begun extensively. To the enterprise of Messrs. Philip Zang, Thomas G. Anderson, H. A. W. Tabor, and the owners of the Lion Brewery, all of whom immediately sunk wells, is largely due the first establishment of the fact that Denver is underlain by economically available bodies of artesian water.

Since that time nearly 400 wells have been drilled within and about Denver, extending for a distance of 40 miles along the Platte River and embracing a width of country of at least 5 miles on its either side, Denver being about at the center of the tract. Besides these there are a few others in isolated positions over the field in general, depending for their flow upon local conditions of stratigraphy.

In the later history of the Denver artesian system the point of chief interest and importance has been the decrease in yield, particularly of the wells within the city limits—the area of greatest demand upon the subterranean supply. Of the many strong wells of earlier years, but six to-day yield a flow at the surface, pumps being generally employed in raising the water. A review of the evidence gathered in the examination of the wells in 1886 indicated that at that time the water supply as a whole had not shown signs of decrease either in the region of greatest concentration of wells or in the outlying districts. Any decrease in the yield of individual wells could then be traced to defects in the bore or its packing, or to the local influence of holes more favorably located, an interference wholly confined within the city limits. Between the years 1888 and 1890, however, a steady and general decrease in the water supply of the city wells took place, and in 1891 the water level stood several feet beneath the surface. The wells in the country still show no perceptible decrease.

WELLS IN INTERMONTANE VALLEYS.

Of the valleys in the mountains of Colorado the San Luis has long since become prominent for its large supply of artesian water. Boring in this valley commenced sometime in the year 1886, possibly not until 1887. On December 1, 1888, there were recorded[1] twelve wells, from 85 to 235 feet deep, and flowing at the surface from 1 to 40 gallons per minute, one reaching 400 gallons. Since then the industry has been vigorously prosecuted. In December, 1890, the flowing wells numbered 394, and at the present day they largely exceed this figure even. The water is used not only for domestic purposes, but in irrigation as well. The head of the wells has materially diminished with the great increase in their number.

More extended accounts of the San Luis wells may be found in the several reports of the State engineer of Colorado, and in the volume of the Eleventh Census on "Agriculture by irrigation," by Mr. F. H. Newell.

The yield of the San Luis wells is said to be derived from Quaternary gravels, a source similar to that of the Utah wells.

In the Uncompahgre Valley well boring began at about the same time as in the San Luis. At Montrose[2] there were reported on December 1, 1888, two flowing wells, yielding 27 and 35 gallons per minute, respectively, from depths of 936 and 800 feet.

On the confines of the Florence oil field between the years 1880 and 1890 artesian water was encountered in several instances in boring for petroleum. The flows from the Dakota sandstone are invariably large and usually quite strongly mineralized.

ARTESIAN CONDITIONS OF THE DENVER BASIN.

An artesian well is one that taps a subterranean body of water at a point where it is under hydrostatic pressure sufficient to cause the water to rise in the well and flow at the surface. Wells which show a rise only, without flowing at the surface, are not, in the proper use of the term, artesian.

[1] Colorado State Engineer's Report, 1887–88, p. 299.

[2] Idem, p. 355.

The essential conditions of an artesian supply are:

1. A permeable layer of rock confined between impermeable layers.

2. An inclined position of the beds and their outcropping in a manner to present an extensive area of absorption to rains and stream waters.

3. An effective barrier to the outlet of the contained water at a lower level than the surface of the well area, whether a barrier of texture, structure, or position.

4. A difference in altitude between the area of absorption and the surface of the well area such that the resulting increase in hydrostatic pressure shall be sufficient to overcome the frictional resistance encountered in the passage of the water from the source to the point of delivery.

5. An adequate rainfall.

The first four of these conditions are illustrated in the following figures, taken from a paper by Prof. Thomas C. Chamberlin:[1]

FIG. 17.—Ideal section illustrating the chief requisite conditions of artesian wells. A, a porous stratum; B and C, impervious beds below and above A, acting as confining strata; F, the height of the water level in the porous bed A, or, in other words, the height of the reservoir or fountain head; D and E, flowing wells springing from the porous water-filled bed, A.

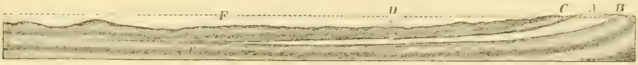


FIG. 18.—Section illustrating the thinning out of a porous water-bearing bed, A, inclosed between impervious beds, B and C, thus furnishing the necessary conditions for an artesian fountain, D.

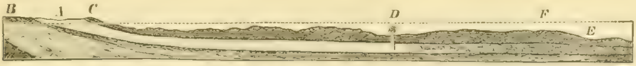


FIG. 19.—Section illustrating the transition of a porous water-bearing bed A, into a close-textured impervious one. Being inclosed between the impervious beds, B and C, it furnishes the conditions for an artesian fountain, D.

From what follows it will be seen that the artesian conditions of composition, stratigraphy, and structure are well fulfilled in the Denver field. The formations affording the water supply—the Denver, Arapahoe, and Laramie—are a succession of sands and shales, and the structure of the field is that of a shallow basin, its mountain edge sharply upturned.

[1] The requisite and qualifying conditions of artesian wells: Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 125–173.

THE CONDITIONS OF COMPOSITION AND STRATIGRAPHY IN THE DENVER BASIN.

WATER-BEARING HORIZONS.

The water-bearing sandstones underlying the Denver Basin at depths within economic reach are: That capping the Fox Hills formation; the basal member of the Laramie; the conglomerates and coarse sands at the bottom of the Arapahoe; a broad arenaceous zone midway in this formation; and several sandy layers distributed throughout the shales of these formations and of the overlying Denver beds. Beneath this series the water-bearing strata lie at great depths: the first several thousand feet down in the Montana clays; a second—the Dakota sandstones—between 1,000 and 2,000 feet lower; and, finally, the series of sandstones and conglomerates of the Trias.

The sandstones which occur in the clays of the Laramie, Arapahoe, and Denver formations are uncertain. They generally assume a lenticular form, although perhaps attaining considerable areal extent. They enhance the value of the formation in which they occur as a water-bearing series, however, by their recognized liability to occur at any horizon. In the Arapahoe their importance in this respect has become well established; in the Laramie, such bodies are of less frequent occurrence.

The several water-bearing sandstones differ in composition and texture one from another and also within themselves from point to point, but those of most uniform distribution are also the most uniform in texture.

Fox Hills.—The Fox Hills sandstone, which occurs at the summit of the formation, is composed chiefly of fine quartz grains, with a little mica. It is somewhat ferruginous, of greenish-yellow color and even texture. It passes by gradual transition to the shales below, which become less and less arenaceous in depth and finally take on all the characteristics of the great body of Montana clays.

Lower Laramie.—The sandstones of the lower Laramie are of much coarser grain than the Fox Hills, are white or light-gray in color, but slightly ferruginous, are open in texture, and occur in heavy benches, the lowest two either in a single body or separated by a narrow band of coal or carbonaceous shale. These last are, together, 120 feet, and with the

Fox Hills sandstone, immediately beneath, form a water-bearing zone of nearly 200 feet. The remaining sandstones in the lower Laramie occur at short intervals within the succeeding 50 feet; they are between 5 and 10 feet thick, and are interbedded with clays, lignitic shales, and coal. Except on the confines of the field the foregoing strata have not been pierced in the exploitations for artesian water, unless in a single instance, in some of their upper layers, in one of the deepest wells in Denver.

The Fox Hills and lower Laramie sandstones may be regarded as a single water-bearing zone confined between two great bodies of impervious clays, those of the Montana below and of the upper Laramie above. It is the lowest practicable artesian zone in the Denver Basin.

The conglomerates and sandstones at the base of the Arapahoe.—The Arapahoe formation supplies the greater part of the artesian water of the Denver Basin. The heavy bed of conglomerate and sandstone at its base is doubtless persistent beneath the entire area occupied by the formation; wherever it outcrops or has been pierced its thickness has never been found less than 25 feet, often approaching 200 feet, and occasionally attaining even a higher figure. It consists of the débris of the older sedimentary and crystalline rocks. The sandstone is coarse-grained and the texture is therefore open. It is the most pervious of all the strata underlying the Denver field.

The upper body of sands.—This lies from 200 to 350 feet below the summit of the Arapahoe. It passes gradually into the arenaceous shales above, but from those below it is somewhat more sharply defined. Locally, however, it may extend quite to the lower sandstones. The material of the upper sands is quartz, of a smaller grain than the basal members. There is also a small percentage of clay either distributed through the sands or as interbedded layers which split the zone into several minor divisions. Along the outcrop of the formation bordering the foothills, owing to the comparative fineness of its materials, the existence of the upper zone is not so clearly shown as that of the lower.

The shales of the Arapahoe.—These are arenaceous, with a percentage of clay that is variable, but usually too great for the free passage of water. It is doubtful, however, that any portion of them is absolutely impervious. That there are definite flows is probably due rather to a difference in the degree of porosity than to a permeable layer confined between strictly impermeable layers.

Such a distribution of materials as the above explains both the frequency and the certainty with which flows are encountered in descending through the formation, and also the peculiarity that in two wells tapping the same horizon there may be a marked difference in yield or freedom of flow, or even entire absence of a flow in one of them.

The Denver formation.—This enters but slightly into the artesian system of the field, on account of its shallow depth. The component beds are conglomeratic, sandy, or argillaceous. Conglomerates and sandstones are well developed over extended areas, but their appearance beneath the prairies is more or less irregular and uncertain on account of proximity to the base of the formation and the unconformability existing between this and the underlying Arapahoe and Laramie formations. The clays of the Denver series are usually arenaceous. The character and texture of all the sediments vary from place to place and the yield of water changes accordingly.

AN UPPER CONFINING STRATUM.

The porosity of the Denver and Arapahoe formations, not only in their more sandy members but also in their clayey beds, considered in reference to their position immediately beneath the surface and the gentle slope of their strata, illustrates one of the primary elements of what Prof. T. C. Chamberlin calls the confining stratum above.[1] His statement in regard to this feature is as follows:

> The element to be recognized here is, I believe, essentially new to discussions of the subject, viz, the height of the surface of the common ground-water in the region between the proposed well and the fountain-head. It is a familiar fact that the common underground water stands at varying heights. Our common wells testify to this. The subterranean water-surface is almost invariably higher than the adjacent streams, and slowly works its way into them by springs, seeps, and invisible percolation. Speaking generally, the underground water-surface rises and falls with the rise and fall of the land-surface, only less in amount. Now, if the subterranean water in the region between the proposed well and its source—which we may call the cover-area—stands as high as the fountain-head (except at the well, where, of course, it must

[1] Fifth Ann. Rept. U. S. Geol. Survey, p. 139.

be lower), *there will be no leakage*, not even if the strata be somewhat permeable, for the water in the confining beds presses down as much as the fountain-head causes that of the porous bed to press up, since both have the same height. Capillarity does not disturb the truth of this. Under these conditions a flow may sometimes be secured when it would be impossible if the intervening water-surface were lower.

If the water between the well and fountain-head is actually higher than the latter, it will tend to penetrate the water-bearing stratum, so far as the overlying beds permit, and will, to that extent, increase the supply of water seeking passage through the porous bed, and will, by reaction, tend to elevate the fountain-head, if the situation permit.

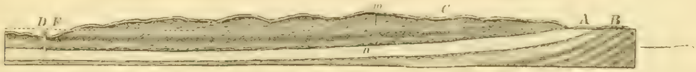


FIG. 20.—Section intended to illustrate the aid afforded by a high water-surface between the fountain-head and the well. A, a porous bed; B, a confining bed below; and C, a confining bed above. The dark line immediately below the surface represents the underground water-surface. Its pressure downward is represented by the arrow *m*. The pressure upward, due to the elevation of the fountain-head, is represented by the arrow *n*. The line F represents the level of the fountain-head. There can be no leakage upward through the bed C except near the well D. There may be some penetration from the bed C into A, which would aid the flow.

I conceive that one of the most favorable conditions for securing a fountain is found when thick semiporous beds, constantly saturated with water to a greater height than the fountain-head, lie upon the porous stratum, and occupy the whole country between the well and its source, as illustrated by fig. 15 [fig. 20, above]. This is not only a good but an advantageous substitute for a strictly impervious confining bed. Under these hydrostatic conditions, limestone strata reposing on sandstone furnish an excellent combination.

If, on the other hand, the underground water-surface between the proposed well and the source of supply is much lower than the fountain-head there will be considerable leakage, unless the confining beds are very close-textured and free from fissures. For example, if it be 100 feet lower there will be a theoretical pressure of nearly three atmospheres, or about 45 pounds to the square inch, upward, greater than that of the underground water downward, disregarding the influence of capillarity, and this will be competent to cause more or less penetration of the water upward through the pores and crevices of the rocks, and consequent loss of head and forcing power.

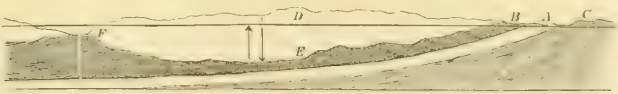


FIG. 21.—Double section illustrating the effects of high and low water-surface in the cover-area. (For explanation, see text.)

Both of the above points may be illustrated by the accompanying double profile [fig. 21], in which A represents a porous stratum inclosed between the impervious beds B and C. The source of water-supply is at A, and the proposed well at F. Let E be supposed to represent the surface of the ground (and, for convenience, also, the surface of the common ground-water) in one of the two supposed cases, and D the surface in the other. The arrow springing from the surface E represents the upward tendency of the water in the porous bed, owing to pressure from the fountain-head, while the arrow depending from the line D represents the downward pressure of the ground-water, whose surface is represented by D, and is, it will be observed, more than equivalent to the upward tendency due to pressure from the fountain-head. A flow at F could very safely be predicted if the surface were as represented by D, while it might be doubtful whether one could be secured if the surface were as represented by E.

My attention was first directed to this consideration by observing that where the intermediate country was elevated and had a high water-level, wells flowed at heights suprisingly near theoretical estimates, almost no deduction for obstruction and leakage being necessary, whereas in those cases where the opposite was true there was a very considerable falling short of theoretical estimates.

THE CONDITIONS OF STRUCTURE IN THE DENVER BASIN.

Form and extent of the basin.—The form of the Denver Artesian Basin is somewhat irregular, but the many observations of dip indicate it to be a shallow syncline, the axis of which passes in the vicinity of the Platte River at Denver and is approximately parallel with the trend of the mountains. The western rim of the basin is sharply upturned and clearly defined; the eastern, northern, and southern rims are of gentle and irregular rise, portions of them, especially the eastern, remaining open-lipped.

The extent of the basin involving the upper zone of water-bearing strata, that is, the Denver and Arapahoe sands, is coincident with that of the formations themselves, although the area of flowing wells is necessarily considerably less. The exploited region, with few exceptions, is a belt about 10 miles in width, lying along either side of the Platte, and 25 miles in length, reaching from the vicinity of Littleton, 10 miles above Denver, to Henderson Island, 15 miles below. The several transverse sections of the field (structure sheet, Pl. IV) show the general character and configuration of the basin and the gentle dips which the strata everywhere have when beyond the influence of the sharp fold at the immediate base of the mountains.

Position of the strata favorable to absorption.—The shallow depth of the basin brings the upper water-bearing strata within easy reach of the surface by the drill; the general introversal dip assures a flow through the permeable beds from periphery to center, and the low degree of dip is most favorable to an extended and broad area of absorption in the belt within which the strata of the upper water zone lie exposed at the surface.

The absorbent area of the rocks of the lower water zone—the Fox Hills and lower Laramie—is reduced to a minimum, these strata being vertical and exposed for absorption only along the western edge of the field. In the northwestern portion of the field the advantage that otherwise might have been derived from their approximately horizontal position and broad area of exposure is completely counteracted by the system of faults so extensively developed. The permeable strata that may occur in the upper, clayey member of the Laramie present a minimum surface of absorption along the foothills, but in the northwestern portion of the field this surface is largely increased by the gentler dip and more extended area of exposure. It is doubtful whether the body of Laramie outcropping in the eastern portion of the field enters into the supply of artesian water in a material degree, for while its dip is often to the west, much of the exposed series of rocks is of a considerably higher horizon than the strata underlying the developed artesian area.

The Arapahoe formation is the most favorably exposed of all for the reception of water falling upon it. With the exception of the short distance from Bear to Ralston creeks, along which it is highly upturned and confined in a narrow belt between the Denver and Laramie formations, the Arapahoe for the most part lies at a low angle of dip, and in the broad areas over which it is without cover its water-bearing beds are exposed to the falling rains and become completely saturated from summit to base.

The absorbing surface of the Denver formation is greater than that of any of the other terranes, but on account of the comparatively slight depth to which it underlies the prairies, its lack often of a confining cover, and its proximity to the irregular floor of Arapahoe and Laramie beds upon which it was deposited, it will not become an important factor in the artesian supply of the field.

The Quaternary of the Denver area, excepting in the stream bottoms, consists largely of a porous loess, often sandy rather than argillaceous. It varies greatly in depth and is frequently absent over large tracts. Its value, therefore, as a confining stratum is variable. The deposit usually carries an abundance of water, which may afford a copious or diminished yield, according to the permeability of the underlying beds.

Barriers effecting confinement of artesian water in the basin.—The configuration of the floor upon which the Arapahoe formation was laid down is of considerable irregularity. This is clearly shown along the northwestern edge of the younger formation, while on the eastern side of the field, in the region of First and Second creeks, the upper Laramie clays appear to have formed an ancient hill of considerable diameter, now laid bare of any sediments that may have once formed a cap to it. North of this area for some distance the Arapahoe still forms a thin overlying sheet, while on the western and southern flanks of the early Laramie eminence the Arapahoe and Denver formations both occur in increasing depth as distance from the crest of the ancient hill is gained.

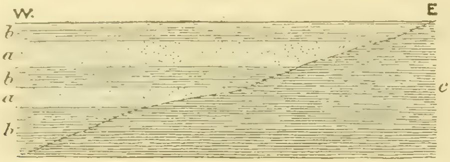


Fig. 22.—Section of barrier clays. *a*, Sandstones of the Arapahoe; *b*, clays of the Arapahoe; *c*, clays of the Laramie.

The Denver formation, along the northwestern border of its area, presents the same relations with the Arapahoe as exist on the eastern side of the field between these formations and the Laramie. The Denver beds rest against elevations of Arapahoe clays, the latter having formed hills upon the Denver floor, as did the Laramie upon the Arapahoe floor.

These relations between the three important water-bearing formations of the Denver field are shown in the general sections.

It is apparent from the foregoing conditions that, while in part the water is held in its basin by the introversal dip, it is also confined by the barrier presented in the opposition to the water-bearing sands of the Arapahoe and Denver of the strictly clayey strata of the Laramie. This is illustrated in fig. 22, where the water-bearing sands, *a*, confined between two impervious layers, *bb*, of the same formation are opposed at the line of unconformity by clays of the older formation.

HYDROGRAPHY.

THE RAINFALL.

For the twenty years 1870 to 1889 the average annual rainfall at Denver, as observed by the United States Signal Corps, was 14.113 inches, having varied in this period from 8.85 to 20.12 inches. This may fairly be considered the rainfall for the area of the Denver Basin, but it is doubtless considerably below that for the valley of the Platte in general, for in the mountains precipitation reaches a much higher figure.

Tabular statement of rainfall at Denver.

Year.	Rainfall in inches.	Year.	Rainfall in inches.
1870	13.29	1880	9.58
1871	12.35	1881	12.78
1872	18.05	1882	14.49
1873	11.81	1883	19.49
1874	13.46	1884	15.07
1875	17.25	1885	15.95
1876	20.12	1886	15.07
1877	16.28	1887	12.49
1878	15.51	1888	9.51
1879	10.86	1889	14.75

DISCHARGE OF STREAMS (RUN-OFF).

The monthly discharge of the streams, or run-off, has been calculated for many catchment areas in the Rocky Mountain region by Mr. F. H. Newell, of the hydrographic division of the Geological Survey, from observations by that division and by engineers or others prior to the establishment of irrigation work by the Survey. The run-off for the Platte Basin has not been investigated, but for the Cache la Poudre to the north and the Arkansas to the south the following table has been prepared.

The table gives the discharge from the drainage basin in two units. In the first column is the total quantity of water flowing in a given period reduced to equivalent depth in inches over the entire drainage basin; this is immediately comparable with the rainfall upon the basin, usually given in inches. The second column gives the average rate of flow per square mile drained, in cubic feet per second, or second-feet.[1]

[1]One second-foot = 62.5 pounds = 7.48 gallons.

Cache la Poudre, at Fort Collins, Colo.

[Drainage area, 1,060 square miles.]

Month.	Discharge.	
	Equivalent depth on basin.	Per square mile drained.
1884.	*Inches.*	*Sec. feet.*
March 15 to 31	0.07	0.06
April	.23	.21
May	2.77	2.39
June	5.08	4.54
July	2.33	2.03
August	.86	.75
September	.32	.29
October 1 to 16	.22	.19
Total	11.88	10.46
1885.		
April 4 to 30	0.47	0.42
May	1.55	1.34
June	3.07	2.75
July	3.46	3.01
August	.71	.62
September	.29	.25
October 1 to 10	.22	.19
Total	9.77	8.58
1886.		
April 27 to 30	0.43	0.38
May	1.42	1.23
June	1.97	1.77
July	.78	.68
August	.37	.33
September	.19	.17
October	.14	.12
Total	5.30	4.68
1887.		
May 18 to 29	1.99	1.72
June 14 to 30	1.47	1.32
July	.80	.69
August	.33	.29
September	.18	.17
Total	4.77	4.19
1888.	*Inches.*	*Sec. feet.*
April	0.19	0.17
May	.53	.46
June	1.17	1.05
July	.46	.40
August	.23	.20
September	.11	.10
Total	2.69	2.38
1889.		
January	0.16	0.14
February	.10	.10
March	.05	.04
April	.12	.11
May	.71	.61
June	1.41	1.26
July	.56	.48
August	.20	.18
September	.07	.06
October	.08	.06
November	.09	.08
December	.07	.06
Total	3.62	3.18
1890.		
January	0.09	.08
February	.08	.08
March	.09	.08
April	.21	.19
May	1.13	.99
June	1.35	1.21
July	.71	.61
August	.31	.27
September	.11	.10
October	.09	.08
November	.07	.06
December	.08	.07
Total	4.32	3.82

Arkansas, at Canyon, Colo.

[Drainage area, 3,060 square miles.]

Month.	Discharge.		Month.	Discharge.	
	Equivalent depth on basin.	Per square mile drained.		Equivalent depth on basin.	Per square mile drained.
1888.	*Inches.*	*Sec. feet.*	1889—Continued.	*Inches.*	*Sec. feet.*
January	0.15	0.13	August	0.13	0.11
February	.17	.16	September	.08	.07
March	.22	.20	October	.08	.07
April	.36	.33	November	.11	.10
May	.54	.47	December	.13	.11
June	.76	.68	Total	1.92	1.71
July	.51	.44			
August	.35	.30	1890.		
September	.22	.20	January	0.12	0.10
October	.19	.16	February	.12	.12
November	.18	.16	March	.12	.10
December	.15	.13	April	.17	.16
Total	3.80	3.36	May	.79	.68
			June	.95	.85
1889.			July	.59	.51
January	0.11	0.10	August	.25	.22
February	.10	.10	September	.19	.17
March	.11	.10	October	.20	.17
April 17 to 31	.11	.10	November	.19	.17
May	.23	.20	December	.19	.16
June	.50	.45	Total	3.88	3.41
July	.23	.20			

Arkansas, at Pueblo, Colo.

[Drainage area, 4,600 square miles.]

Month.	Discharge.		Month.	Discharge.	
	Equivalent depth on basin.	Per square mile drained.		Equivalent depth on basin.	Per square mile drained.
1885.	*Inches.*	*Sec. feet.*	1887.	*Inches.*	*Sec. feet.*
May 16 to 31	0.27	0.24	January	0.10	0.09
June 1 to 23	.79	.69	February	.09	.09
Total	1.06	.93	March	.12	.11
1886.			April	.15	.13
January	0.10	0.09	May	.63	.54
February	.12	.11	June	.84	.75
March	.15	.13	July	.84	.73
April	.19	.18	August	.44	.37
May	.78	.66	September	.25	.25
June	1.35	1.21	October	.20	.18
July	.44	.38	November	.15	.13
August	.37	.32	December	.10	.09
September	.34	.30	Total	3.91	3.46
October	.20	.18			
November	.15	.13			
December	.10	.09			
Total	4.29	3.78			

As shown in the above table, the variation in the run-off has been very great, both from year to year and as between the two regions for which the determinations are made, but a knowledge of the influencing conditions enables one to give an approximate estimate for the Denver area of between 4 and 5 inches annually; say, for convenience in computing, 4.113 inches.

EVAPORATION.

Evaporation plays a most important part in the water economy of the West, but all attempts at estimating it for land surfaces are the merest guesses. From water surfaces in the Denver area in 1889 it amounted to about 61 inches, based upon the following data.

Observations at Cherry Creek[1] during the period from June to November, inclusive, 1889, gave as the evaporation—

	Inches.
For June	8.1
July	7.9
August	8.6
September	6.2
October	4.2
November	2.5
Total	37.5

The monthly percentage of the yearly evaporation at Denver is approximately—

	Per cent.
For January	4
February	5
March	7
April	8
May	10
June	15
July	12
August	12
September	9
October	7
November	6
December	5

Combining in a proportion the total percentage for the months June to November and the actual evaporation as observed at Cherry Creek for this period, the result for the year is the 61 inches given above.

In general, in considerations of the present nature, it is customary to allow for evaporation about one-third of the rainfall. For convenience in subsequent calculations, it will in this report be taken at 4 inches, or a little under one-third.

The run-off and evaporation for the Denver Basin—4.113 inches and 4 inches, respectively—leave of the annual rainfall of 14.113 inches, 6 inches available for absorption by the strata upon which it falls.

WATER AVAILABLE FOR ABSORPTION.

From rainfall direct.—The area of exposure of the lower water-bearing series—the Fox Hills sandstone, the basal sandstones of the Laramie, and

[1] Eleventh Ann. Rept. U. S. Geol. Survey, Part II, Irrigation, p. 34.

narrower bands of the coal series—available for collecting purposes for the artesian supply of the Denver Basin is approximately 51,480,000 square feet, based upon a width of 250 feet and a length of outcrop along the foothills of 39 miles, from Wildcat Mountain, south of the Platte, to South Boulder Creek. The extensive exposures of this series of sandstones in the northwestern part of the field are unavailable for the general artesian supply on account of intervening faults. The area of 51,480,000 square feet covered to a depth of 6 inches, the available rainfall for absorption, affords 25,740,000 cubic feet, or 192,548,585 gallons, of water to be taken up by the underlying rocks each year.

The area of the Arapahoe formation available for absorption, with reference to the Denver artesian system, and which, therefore, excludes the outlier northwest of Dry Creek, is about $161\frac{3}{5}$ square miles, or 4,505,149,440 square feet. The amount of water falling upon this area for the absorption by its strata is 2,252,574,720 cubic feet, or 16,850,430,244 gallons, per year.

The area of the Denver formation, disregarding the covering of loess which overlies it in many localities, is approximately 289 square miles, or 8,056,857,600 square feet, receiving upon it 4,028,428,800 cubic feet, or 30,134,742,207 gallons, of water per year, as the amount here available for absorption.

The total quantity of water falling annually upon the artesian strata of the Denver Basin and available for absorption by them is 47,177,721,036 gallons.

From water of irrigation.—Prof. P. H. Van Diest,[1] of Denver, has also estimated the quantity of water brought onto the absorbing areas by irrigation ditches. He says:

> But rainfall is not the only source of water within this basin. The many irrigation ditches bring a great amount of stored-up water from rainfall outside of the basin within its limits. It is estimated that of the amount of water brought in at the upper part of the High Line ditch, not more than 60 per cent is utilized for irrigation. This ditch has a flow of nearly 300 cubic feet per second during the thirty maximum days; of one-third of that flow during the thirty days before

[1] The artesian wells of Denver: Scientific Society, Denver, Colo., June, 1884, pp. 37 and 38.

the 10th of June, and of a half during the thirty days of irrigation after the 10th of July.

The Table Mountain ditch has a flow of 131½ cubic feet per second during the maximum season, and the Rocky Mountain ditch of 189 cubic feet, and the same ratio before and after the maximum discharge as given for the High Line ditch. The flow of each of the two principal ditches heading in Bear Creek, not exactly known, will be very nearly equal to the flow of the Table Mountain ditch.

The amount of water thus brought from outside the basin within its limits is, according to the above data, not less than 31,104,000,000 gallons [31,406,155,324: author].

A good deal of this runs away in visible streams, as is amply demonstrated by the many gullies, ravines, and arroyos, which were before known as dry and now are little rivulets, also by the many springs that were formed in the neighborhood of ditches, some feeding lakes and increasing their extent. Another and large part of the above-named amount of water brought on by ditches is evaporated and consumed by vegetation, so that probably not more than 20 per cent percolates to the subsoil. This 20 per cent would make an additional supply of 6,220,800,000 gallons [6,281,231,065: author].

Taking the author's figures, the total water available for absorption for the field from all sources would be 53,458,952,101 gallons per year.

ABSORBING POWER OF STRATA.

The absorbing power of the artesian strata involved in this discussion can, for the most part, only be estimated. A few determinations of this property were made for the lower Laramie and Fox Hills sandstones in the selection of building material for the State capitol at Denver,[1] which are as follows:

Number.	Locality.	Age.	Weight per cubic foot.	Absorption in weight.	Weight of water absorbed per cubic foot.
			Pounds.	*Per cent.*	*Pounds.*
15	Beaver Creek	Niobrara	134.78	5.28	7.12
16	Oak Creek	Fox Hills or Laramie.......	119.81	9.66	11.57
17	Coal Creek........	.....do	130.42	6.05	7.89
18	Trinidad	.....do	151.01	3.12	5.65
36	El Moro...........	.....do	132.29	5.89	7.79

[1] Second Biennial Report of the Board of Capitol Managers to the General Assembly of the State of Colorado, 1886.

The average weight of water absorbed per cubic foot of the above sandstone is 8 pounds, or a trifle less than 1 gallon per cubic foot.

For the strata of the Arapahoe and Denver formations no determinations have been made. The lower measures of the Arapahoe, about 300 feet, are of very coarse material, often conglomeratic, very friable, and porous, and consequently considerably more absorbent than the series at the base of the Laramie. The exposure of their vertical or highly inclined portion is one-fifth shorter than that of the Laramie, but their entire northwestern edge is available at a low angle of dip. The absorbing power of the sandy series constituting the upper water-bearing zone of the Arapahoe formation probably falls somewhat below that of the basal sandstone of the Laramie per cubic foot. Its material is generally a little finer, and it is of somewhat looser texture, but it carries some argillaceous constituents, which must lower the ratio slightly. Its absorbing area is rather greater than that of the lower sandstones of the formation, since it lies at a less angle of dip and often extends well out on the prairie.

The shaly members of the Arapahoe, while distinctly argillaceous, have a considerable proportion of arenaceous material disseminated throughout their mass, and in addition not infrequently carry porous, lenticular bodies of sandstone at several horizons. Though their arenaceous character doubtless renders the shales pervious and sometimes available as water-bearing strata, and the bodies of sandstone increase still more their capacity for water, yet the ratio of absorption of the shaly member as a whole must fall far below that of the sandstones of the formation.

The porosity and absorbing power of the Denver beds underlying the prairie is considerably below that of the older strata, their constitution being much less arenaceous. The formation is, however, sufficiently absorbent to play an important part in the artesian economy of the Denver region, especially in the matter of ground water.

POWER OF TRANSMISSION IN THE WATER-BEARING STRATA.

Closely related in importance to the absorbent power of different varieties of strata is the power of transmission. Like the former, this depends largely on porosity, but also on evenness of texture, and its influence upon the artesian flows of the Denver Basin may be gathered from what has preceded in regard to the composition and distribution of materials. It is not the same for all parts of a stratum, as is frequently instanced in the wells of Denver, and it may vary to such a degree as to completely shut off the flow in certain areas. The coarse sandstones and conglomeratic layers have the greatest power of transmission, and it is quite possible, also, that they act, when tapped, as an inspirator or injector, drawing water by greater freedom of flow from the less permeable strata into their own general current which is escaping by the artesian wells.

CAPACITY OF THE STRATA, THEIR YIELD, AND THE RAINFALL, CONSIDERED RELATIVELY.

It has not been possible to obtain data regarding the flows of the artesian wells of the Denver Basin within an interval of time that would permit determination of the total yield at a given instant. Furthermore, the influence of wells upon one another is a marked feature in all parts of the central portion of the exploited area, that is, within and in the immediate vicinity of the city of Denver. Large original flows in certain wells have seriously diminished upon tapping the same flow in a later well sunk in a more favorable position. Upon the establishment of this fact, to regulate the flows for mutual benefit and avoid waste, valves were applied to most of the wells. Again, flows have diminished from mechanical defects, either in sinking the well or in the packing employed, and such diminution may have been either temporary or permanent. Finally, in arriving at the yield of the system, individual estimates have occasionally been necessary, the parties drilling or owning the wells having neglected to record measurements.

Had the original flows of all the wells been maintained, including also a few that from position or otherwise have always required pumping, with the most careful determinations possible from the data at hand, the maximum yield of the basin would not have fallen far short of 10,000,000 gallons per day, or 3,650,000,000 gallons per year, an amount that is only $21\frac{3}{5}$ per cent of the rainfall available for absorption by the strata furnishing the bulk of the artesian supply of the field, that is, the Laramie and Arapahoe formations, the Denver formation being excluded from consideration on account of the slight extent to which it enters into the actual supply. The rainfall of the Denver Basin is therefore more than adequate to the absorbing and transmitting power of the beds. The failure of the wells to yield a larger supply is due to texture, by which these properties are governed.

THE WELLS.

The 394 wells along the Platte Valley may conveniently be considered in two divisions—one comprising those within Denver and its immediate suburbs, 209 in number; the other, those in the country, 185 in number. Between the wells of the former division clearly developed relations exist, relations that can not be distinguished between the wells in the country or between these and the city wells. The interrelation between the city and its suburban wells is attributable to their concentration within a limited area which undergoes but slight change in the geological conditions of its strata; and the absence of such relations between the wells of the country is due to their wide distribution and the ever-recurring, though slight, changes in structural and stratigraphical conditions sure to exist over an extended area.

THE WELLS OF DENVER AND ITS SUBURBS.

In the following discussion the datum level to which depths of wells, flows, and stratigraphical planes have been referred is the general level of the Platte River at the foot of Fifteenth street, Denver. Where departures from this reference plane have been necessary they are specifically noted.

In the consideration of the city wells the position of the strata underlying the area including them has been regarded as horizontal, which is, at least, very near the actual case. There is, perhaps, a general dip of half a degree to the northward, or down the Platte. Flexures, if present, are insignificant.

RANGE OF FLOWS IN STRATIGRAPHIC HORIZON.

The thickness of the formations underlying the city of Denver and involved in the artesian supply is about 1,500 feet, of which 100 feet may be assigned to the Denver beds, 550 to 600 feet to the Arapahoe formation, and 700 to 800 feet to the Laramie, making the bases of the formations respectively 100 feet, 650 to 700 feet, and 1,350 to 1,500 feet beneath the datum level of the Platte River. The vertical and lateral distribution of the materials of this series of strata has already been discussed, but the distribution of the flows in connection therewith now requires brief consideration.

Two broad water-bearing zones are clearly defined: A lower, corresponding in thickness and position with the lower zone of conglomerates and sandstones of the Arapahoe formation; an upper, between 100 and 200 feet thick, corresponding with the series of sandy strata in the upper part of the Arapahoe, a zone which at most points along the outcrop of the formation does not appear so distinctly developed as beneath the central portions of the field.

Extending below these zones into the Laramie formation, there are but 10 wells, which vary greatly in depth and are widely distributed in location. They indicate little as to the value of the upper Laramie as a water-bearing series, but from the general succession of beds in the areas of outcrop it is doubtful if the formation becomes of economic importance until its lower, basal member of sandstones is reached. Moreover, the waters from the deepest wells in the Laramie of the Denver Basin are considerably mineralized.

The flows recorded from within the Denver formation are but eight in number, only three of which are utilized.

The irregularities which have been encountered in the vertical and lateral distribution of the several flows are not altogether indicative of equal irregularities in the water-bearing capacity of the strata or of the actual absence of flows in localities in which wells have not been sunk to the lowest horizon. On the contrary, it is highly probable that had all the wells been drilled to a uniform depth, as, for instance, to the lower limit of the Arapahoe, the water-bearing zones would have appeared much more unbroken. This is borne out both on natural grounds and from an examination of the flows of the upper zone over those portions of the field from which the most complete information has been obtained. It has not always been possible to obtain data as to minor flows, these having often been passed without comment in the search for greater yields. The value of their record, however, is established in such instances as are given, for not only is a greater persistency thus indicated for the flow, but the actual water-bearing character of the zone is preserved. A flow nonutilized in one locality or well may become of importance in another either through natural increase or through the diminution of other flows in this particular region. Examples of but two distinct flows, from different layers in the same water-bearing zone, either the lower or upper, are also not infrequent; in the vertical interval, however, at other localities, several flows may be recorded. This is in harmony with the distribution of the materials constituting the water-bearing zones, which is not everywhere uniform; the materials may vary laterally from an open, porous bed of sand or conglomerate to one of much closer texture, almost impermeable to water, or, at least, by difference in texture and porosity, affording an easier channel in one direction than in another.

The upper and lower water-bearing zones of the Arapahoe formation are separated by a more or less clearly defined body of shales of a general thickness of about 130 feet. Occasionally the lower zone shows a tendency toward an upward extension, while the upper one has here and there a flow slightly below its average lower limit. Within the median zone there are locally developed beds of a more or less arenaceous composition, which yield excellent flows to the scattered wells tapping them, and which apparently constitute an almost continuous water-bearing body beneath the lower or northern portion of the city, from Twenty-sixth street to the Grant smelter, and, again, in the vicinity of Argo. Considering the field as a whole, the midde zone may be regarded as in a measure blending the more highly developed upper and lower water-bearing series of the Arapahoe.

Of the wells deriving their flows from the Laramie, the Evans is of particular interest as having alone reached in depth the upper portion of the coal series at the base of the formation. The details of this well are given in the chapter on individual wells. The other wells of the Laramie are sunk only to locally developed water strata in the clays of the upper member.

THE RELATIVE PRODUCTIVE POWER OF THE SEVERAL WATER-BEARING ZONES.

The number of wells taking water from the Laramie and Denver formations is too small to afford material for reliable estimates of the productive power of these horizons. For the three zones of the Arapahoe, however, the number is larger, and approximate estimates may be inferred from the original yield of the wells, notwithstanding the fact that the actual number of wells drawing their supply from the several zones varies very considerably.

The average daily yield of the Arapahoe wells, supposing them all to have flowed at the rate originally recorded, would have been—

	Gallons.
For the upper zone	64,075
For the intermediate zone	45,540
For the lower zone	93,673

These figures are based upon reported actual flows, and for the upper zone are the average of 22 wells, for the middle zone of 8 wells, and for the lower zone of 27 wells, the distribution of the wells including the entire center of the Denver Basin. It thus appears that the rate of yield of the several zones is in general accord with their observed texture and composition.

THE YIELD OF THE WELLS.

Daily yield.—In a preceding section the yield of the artesian wells of the Denver Basin was considered with reference to the adequacy of the rainfall, and for the purpose of bringing the results within any possible error of an overestimate the original rate of yield was regarded as an actual daily yield, and all the wells as flowing at the same instant. The figures representing the total amount of water were thus far in excess of those which would represent the actual discharge by flow and by pump, but clearly established the adequacy of the rainfall to the power of transmission of the strata.

Of the actual quantity of water supplied by the artesian wells of Denver and its suburbs at a stated time, it is difficult in the absence of the requisite data to form an estimate; and such data, satisfactory and sufficiently complete, it has been impossible to obtain. Only a minority of the wells have ever made a continuous draft upon their supply, the majority drawing upon it for but a few hours of the day or as domestic purposes demanded. It is probable, indeed, that all in use at the time of the investigation, December, 1890, could have been pumped unremittingly for a considerable length of time, but it would have resulted in a lowering of the water-level and its passage beyond the reach of many of the pumping plants. The best approximate estimate of the daily yield of the Denver and suburban wells at the close of 1890 is, perhaps, 1,500,000 gallons. This is a little more than one-seventh of the original rate of discharge, that for 1886 having been closely determined at about one-fourth the original. Since 1890 there has been a still further decrease, and the city is now almost wholly supplied with water brought from a distance.

In the months of May and June, 1884, there was a marked increase in pressure and flow in several wells, all of which were in the 375-foot seam. Among these wells were the Opera House (pressure doubled), the Eckhart, Electric Light, and Steam Heating Wells. Various explanations of this phenomenon have been advanced, none of which is wholly acceptable.

Van Diest's estimate of total yield to date.—In collecting and tabulating the statistics in 1890, Prof. P. H. Van Diest, of Denver, estimated approximately the yield of the Denver Basin from the inception of artesian-well boring to the close of that year. His discussion is as follows:

The average thickness of the water-bearing strata of the wells in and around Denver is 135 feet (based on a statement for North Denver by an experienced well contractor). Forty miles, or 211,200 feet, of lineal outcrop by a width of 135 feet gives 28,512,000 square feet of water-collecting or rather water-retaining area.

The data of the original height of flow above and of the present level of the water-table in wells below the surface give an average difference in height of 70 feet. A mass of sandstone 40 miles long, 135 feet wide, and 70 feet high contains 1,995,840,000 cubic feet.

The absorption to saturation of this sandstone can be placed at 7 per cent of its weight, according to tests of similar sandstones made by the committee reporting on building stones for the Colorado capitol. Seven per cent is the equivalent of 349,272,000 [299,535,667 : author[1]] cubic feet of water, or 2,619,540,000 [2,240,682,548:

[1] The author took the weight of stone at 134 pounds per cubic foot, an average of several specimens, and a cubic foot of water at 62½ pounds, or 7.48052 gallons. Mr. Van Diest evidently assumed somewhat different data.

author] gallons, which amount has flowed or has been pumped from the wells in the six years of existence of most of them, besides, of course, the amount supplied by rainfall in these six years on the collecting area.

It is more difficult to estimate the yearly supply on the collecting area with any degree of accuracy. Accounts of the regular discharge of wells, either flowing in 1886 or pumping in 1890, could only be obtained in a few instances. Mr. Slack, who collected the statistics for 1886, estimates that in February of that year the average discharge of all the wells in the basin, in Denver and in the surrounding country, was 2,900,000 gallons every twenty-four hours. The number of flowing wells was at this time at a maximum. Since, the aggregate capacity of the wells has yearly fallen off, but how much can not be determined. Within wide limits the average production during the last six years could perhaps be estimated in the following manner: Accept that 25 per cent of the rainfall enters the earth, the balance being carried away over the surface as visible streams, evaporated, and taken up by vegetation. The yearly rainfall is about 14 inches. Twenty-five per cent of this amount is $1\frac{3}{4}$ feet n six years, which, sinking into a collecting area of 28,512,000 square feet, equals 49,896,000 cubic feet, or 374,220,000 [373,248,026: author] gallons, in two thousand one hundred and ninety days, an average of 170,900 [170,433: author] gallons per twenty-four hours. Adding to the above estimated amount of 49,896,000 cubic feet collected in six years, the 349,272,000 [299,535,667: author] cubic feet of water lowered or drained out of the originally saturated sandstone strata before wells were bored makes 399,168,000 [349,431,667: author] cubic feet in two thousand one hundred and ninety days, or 182,270 [159,557: author] cubic feet per day, equal to 1,367,025 [1,193,569: author] gallons average daily production of wells during the last six years.

Comparing this figure with the estimate of Mr. Slack and considering the falling off in discharge since he made his estimate, it would seem that this daily average of 1,367,025 [1,193,569: author] gallons for the last six years might approximate the truth.

From the foregoing we may conclude with some degree of certainty that the probable average amount of water permanently available from artesian wells in and around Denver does not exceed 180,000 cubic feet daily, which is about $1\frac{7}{10}$ cubic feet per capita of Denver's population in 1890. We may also conclude that if all the wells in Denver were plugged, it would take forty years before the water-bearing strata of the Tertiary in the Denver Basin were again in the condition of saturation existing when the first well was sunk.

THE LIFE OF THE WELLS.

The wells of the city of Denver and its suburbs range in date of sinking from March, 1883, to the present day, although in the past six years operations have been at a minimum. Well statistics gathered in February, 1886, and again in December, 1890, show for the intervening period a gradual but pronounced diminution in yield, appearing first as a decrease in the strength of flow and in the discharge for a particular area, followed by an increased influence of one well upon another and a not infrequent failure to flow at the surface, this gradually extending throughout the entire district; finally, there appears under the heavy overdraft by pumping an actual lowering of the water-table to a considerable depth beneath the surface. It is difficult to formulate a more detailed statement than this regarding the action of the wells, on account of their interrelations, the silting up of the tubes, leakage, and the imperfect methods of packing, casing, and drilling.

The period of 1885–1887 was one of special activity in well-boring, and during this time the effects of over-development, which in later times increased to an actual drain on the total water supply, gradually became evident. Between the years 1888 and 1890 but few of the wells yielded flows at the surface, and these only for a short time. In December, 1890, from the long and heavy overdraft, there were but six flowing wells, and, with these exceptions, the water-levels had sunk to between 15 and 200 feet beneath the surface. The surface of the water-table of 1890 is found to be undulating, approximately with the surface of the ground. The plane is naturally somewhat broken, for the relative positions of the wells and the character and texture of the strata are not without their influence, and in special instances of heavy drain, as at the well of the Union Depot, the water has lowered a considerable distance beyond the general level.

The life of individual wells has varied greatly, ranging from two months to six years and over, though in the latter case the flows have materially diminished in quantity. In regard to the wells sunk most recently, a small number flowed for a few days or weeks, when the water then fell beneath the surface and in time assumed a level, the further lowering of which became evident only after considerable lapse of time.

The following table represents the condition of the wells at the time of investigation in December, 1890:

	In use.		Out of use.		In doubt.	Not in use at time of examination.
	Flowing.	Pumping.	Plugged.	Abandoned.		
Wells bored prior to 1886	2	67	4	49	23	7
Wells bored between 1886 and 1890	4	52	....	1	....	....
Total, 209	6	119	4	50	23	7

The flowing wells are located along the Platte bottoms. Many wells of like location, the collars of which have practically the same altitude, were not flowing, being heavily pumped for manufacturing purposes; had this demand lessened it is probable that the water-level along this portion of the field would have risen considerably and many wells then falling below the surface would have again flowed.

CAUSES OF DECREASE IN FLOWS.

The causes of decrease in flow and of the total failure of so many wells are mainly three: First, poor casing and packing; second, filling or clogging with sand; third, tapping of the same water-bearing stratum by too many wells.

Defective casing and packing.—Instances of defective casing and packing were of frequent occurrence in the earlier wells of the Denver field, the result of inexperience. In casing, the chief fault lay in the selection of unsuitable material, even stovepipe at one time being used in some of the wells.

Of the packing employed in the Denver Basin, the device of the seed bag is the most common, but shot, cement, leather, rubber, and a composition of sand, iron filings, and sal ammoniac have not infrequently been used. The fault in packing lay almost wholly in the improper preparation of the material and in placing it in the bore.

Clogging.—A typical illustration of this is found in one of the Denver and Rio Grande wells, No. 50 of the series. After a steady decrease in flow for six months the well was examined and found to have filled with sand to a height of 50 feet from the bottom. Upon cleaning, the former flow was at once resumed. Instances of this nature have been frequent, and occasionally wells have been permitted to flow continuously for the purpose of obviating this difficulty.

Tapping the same water-bearing stratum.—But two illustrations of the many that might be cited are given. The first involves the Union Depot and Gas House wells, Nos. 26 and 63, respectively. These wells individually discharged to the same altitude, but when the Gas House well was allowed to flow continuously a decrease of 50,000 gallons per day was noticed in the discharge from the well at the Union Depot. Other wells in the vicinity also came under this influence in greater or less degree. The second instance is that of wells Nos. 115 and 116, known as the Eckhart wells, and situated on elevated ground in North Denver. The original pressure of these wells was 35 pounds to the square inch. The Gurley well, No. 120, at a lower level, upon tapping the same water-bearing stratum that supplied the Eckhart wells, so lowered their water-level as to cause their abandonment.

A still further illustration of the interrelations of wells is found in the increase of flow in summer over that in winter in the wells in the vicinity of the Steam Heating Company, the water demanded by this company being considerably less in the warmer than in the colder season.

WELL DATA OF DENVER AND SUBURBS.

The following table (pp. 432–447) embodies a large proportion of the well data of Denver and its suburbs, collected in 1886 and 1890 by Messrs. Slack and Van Diest respectively.

In the "Depth" column the figures give the total depth attained below an arbitrarily adopted datum level—mean water in the Platte River at the foot of Fifteenth street, Denver. To this is appended, with a plus or minus sign, the number of feet above or below the datum level of the surface of the ground at the bore. This second set of figures enables one to make a direct comparison of the horizons of the various flows, and a like comparison of the original, or later "heads," and the present water levels in individual wells.

The lack of uniformity which appears in the data of the three columns "Rate of discharge, head, or pressure" is due to the different manner in which the observations of the owners were made and recorded at the time of the completion of the well. By some there was made a direct measurement in gallons of the amount of water flowing; by others the pressure alone was found by means of a gauge applied after the flow was under control; while by a third portion of the well owners the head, or height to which the water rose in the casing extended, was considered the desideratum. It has been thought best not to attempt a reduction of these different factors to a common basis of measurement, but to present the data as collected from those who made the original observations. In the columns for February, 1886, and December, 1890, the language is of these times.

ARTESIAN WELLS OF DENVER.

No.	Name of well.	Location.	Date of sinking.	Depth.	Casing used.	Depth below surface of flows cut.
1	Anderson	Cor. Colfax ave. and California st.	June, 1883	Orig. 600′, now 730′ +40′.	375′ of 3″ and 600′ of 2″.	154′, 244′, 290′, 300′, 320′, 350′, 375′, and 600′.
2	Carico	Cor. Colfax and S. 12th st.	Completed Nov., 1884.	390′+40′	375′ of 4½″	156′, 230′, and 375′.
3	Collins	Cor. Stout and 12th sts.	Comp. Jan., 1884	380′+31′	100′ of 5″ and 375′ of 4″.	200′ and 375′.
4	Ester	No. 65 S. 12th st.	Comp. Dec., 1885	620′+31′	300′ of 4½″ and 593′ of 2″.	400′ and 600′.
5	Oakes	Cor. Curtis and 12th sts.	Comp. May, 1884	365′+35′	To bed rock 2½″, 329′ of 1¾″ and 36′ of 1½″.	290′ and 365′.
6	Eckhart	Cor. Stout and 15th sts.	Comp. Oct., 1883	397′+45′	4″, nearly to the bottom.	....
7	"The Rink"	16th st., near California.	Jan., 1884	627′+45′	....	....
8	County Court-House	Cor. 16th and Tremont.	Spring of 1884	930′+45′	Drive pipe 10″, 567′ of 7⅝″, 811′ of 5⅝″ and 898′ of 4″.	375′, 600′, and 930′.
9	Kinsey	Cor. California and 18th sts.	.....do	625′+45′	600′ of 4″	280′, 580′, and 615′.
10	Albany Hotel	Cor. 17th and Stout	Feb., 1885	717′+45′	700′ of 6⅝″	....
11	Timerman	Cor. 17th and Champa.	June, 1884	666′+45′	4⅞″ to near the bottom.	375′ and 600′.
12	Cowell	18th, bet. Curtis and Champa.	Aug., 1884	640′+45′	75′ of 8″, 200′ of stove-pipe, and 525′ of 5⅝″.	350′ and 580′.
13	Charles	Cor. Curtis and 15th sts.	Fall of 1883	580′+45′	6″ to first flow and 4″ to second flow.	235′, 364′, and 564′.
14	St. James Hotel	Curtis, bet. 15th and 16th.	Summer of 1884	670′+45′	600′ of 6⅝″, and 5⅝″ nearly to the bottom.	....
15	Tritch	17th, bet. Arapahoe and Curtis sts.	Comp. May, 1884	700′+45′	650′ of 5⅝″	400′, 600′, and 650′.
16	Tabor Opera House	Cor. Curtis and 16th.	1883	390′+44′	190′ of 4″	179′, 220′, 333′, and 375′.
17	Welker	423 Arapahoe st.	Fall of 1884	660′+35′	8″ drive pipe and 643′ of 5⅝″.	355′ and 650′.
18	Daniels & Fisher	Cor. 16th and Lawrence.	Comp. in summer of 1884.	669′+40′	6⅝″ nearly to bottom	....
19	McClelland	Lawrence, bet. 15th and 16th sts.	Aug., 1884	Orig. 607′, now 708′ +40′.	8″ for 40′, 5⅝″ for 560′, and 4½″ for 100′.	....
20	Goode	16th, bet. Larimer and Holliday (Market) sts.	Winter of 1884	680′+33′	50′ of 8″ and 650′ of 5⅝″.	600′ and 680′.
21	Metropolitan	Cor. 16th and Holliday (Market) sts.	Nov., 1883	545′+30′	225′ of 5½″ and 3″ nearly to bottom.	225′ and 545′.
22	Lothrop	Cor. Lawrence and 18th sts.	July, 1883	473′+36′	400′ of 3″	....

[1] Decrease supposed to be due to the sinking of too many wells.

[2] Since 1886 sunk to 730′.

[3] Decrease supposed due to sand and the sinking of other wells.

[4] Diminished from 40′ above surface to 25′ below; cause, too many wells near.

[5] End of pipe perforated and wrapped with copper wire gauze.

[6] Decrease supposed due to poor casing and packing.

[7] Not used since the removal of the rink building and erection of McNamara's; at first came to surface, but soon fell below.

[8] Flow of mineral water at 930′.

[9] At start rose 50′ above surface and so continued for 4 months; it then gradually diminished, and in 1886 stopped flowing. At present even with the surface; two flows used; 900 foot flow small.

[10] Decrease supposed due to faulty construction.

[11] At start rose 30′ above surface; at present 25′ below. On attempt to pump, well was found stopped with mud. Abandoned.

ARTESIAN WELLS OF DENVER.

Depth of flows utilized.	Original rate of discharge, head, or pressure.	Rate of discharge, head, or pressure February, 1886.	Rate of discharge, head, or pressure December, 1890.	Cost.	No.
375′ and 600′.	140,000 galls. per day from 375′; 60,000 from 600′.	375′ flow, 6′ head; 600′ flow, 20′ head.[1]	None since July, 1888; no longer in use.[2]	....	1
375′	Orig. head 5[illegible]′	Head, 8′[3]	Pumping; yield not known.	$600	2
375′	51,000 galls. per day	Decreased slightly	....	1,000	3
400′ and 600′.	Upper flow, head 10′; lower flow, 40,000 galls.	No decrease	Pumping well; yield 1,000 galls. per hour.[4]	1,200	4
365′	24 galls. per minute	do.[5]	Abandoned	410	5
375′	Orig. press., 32 pounds to the square inch.	Ceased flowing[6]	....	990	6
....	Not determined; good flow	Has ceased flowing and is pumped at present.[1]	Well plugged[7]	1,600	7
600′ and 930′	Orig. flow from 600′, 60,000 galls. per day.	2 galls. per minute[8]	Pumping well[9]	....	8
615′	60 galls. per minute	Ceased flowing[10]	Well plugged[11]	....	9
700′	50,000 galls. per day	No decrease	Pumping; yield not known[12]	3,090	10
6[illegible]′	Flow not large	Almost ceased[13]	Not in use[14]	3,000	11
580′	40,000 galls. per day	Largely decreased[15]	Plugged	2,000	12
364′ and 561′.	Orig. press., 80 pounds	Ceased flowing[16]	Now pumping well; stopped flowing Nov., 1887.[17]	2,000	13
670′	45,000 galls. per day	No decrease	Not in use[18]	2,250	14
650′	Orig. head, 25′	Ceased flowing[19]	Abandoned since 188[illegible]	....	15
220′, 333′, and 375′.	Orig. press., 36 pounds	No pressure; well pumped at present.	Pumped[20]	....	16
355′ and 650′.	Orig. head, 50′	Pres. head, 22′; 120,000 galls. per day.	Is pumped	....	17
....	40,000 galls. per day	No decrease	Pumping well[21]	....	18
....	Orig. head, 75′	do	do[22]	....	19
600′ and 680′.	85,000 galls. per day	do	do[23]	2,000	20
225′ and 545′.	Orig. press., 70 pounds	Undetermined, but very much decreased.	Flow stopped in 1886; abandoned; never pumped.	....	21
....	15 galls. per minute	5 galls. per minute	Abandoned[24]	900	22

[12] At start rose 50′ above the surface, stopped flowing in 1887, and not used for 1 year; pump then put in. Water at present 20′ below surface; water very soft.

[13] Trouble supposed due partly to the nature of the 600′ sandstone and partly to poor construction.

[14] Flowed full for 4 months after sinking and then diminished; water now 20′ below surface. Has been pumped.

[15] Decrease supposed due to the sinking of other wells.

[16] Decrease directly due to the sinking of other wells.

[17] At start flowed 20′ above surface; at present 20′ below.

[18] Flowed 18 months; water at present 27′ below surface.

[19] Decrease supposed to be due to a filling up with sand.

[20] Flowed but a very short time; now 12′ below surface.

[21] At start rose 78′ above surface; at present very far below. Uses a 200′ plunger; at one time threw up considerable mud and sand; not clear now.

[22] At start 75′ above surface; now 50′ below.

[23] At start water rose 75′ above surface, but when well at Burlington shops was sunk fell gradually, and at present is 25 below surface. Only lower flow used in 1886.

[24] Water rose 12′ at start, but stopped flowing in summer of 1886. Never used pumps.

ARTESIAN WELLS OF DENVER—Continued.

No.	Name of well.	Location.	Date of sinking.	Depth.	Casing used.	Depth below surface of flows cut.
23	Barkley Block	Cor. 18th and Larimer sts.	Comp. Aug. 4, 1883.	602′+30′	285′ of 5⅝″ and 538′ of 4½″.	
24	Windsor	Cor. 18th and Larimer sts.	Comp. Aug. 30, 1883.	Orig. 530′, now 900′ +30′.	10′ of 10″, 480′ of 5⅝″, 495′ of 4½″.	342′, 515′, and 900′.
25	Stacy	Cor. 21st and Holliday (Market) sts.	Comp. Apr., 1884.	600′+27′	45′ of 5⅝″, 130′ of 4½″, and 460′ of 3″.	250′, 335′, and 585′.
26	Union Depot	Foot of 17th st	Dec., 1883	506′+10′	362′ of 6″ and 506′ of 4″.	365′ and 506′.
27	Mars, Middleton & Hunter.	Wazee, bet. 17th and 18th.	Comp. July, 1884.	520′+10′	1½″ nearly to the bottom.	315′ and 480′.
28	American House	Cor. 16th and Blake sts.	Comp. Aug., 1884.	545′+20′	25′ of 8″, 303′ of 5⅝″, and 491′ of 4½″.	303′ and 491′.
29	Columbus House[7]	Wazee, bet. 15th and 16th.	Jan., 1883	356′+10′	287′ of 1¼″	185′ and 287′.
30	Tremont House	13th, bet. Holliday (Market) and Wazee.	Feb., 18[illegible]	325′+15′	75′ of 3″	
31	Anheuser-Busch	Cor. 10th and Wazee sts.	July, 1883	314′+12′	About 310′ of 5⅝″	130′, 190′, 240′, and 314′.
32	Mullen	Cor. 8th and Wazee sts.	June, 1883	360′+12′	75′ of 5″	
33	Mayer	8th, bet. Holliday (Market) and Wazee sts.	July, 1885	[illegible]+15′	40′ of 6″	
34	D. & R. G. No. 1	Cor. 6th and Wazee	Latter part 1883	350′+13′	260′ of 5⅝″	
35	Wagner	Cor. 9th and Larimer	Comp. Oct. 7, 1884.	330′+15′	37′ of 3½″	80′ and 300′.
36	Lindell Hotel	Cor. 10th and Larimer.	Sept., 188[illegible]	360′+15′	4″ nearly to the bottom.	180′ and 360′.
37	Milwaukee Brewery	Cor. 10th and Larimer sts.	...do	354′+18′	286′ of 4″	
38	Spitzer	Cor. 11th and Larimer.	July, 188[illegible]	333′+15′	10′ of 4″	130′, 210′, and 300′.
39	Western Hotel	12th, near Larimer	Oct., 1884	585′+22′	40′ of 7″ and 550′ of 5″.	340′ and 550′.
40	Knight	Cor. 12th and Larimer.	Comp. Nov. 17, 1883.	340′+22′	Cased with 3″ gas pipe	200′ and 315′.
41	Denver Brewing Co.	Cor. 9th and Lawrence sts.	June, 1883	Orig. 360′, now 600′ +31′.	306′ of 4″	150′, 200′, 306′, and 358′.
42	Lion Brewery	Cor. 8th and Larimer sts.	188[illegible]	294′+25′	278′ of 2½″	
43	Chase	Cor. 11th and Lawrence sts.	Comp. Jan., 1885.	366′+25′	333′ of 1½″	
44	Bomblitz	Cor. 4th st. and Grand ave.	Feb., 1885	315′+25′	40′ of 2½″ and 260′ of 1¼″.	200′ and 315′.

[1] Decrease supposed to be due partly to filling with sand, partly to sinking of other wells.
[2] At start rose above surface; at present about 15′ below.
[3] Being sunk deeper.
[4] At start had pressure of 50 lbs.; at present water 92′ below surface.
[5] Pumped.
[6] At start pressure was 20 lbs.; at present water level is 200′ below surface.
[7] Now the Watkins Building.
[8] Water 15′ below surface.
[9] Decrease supposed to be due to the sinking of other wells in the vicinity.
[10] Much affected by the Mayer well.
[11] Water 15′ below the surface.
[12] Has not flowed since Ice Co. completed their well, except at night for 4 months after Ice Co. started.
[13] Diminished one-third in capacity; cause, too many wells. Rose 7′ above surface to July, 1885; then ceased flowing.
[14] Not flowed since June, 1888; at present 3′ below surface.

ARTESIAN WELLS OF DENVER—Continued.

Depth of flows utilized.	Original rate of discharge, head, or pressure.	Rate of discharge, head, or pressure February, 1886.	Rate of discharge, head, or pressure December, 1890.	Cost.	No.
....	76,320 galls. per day	77,581 galls. per day[1]	Pumping well; pumps 3,000 galls. per hour.[2]	....	23
342', 515', and 900'.	300,000 galls. per day	(3)	Pumping well[8]	$2,200	24
585'	Orig. press., 35 pounds	Not determined; flow still large.	Abandoned	....	25
365' and 506'.	180,000 galls. per day; press., 20 pounds.	100,000 galls. per day.[5]	Pumping well; not in use at present.[6]	....	26
480'	Orig. head, 20'	No decrease	No longer in use	800	27
303' and 491'.	Press., 13 and 25 pounds	....do.[5]	Pumping well	1,800	28
287'	12 galls. a minute	....do	Plugged	....	29
....	Orig. head, 2[illegible]'	....do	Pumping well[8]	300	30
314'	100,000 galls. per day	Flow ceased; pumped at present.[9]	Pumped; capacity not more than one-tenth of original flow.	700	31
....	Not determined	About three-fourths of original.[10]	Pumping well; capacity not known.[11]	700	32
....	Not estimated	Not as large as at first	Pumping well[12]	400	33
....	Orig. head, 38'	Ceased to flow; pumped 20,000 galls. per day.	Pumping well; capacity 50 galls. per minute.[13]	....	34
80' and 300'.	Not estimated	Head, 4'	Pumping well; water not diminished so far as known.[14]	400	35
360'	86,400 galls. per day; head, 15' to 30'.	Head, 6'	Pumping[15]	....	36
....	Orig. head, 27'	No decrease	Pumping well[16]	....	37
130', 210', and 300'.	30 galls. per minute	3 galls. per minute	Abandoned[17]	600	38
550'	150,000 galls. per day	No decrease	Pumping[18]	1,500	39
315'	2,500 galls. per hour	....do.[19]	Abandoned[20]	600	40
306' and 358'.	100,000 galls. per day	Flow ceased; pumped at rate of 27,000 galls. per day.[21]	Pumping well[22]	800	41
....	Head, 40'	1,102 galls. per hour[23]	Pumping well[24]	510	42
366'	Head, 8'	No decrease	Abandoned[25]	400	43
315'	Orig. head, 40'	....do	Not in use[26]	150	44

[15] Diminished from 30' above to 10' below surface.

[16] Flowed through 2-inch pipe 27' above surface when first sunk; diminished to 3' above early in 1889; ceased flowing July, 1889; now 6' below surface.

[17] Never used after flow stopped.

[18] Water at present 18' below surface.

[19] Very much affected by well at Western Hotel until latter was cased.

[20] Has not been used for 3 years.

[21] Decrease due to the sinking of the well at the Lindell Hotel.

[22] Flowed for one year, about 3' above surface; at present 28' below. Uses 200' plunger.

[23] Much affected by Spitzer and Lindell wells.

[24] At present water is 8 feet below surface.

[25] Flowed for one year about 8' above surface; then used pump until April, 1890, when pump could not raise enough for stable.

[26] Well flowed from time of sinking until Jan., 1889; water raised 40' above surface for about 3 years; at present it is 4' below surface.

ARTESIAN WELLS OF DENVER—Continued.

No.	Name of well.	Location.	Date of sinking.	Depth.	Casing used.	Depth below surface of flows cut.
45	Wells at waterworks on Vine street; sunk in 1883; from 568' to 600' deep.			+25'		
46				+25'		
47				+25'	....	....
48				+25'		
49				+25'		
50	D. & R. G. No. 2	At Burnham	1883	800'+58' ..	665' of 5⅜"	....
51	A. E. Pierce	Cor. Lincoln and Ellsworth sts.	Fall of 1884	720'+70' ..	5" to first flow, 520' of 4", and 720' of 3".	520' and 720'.
52	Brown	Cor. Sherman and Ellsworth sts.	Fall of 1883	995'+70' ..	100' of 7", 600' of 6", and 700' of 4".	685' and 850'
53	Fleming	Out beyond Expos. building.	Comp. Mar., 1884 ..	670'+80' ..	64' of 8", 430' of 5⅜", and 655' of 4½".	300', 430', and 650'.
54	Miles	S. 15th, bet. Moose and Deer sts.	Comp. Sept., 1885 ..	61[illegible]+45' .	4½" nearly to the bottom.	....
55	Bonesteel	Cor. Deer and Alta sts.	Comp. June, 1884 .	850'+125' .	750' of 4"; 3" nearly to the bottom.	[illegible], 650', 725', and 850'.
56	[illegible]	Cor. Hallet and Pine sts.	Fall 18[illegible]	[illegible]+120' .	....	....
57	Cemetery	Riverside Cemetery ...	Comp. June, 1885 ..	525'—75' ..	515' of 4½"	....
58	Waverly	Cor. Waverly and 23d sts.	1884	860'+50' ..	579' of 4½" and 730' of 3".	310', 580', and 730'.
59	Cowan	Cor. Stout and 21st sts.	Mar., 188[illegible]	670'+45' ..	570' of 4" and 670' of 3".	308', 590', and 670'.
60	Knox	Cor. Champa and 23d sts.	Comp. Aug., 1884 ..	700'+45' ..	580' of 5⅜"	....
61	Stevens	25th, bet. Curtis and Champa.	Comp. Apr., 1885 ..	750'+40' ..	550' of 5⅜" and 640' of 4¼".	550', 640', and 735'.
62	Home Artesian Well ..	10th ave., bet. Rogers and Gilpin sts.	May, 1885	685'+150' .	8" to bed rock; 670' of 5½".	600' and 685'.
63	Gas Works	Near cor. Wewatta and 19th.	Comp. June, 1884.	Orig. 500', now 610' ±0.	25' of 10", 300' of 6⅝", and 449' of 5⅜".	320' and 495'.
64	Germania House	Cor. 19th and Wanetta	Sept., 1885	341' ±0	40' of [illegible]	....
65	Steam Heating Co	Cor. 19th and New Haven.	Dec., 1883	325' ±0	8" to bed rock and 248' of 6".	....
66	[illegible]	On New Haven st	Dec., 1884	309' ±0	1½" nearly to the bottom.	300' ....
67	[illegible]	Wewatta, bet. 19th and 20th sts.	May, 18[illegible]	Orig. 310', now 535' ±0.	2¼" nearly to the bottom.	190' and 300'.
68	[illegible]	Cottage Lane, near Wewatta.	Comp. Nov., 1885 ..	325' ±0	200' of 2"	....
69	[illegible]	Cor. Stanton and McNassar aves.	Winter, 1883	300' ±0	3" to near the bottom.	....
70	Bareslaux	11½ McNassar ave	Comp. Feb., 1885 ..	304' ±0	38' of 2½" and 265' of 1¼".	150', 200', and 265'.
71	[illegible]	On McNassar ave	18[illegible]	320' ±0	....	300' ....
72	[illegible]	No. 30 Argolt st	Comp. Oct., 1885 ..	300' ±0	150' of 1¼"	245' and 300'.

[1] Abandoned for the last three years; pressure diminished and the water level sank below the surface.

[2] Cost about $1,200 each.

[3] Decrease supposed due to filling with sand.

[4] At start rose about 30' above surface; gradually diminished, and stopped flowing in 1886. Pump put in, but abandoned in 1888.

[5] Seemed to be affected by the sinking of the wells at the waterworks.

[6] Decrease supposed to be due to defective casing.

[7] Flowed 22' above surface at start, but fell off rapidly, and in 18 months was even with surface. Pump set and used until 1888, when, finding it difficult to pump enough, well was abandoned.

[8] Pumped until summer of 1885, when it gave out.

[9] Decrease due to the sinking of other wells and filling of this with sand.

ARTESIAN WELLS OF DENVER—Continued.

Depth of flows utilized.	Original rate of discharge, head, or pressure.	Rate of discharge, head, or pressure February, 1886.	Rate of discharge, head, or pressure December, 1890.	Cost.	No.
....	Flow from first well, 156,000 galls. per day.	Total flow from 5 wells, 200,000 galls. per day.	(1)	(2)	45, 46, 47, 48, 49
....	Orig. head, 30′; good flow..........	Decreased 60 per cent[3]......	Abandoned[4]...............	$1,800	50
720′........	100,000 galls. per day; press., 30 pounds.	No decrease...............	.....do.....................	2,500	51
850′........	Not estimated, but very large......	Ceased flowing; pumped at present[5]	.....do.....................	....	52
430 and 65[illegible]′.	165,575 galls. per day	No decrease	....	2,5[illegible]0	53
600′........	Not estimated; good flow..........	Almost ceased[6]............	Abandoned	1,100	54
850′........	21,600 galls. per day	Ceased flowing[3]............	.....do.[7]....................	3,500	55
....	No flow	(8)	.....do	......	56
515′........	500,000 galls. per day; press., 35 pounds.	No decrease	Stopped flowing	1,000	57
730′........	140,000 galls. per day..............	Not estimated; still large...	Abandoned	4,300	58
590′ and 670′.	147,000 galls. per day..............	75,000 galls.[9]...............	(10)	2,000	59
....	Orig. press., 24 pounds............	Very little decrease........	Abandoned[11]	2,200	60
550′, 640′, and 735′.	80,000 galls. per day..............	No decrease...............	....	2,300	61
685′........	45,000 galls. per day..............	Slightly increased; 50,000 now.	....	2,500	62
320′ and 495′.	300,000 galls. per day..............	150,000 galls. per day[12]......	Pumping well[13]	....	63
....	1,500 galls. per hour..............	Almost ceased flowing......	Abandoned June, 1888[14].....	350	64
....	200,000 galls. per day..............	50,000 galls.[15]...............	Abandoned[16]...............	....	65
300′........	Head, 25′........................	No decrease	....	[illegible]	66
300′........	29 galls. a minute..................	Almost ceased..............	Pumping well[17]	465	67
....	Orig. head, 15′....................	No decrease	.....do.[18]....................	....	68
....	Water rose into second stories.....	Head, 2′ or 3′...............	Abandoned..................	....	69
265′........	24 galls. a minute..................	10 galls. a minute..........	(19)	....	70
300′........	....	Head, 20′	(19)	....	71
300′........	Not determined....................	Decreased ½................	(19)	200	72

[10] Stopped flowing and abandoned in 1886.

[11] Has not flowed since 1886.

[12] Decrease of 50,000 galls. when neighboring wells are being pumped.

[13] At start flowed 20′ above surface; at present 25′ below.

[14] Never pumped. Water at present 12′ below surface.

[15] Very much affected by Union Depot and Gas House wells.

[16] At first rose 20′ above surface, but at present 25′ below. Bored, near by, another well in 1889.

[17] In 1886, upon stopping of flow, well was deepened to 535′ without obtaining additional water. At present, water is 55′ below surface.

[18] When drilled rose 15′ above; at present 8′ below surface.

[19] In the Italian quarters. Could get no information except that no artesian water is used now.

ARTESIAN WELLS OF DENVER—Continued.

No.	Name of well.	Location.	Date of sinking.	Depth.	Casing used.	Depth below surface of flows cut.
73	Electric Light Co	Foot of 22d st	July, 1883	330′+14′	6″ drive pipe and 285′ of 4½″.	
74	Schindelholz	Cor. 26th and Holliday (Market) sts.	Comp. Nov., 1883	416′+23′	300′ of 3″	
75	Belisle	Lawrence, bet. 25th and 26th sts.	July, 1884	420′+30′	Cased 50′	
76	City Laundry	27th, bet. Larimer and Lawrence sts.	Oct., 1884	406′+34′	5″ to bed rock and 300′ of 3½″.	
77	Universal Sampling Works.	Cor. 28th and Blake	Winter, 1883	400′ ± 0	250′ of 5⅝″	375′
78	Swift	28th, near Champa	1883	457′+46′	345′ of 3″	280′, 318′, and 448′.
79	Bennett	Cor. California and 31st sts.	Aug., 1883	450′+41′	95′ of 6″, and 4½″ nearly to the bottom.	
80	30th and Arapahoe sts.	Cor. 30th and Arapahoe.	July, 1884	620′+20′	350″ of 5½″ and 610′ of 4½″.	100′, 375′, 500′, and 610′.
81	Savage	Cor. 35th and Holliday (Market) sts.	Comp. Mar., 1884	400′+5′	50′ of 4″ and 339′ of 2″.	160′, 220′, and 370′
82	Walker	32d st., bet. Lawrence and Arapahoe.	Summer of 1884	587′—5′	90′ of 8″, 250′ stove-pipe, and 525′ of 5⅝″.	250′, 375′, and 580′.
83	Colorado Iron Works.	Cor. 33d and Wynkoop sts.	Dec., 1883	420′—10′	375′ of 4⅝″	
84	Adair	Blake, bet. 35th and 36th sts.	July, 1885	392′—5′	50′ of 5⅝″ and 340′ of 3½″.	250′ and 375′.
85	Nichols	Cor. 36th and Wazee	Comp. Aug., 1883	366′—5′	316′ of 3″	
86	Morrison Bros	Holliday (Market), bet. 36th and 37th sts.	Comp. Feb., 1884	400′—5′	60′ of 6″ and 350′ of 2½″.	180′ and 375′.
87	U. P. Hospital	Near the Grant smelter.	Latter part of 1884	675′—5′	390′ of 5⅝″ and 640′ of 4½″.	400′ and 675′.
88	Grant Smelter	At smelting works	1883	620′—30′	387′ of 7⅝″ and 556′ of 5⅝″.	130′, 180′, 240′, 325′, 575′.
89	McNassor	Near Argo	Sept., 1885	300′—10′	170′ of 1¼″	188′ and 288′.
90	Morrison	do	Feb., 1886; finished 1887.	400′—10′	2½″ for 200′	
91	D. U. and P. R. R.	At shops in North Denver.	Dec., 1885	306′ ± 0′	2″ nearly to the bottom.	300′
92	Smedley	Cor. Clear Creek ave. and Backus st.	Apr., 1884	647′+50′	400′ of 4″	
93	John Mullen	Bell ave., bet. Wanless and Kent sts.	Sept., 1885	300′+25′	100′ of 1¼″	
94	Doyle & White	On 19th, near Central.	do	320′+25′	80′ of 1¼″	
95	Sanderson	Cor. 18th and Boulder sts.	Feb., 1884	579′+30′	2½″ nearly to the bottom.	240′, 375′, and 575′.
96	Green	18th, bet. Central and Boulder.	Jan., 1884	500′+30′	2½″ for 18′	300′ and 500′.

[1] Decrease supposed due to the sinking of the Gas House and Steam Heating Co.'s wells.

[2] Water sank considerably below surface after 1887.

[3] Decrease due to the sinking of other wells and the filling of this with sand.

[4] Stopped flowing at a date not known. Small hand pump put in, but unsatisfactory; well abandoned.

[5] Flowed for 6 months after drilling; then pumps used. In 1885 fine sand came up, but well pumps free now.

[6] Failure supposed due to leaky casing.

[7] Well has not flowed since 1888; water soon sank to 27′ below surface; pump was then put in.

[8] Decrease supposed due to filling with sand.

[9] Water at first rose 140′. Flowed for 2 years 380 galls. per minute. Water now 6′ below surface.

[10] Flow stopped 1885. Never pumped.

[11] Stopped flowing in 1888, and pumps used. At present 20′ below surface. Two upper flows were shut off.

[12] Never pumped.

[13] Decrease supposed due to the sinking of other wells.

[14] Flowed with great pressure at first, which gradually diminished, and ceased in 1883. Fell 12′ when Nichols' well was finished. At present 25′ below surface.

[15] Used two flows; upper one gave out in a year; lower one flowed till 1887. Well was cleared, but water did not come to surface again.

ARTESIAN WELLS OF DENVER—Continued.

Depth of flows utilized.	Original rate of discharge; head, or pressure.	Rate of discharge, head, or pressure February, 1886.	Rate of discharge, head, or pressure December, 1890.	Cost.	No.
	Orig. press., 30 pounds	Press., 10 pounds[1]	Pumping[2]	$700	73
	Orig. head, 40′	Ceased flowing[3]	Abandoned[4]	900	74
	10 galls. a minute	No flow	Pumping[5]	400	75
	Orig. press., 19 pounds	Ceased to flow[6]	do.[7]		76
375′	Not estimated	Head, 4′[8]	do.[9]		77
348′ and 448′.		Ceased flowing[8]	Abandoned[10]		78
	75 galls. a minute	Very little flow; pumped at present.	Pumping[11]		79
610′	130,000 galls. per day	No decrease	Abandoned[12]	2,340	80
370′	Orig. head, 50′	Pres. head 8′[13]	Pumping[14]	600	81
375′ and 580′.	125,000 galls. per day	Diminished	Abandoned[15]	2,000	82
	Orig. press., 35 pounds	Press., 25 pounds	Pumping well[16]		83
375′	50 galls. a minute	35 galls. a minute	do.[17]	[illegible]	84
	Orig. press., 40 pounds	Press., 5 pounds[8]			85
375′	Head, 30′	Head, 3′	Abandoned[18]	1,500	86
400′ and 675′.	Press., 40 lbs	90,000 galls. per day		3,000	87
240′, 325′, and 575′.	Press., upper flows, 35 lbs.; press., lower flow, 45 lbs.	Slight decrease in upper flow—none in lower.[19]	Pumping well[20]		88
288′	Orig. head, 23′	No decrease		150	89
		([21])	Pumping well[22]		90
300′	Orig. head, 25′	No decrease	do	250	91
	150 galls. per minute	Almost ceased[23]	do.[24]		92
	15 galls. per minute	No decrease		200	93
	Orig. head, 20′	Head, 5′	Abandoned[25]		94
575′	Orig. press., 30 lbs	No decrease	Pumping[26]		95
300′ and 500′.	Orig. head, 30′	Ceased flowing[27]	Abandoned[28]		96

[16] Well stopped flowing in Feb., 1890. It was then sunk to a depth of 540′, but no water came to surface; now 8′ below.

[17] Flowed for one year; then hand pumps used. Water at present 6′ below surface.

[18] Stopped flowing in 1886; pumped until 1888, when water sank lower. Now abandoned.

[19] Outer casing perforated, to receive flow.

[20] Use water from two flows, but get very little from the upper. Water is considerably below surface at present.

[21] Being sunk at present.

[22] Flowed originally, but after 5 months ceased, and the water is now 60′ below surface.

[23] Well supposed to be caved.

[24] At start threw up quantities of shale. After flowing one year ceased; water now 76′ below surface. 140 ft. débris in bottom.

[25] Well flowed for 10 months after sinking.

[26] Stopped flowing in 1888. Hand pump set. Water now 25′ below surface.

[27] Decrease supposed due to the sinking of too many wells.

[28] Has not flowed for years. Water rose 30′ when well was first sunk; after a year gradually diminished.

ARTESIAN WELLS OF DENVER—Continued.

No.	Name of well.	Location.	Date of sinking.	Depth.	Casing used.	Depth below surface of flows cut.
97	Hanson	18th, bet. Central and Boulder sts.	Dec., 1885	600′+20		
98	Hecker	Cor. Central and 18th sts.	Feb., 1885	316′+30′	40′ of 2¼″ and 150′ of 1¼″.	190′ and 305′.
99	Poole	Cor. 18th and Central sts.	Nov., 1883	371′+26′	2½″ to bed rock	
100	Granton	Platte, bet. 17th and 18th sts.	Feb., 1884	238′+25′	1¼″ nearly to the bottom.	100′ and 238′.
101	Marquis	Cor. Platte and 17th sts.	do	290′+25′	200 of 1″	100′ and 290′.
102	Scanlon	Platte, bet. 16th and 17th.	Mar., 1884	251′+25′	214′ of 1¼″	100′ and 240′.
103	Oppenlander	16th, bet. Platte and Central.	1883	515′+25′	3½″ to 1st flow and 2½″ to 2nd flow.	300′ and 515′.
104	Frey & Hoelzle	Cor. Platte and 16th sts.	Nov., 1885	312′+25′	185′ of 2″	
105	Spitzer	Cor. Platte and 15th sts.	July, 1883	270′+25′	200′ of 4″	
106	Highland House	Cor. Platte and 15th sts.	Comp. June, 1883	512′+25′		
107	Crisman	15th st., bet. Water and Platte.	Oct., 1883	296′+25′	34′ of 2½″	
108	Shannon	Near cor. Bert and Fay sts.	Fall, 1883	364′+95′	4½ to bed rock	
109	Clark & Killison	Ashland ave., near Bert.	July, 1884	371′+90′	Cased to bed rock	
110	Montague	Near the cor. of Ashland and Gallup.	Fall of 1883	370′+140′	2½″ to bed rock	
111	Ashland School House.	do	Comp. in spring, 1885.	711′+140′	600′ of 1¼″	365′, 550′, and 650′.
112	Meanea	Cor. Platte and 13th sts.	Aug., 1883	185′+45′	2½″ nearly to the bottom.	80′ and 180′.
113	Swenson	10th, bet. Platte and Water.	May, 1884	293′+39′	1¼″ nearly to the bottom.	
114	Norton	8th, bet. Highland and Platte.	June, 1884	509′+80′	475 of 1¼″	
115	Eckhart well No. 1	Highland ave., bet. 4th and 5th.	Spring, 1883	665′+140′		
116	Eckhart well No. 2	do		840′+140′		
117	Quayle	Cor. 6th and Emerald sts.	Comp. spring, 1884	565′+140′	40′ of 4″ and 350′ of 2½″	
118	Zang No. 1	Cor. 7th and Water sts.	Spring, 1883	300′+50′	180′ of 93″	
19	Zang No. 2	do	June, 1883	480′+50′	350′ of 5⅝″	

[1] Stopped flowing Sept., 1888. Hand pumps used since. Water now 12′ below surface.

[2] Has not flowed since 1888. Water originally rose 35′; now 28′ below surface.

[3] Stopped flowing in 1887, and in 1890 abandoned. Water now 15′ below surface. Pumps used for a while.

[4] At start flowed 40′ above surface, but gradually decreased, and stopped flowing Oct., 1890. Pump now used.

[5] Rose 20′ above surface for 5 years; now 8′ below surface. Has not flowed for a year.

[6] At start rose 70′ above surface, but gradually diminished, and stopped flowing Aug., 1890. Now 8′ below surface Pumped at present.

[7] Good flow up to Sept., 1889, when it stopped. At present water 20′ below surface.

[8] Flowed at start 70′ above surface; gradually diminished and stopped in 1888. Water now 12′ below surface.

[9] Water rose when well was completed 40′ above surface, but gradually diminished, and stopped flowing in May, 1890. Water now about 5′ below surface.

[10] Decrease due to sinking wells on lower ground.

[11] Water now 30′ below surface.

[12] Attempt was made to increase flow by using dynamite, but without success.

[13] Never flowed. Water was 8′ below surface when well was completed. At present it is 100′ below surface.

ARTESIAN WELLS OF DENVER—Continued.

Depth of flows utilized.	Original rate of discharge, head, or pressure.	Rate of discharge, head, or pressure February 1886.	Rate of discharge, head, or pressure December, 1890.	Cost.	No.
....	Not estimated	No decrease	....	......	97
190′ and 305′.	Orig. head, 16′....................	Head, 2′.....................	Pumping [1]	$287	98
....	Orig. head, 35′....................	Almost ceased	.....do. [2]	300	99
238′	Orig. pressure, 22½ pounds	No decrease	Pumped [3]	125	100
290′	Orig. head, 40′	.....do	Pumping [4]	175	101
240′	18 galls. per minute..............	.....do	.....do. [5]	200	102
300′ and 515′.	Orig. press., 31 pounds............	Press., 23 lbs..............	.....do. [6]	......	103
....	Orig. head, 25′ to 30′..............	No decrease	....	......	104
....	31½ galls. per minute..............	About one-fifth of original.	Not in use [7]	450	105
....	Head 70′	No decrease	Pumping [8]	[illegible]	106
....	Orig. head, 40′	Head, 25′....................	Pump not in use at present. [9]	......	107
....	60 galls. per minute	Ceased flowing [10]............	Abandoned [11]	500	108
....	No flow at surface	....	Abandoned [12]	375	109
....	....do	Pumped	.....do. [13]	[illegible]	110
....	....	.....do	Not in use	[illegible]	111
180′	Not estimated; good flow..........	Decreased about one-half...	Abandoned [14]	200	112
....	6 galls. per minute	3 galls. in 10 min. [15]	Pumping well [16]	200	113
....	15 galls. per minute	Slightly decreased..........	Abandoned [17]	500	114
....	Orig. press., 35 lbs................	Ceased flowing [18]	Abandoned in 1887 [19]	......	115
....	No flow............................	([20])	Abandoned [21]	......	116
....	Orig. head, 35′....................	Ceased flowing [22]............	Pumping well [23]	[illegible]	117
....	Orig. press., 20 lbs	Ceased flowing [24]............	Abandoned [25]	......	118
....	400,000 gals. per day	Press., 15 lbs................	Pumping well [26]	......	119

[14] At first flowed 25′ above surface, but gradually decreased, and stopped flowing in 1888. Water now 10′ below surface.

[15] Given in city engineer's table as "Meanies & Alley's well."

[16] At start flowed 14′ above surface; at present water is 20′ below.

[17] At first flowed 30′ above surface; after two months fell below. No pump.

[18] Decrease due to the sinking of the Gurley well.

[19] When first drilled had good flow above surface. When casing was put in ceased to flow. No pump used.

[20] Being sunk deeper.

[21] Contract called for 1,000′ depth. After drilling 850′ and finding no water, abandoned.

[22] Being pumped at present.

[23] Water at present 50′ below surface.

[24] Trouble supposed due to imperfect casing and packing.

[25] Abandoned many years ago.

[26] At start pressure of 20 or 25 lbs.; this gradually diminished, but in 1890 decrease was more sudden. At present, 40′ below surface. Brings up some sand.

ARTESIAN WELLS OF DENVER—Continued.

No.	Name of well.	Location.	Date of sinking.	Depth.	Casing used.	Depth below surface of flows cut.
120	Gurley Bros	River front, Highlands.	Fall of 1883	Orig. 523′, now 775′ +[illegible]7′.	[illegible] of 4″ and 3″ nearly to the bottom.	
121	Weeber	Cor. Boulevard and Jasper sts.	Summer of 1884.	214′+100′	3″	
122	Myer	Near St. Luke's Hospital.		660′+75′	3½″ for 100′, 2½″ for 100′, and bal. 1¼″.	
123	Tegeler	Near the cor. of 4th and Chicago aves.	Jan., 1885	270′+50′	265′ of 1¼″	
124	Higgins	Jacob's addition	Comp. Apr., 1884	Orig. 287′, now 525′ +60′.	4″ nearly to bottom	
125	Agerer	No. 78 Golden ave	Comp. Feb., 1885	280′+20′	2½″ to bed rock	170′, 180′, and 280′.
126	Snively	No. 76 Golden ave	Jan., 1885	280′+20′	5⅝″ to bed rock and 34′ of 2½″.	170′, 180′, and 280′.
127	Heidrer	No. 72 Golden ave	Comp. Aug., 1883	280′+20′	6″ to bed rock and 70″ of 3½″.	170′, 180′, and 280′.
128	Villa Park No. 1	Barnum's subdivision	Summer of 1884	+100		
129	Villa Park No. 2	do	Winter of 1884	763′+100′	750′ stovepipe	660′ and 750′.
130	Weir No. 1	Villa Park dist	Fall of 1883	365′+100′	90′ of 4½″ and 350′ of 3″.	
131	Weir No. 2	do	Comp. Feb., 1885	658′+100′	100′ of 8″, 380′ of 4½″, and 650′ of 3″.	
132	County Hospital		Mar., 1884	635′+45′	621′ of 5⅝″	350′ and 630′.
133	Sloan Lake	Eckhart Place		400′+100′		
134	Reeves	Near St. Luke's Hospital.	Summer of 1884	541′+75′	400′ of 5⅝″ and 4″ nearly to the bottom.	
135	Alkire	Cor. Broadway and Ellsworth st.	Early part of 1884.	700′+60′		
136	Standard Bottling Works.	11th st., bet. Larimer and Market.	1883	350′+15′	5″	
137	United Oil Co	Wewatta and 21st sts.	1883	331′±0	4½″	
138	Union Brewing Co	Cor. 16th and Platte	1883	515′+25′	2½″	
139	Hungarian Mills	Wazee and 8th sts	1883	[illegible]75′+12′	5″	
140	United Oil Co	Wewatta and 21st sts.	1883	331′+0	4½″	
141	Sanderson	18th and Builder sts	1885	679′+30′	4½″ for [illegible]	
142	Highland House	Platte and 15th sts	Winter, 1883	516′+25′	2½″	
143	Denver Brick Co. No. 1		1885	325′+35′	3″	
144	Denver Brick Co. No. 2	Valverde	1885	325′+35′	3″	
145	Haverly	Larimer, bet. 10th and 11th sts.	1885	650′+18′	3″	

[1] Decrease due to the sinking of other wells.

[2] Deepened in 1886 to 775′. Stopped flowing when Zang wells were sunk. Abandoned in 1888.

[3] Water never came to surface. Much alkali in it, which rendered it unfit for drinking purposes.

[4] Due to the sinking of a number of wells in lower ground.

[5] Stopped flowing in 1885. Now 72′ below surface.

[6] Decrease supposed due to a rupture in the seed-bag packing.

[7] Rose 32′ above surface at start; then slowly fell and stopped in Sept., 1890. Now 2′ below surface. Fell 6′ when Zang well was used; also known as the Denver Land and Ice Co.'s well.

[8] Had good original flow. Sunk to 525′ in 1887. Stopped flowing in summer of 1889. Windmill now pumps water.

[9] Flowed 30′ above surface at start; stopped May, 1890. At present 16′ below surface. Will rise to surface when Ice Co.'s well is not pumped.

[10] Probably sunk deeper in fall of 1888. Flowed until June, 1890; at present water stands at 15′ below surface. Will rise to surface when Ice Co.'s well shuts down.

[11] Rose 40′ at start, now 12′ below surface. Will rise to surface when Ice Co. shuts down. Occasionally overflows during the night.

[12] Water at present is 30′ below surface.

[13] Decrease due to bad casing.

[14] Stopped flowing when Weir No. 2 was sunk. Water now 50′ below surface.

ARTESIAN WELLS OF DENVER—Continued.

Depth of flows utilized.	Original rate of discharge, head, or pressure.	Rate of discharge, head, or pressure February, 1886.	Rate of discharge, head, or pressure December, 1890.	Cost.	No.
....	Orig. press., 30 lbs	Press., one-fourth of original.[1]	Abandoned[2]	$1,200	120
....	Yield 1,800 galls. per day[3]	No decrease	Abandoned in 1887	500	121
....	Orig. head, 20′	Ceased flowing[4]	Pumping well[5]	....	122
....	Flow not determined	Slightly decreased[6]	....do.[7]	200	123
....	Not estimated	Perceptible decrease[1]	....do.[8]	500	124
170′, 180′, and 280′.	Not determined	No decrease	....do.[9]	375	125
170′, 180′, and 280′.	....do	10 galls. per min	....do.[10]	525	126
170′, 180′, and 280′.	....do	No decrease	....do.[11]	600	127
....	....do	Ceased flowing	....do.[12]	....	128
770′	....do	....do.[13]	....do.[14]	....	129
....	31½ galls. per minute	....do	Abandoned[15]	900	130
....	Press., 55 lbs	No decrease	Pumping well[16]	2,100	131
350′ and 630′.	500 galls. per hour	Less than 31½ galls. per hour[17]	Pumping well[18]	....	132
....	....	No flow	....	....	133
....	Orig. press., 18 lbs	Ceased flowing[19]	Pumping well[20]	1,500	134
700′	Good flow	No decrease	....	....	135
....	Good flow; head 30′	....	([21])	....	136
....	Water never came to surface	Considerable decrease	Abandoned[22]	....	137
....	Fair flow	....	Pumping[23]	....	138
....	....do	....	....do.[24]	....	139
....	Water never came to surface	....	Abandoned[25]	....	140
....	Originally flowed	....	Pumping[26]	....	141
....	Orig. head, 70′	....	....do.[27]	....	142
....	Good flow	....	Still flowing[28]	....	143
....	Flowed	....	([29])	....	144
....	....do	....	Pumped[30]	....	145

[15] Flowed till 1885, when another well was drilled.

[16] Stopped flowing 1888; well cleaned and sunk 8′ deeper, but did not flow again; pumps then set. Water now 12′ below surface.

[17] Pumped at the rate of 500 galls. per day.

[18] Cleaned and deepened (Oct., 1890) to 654′. Water considerably below surface at present.

[19] Pumped at present.

[20] At start flowed slightly above surface. Stopped flowing 6 months after sinking. Now 60′ below surface.

[21] Has not flowed since 1888.

[22] Fell considerably in 1884. At present 28′ below surface.

[23] Well has not flowed since Jan., 1889. Water at present 16′ below surface.

[24] When sunk water flowed above surface; it is now 12′ below. Flow suddenly ceased when Ice Co. well was sunk. Water soft at first; now hard.

[25] At present water 28′ below surface.

[26] Stopped flowing in 1888. Water now 25′ below surface.

[27] Flowed at start 70′ above surface; gradually diminished; stopped flowing in 1888; now 12′ below surface.

[28] Rises 4 feet above surface.

[29] Flows even with surface.

[30] Rose above surface at first, but gradually diminished in 1888 and stopped flowing. Water now 16′ below surface.

ARTESIAN WELLS OF DENVER—Continued.

No.	Name of well.	Location.	Date of sinking.	Depth.	Casing used.	Depth below surface of flows cut.
E.	Evans	14th and Arapahoe sts.	June, 1886	1,140′	765′ of 3½″ and 1,100′ of 2½″.	
401	Cliff	Near Argo Park	Comp. fall of 1885.	300′	2½″ to bed rock	
402	Symes	do	Fall of 1883	300′	3″ to bed rock	
403	Smith	do	Oct., 1885	360′	3″ to bed rock	
404	Segnor	do	do	340′	3″ to bed rock	
405	Lightburn	do	June, 1885	360′	3″ to bed rock	
406	Sanquinette	do	1886			
301	A. J. Konzie	15th and Wynkoop	Jan. 15th, 1890	605′+10′	3½″	
302	Broadway Theater	18th and Lincoln ave.	June, 1890	653′+50′	7⅝″ to 5⅝″	
303	Wall & Purcell	15th, bet. Wazee and Wynkoop sts.	1888	340′+10′		
304	Armusson	Cor. 12th and Wazee sts.	1887	536′+15′	3½″ to 2″	
305	Haller	Cor. 12th and Larimer.	1888	1,100′+20′.	3″ for entire depth	300′ only flow
306	Electric Light Co	6th and Lawrence	Oct., 1889	630′+25′	5⅝″ to 4½″	
307	Denver and South Park Shops.		Mar., 1890	610½′+25′	7″ to 5″	
308	Tramway, Electric Power House.	Grand ave	Apr., 1890	629′+20′	7″ to 3″	
309	Harman	do	1887	350′+20′	3″ to 1¼″	
310	McClelland	do	Mar., 1887	336′+20′		
311	Hanson	do	Apr., 1887	350′+20′	4″	
312	Browne	do	1887	310′+20′	3″ to 1¼″	
313	Artesian Ice Co	do	Feb., 1889	618′+20′	6⅝″ to 3″	
314	Crisman	10th and Water sts.	July, 1889	435′+15′	2½″ for 400′	
315	Excelsior Laundry	Arapahoe and 12th sts.	Apr., 1886	607′+35′	4″ to within 9′ of bottom.	2 flows shut off.
316	West Denver Gas Works.	Foot of 8th st	do	650′+10′	Outside, 8″ for 300′; inside, 6″ to bottom.	
317	Zang Brewery No. 3	7th and Water sts	Aug., 1890	660′+50′	7⅝″ for 400′, 6⅝″ for 100′, and 5⅝″ for 160′.	
318	New Mining Exchange.	Arapahoe and 15th sts.	Oct., 1890	608′+40′	5½″ to 4½″	
319	Denver City Cable Co.	Lawrence and 18th sts.	July, 1890	650′+36′	7⅝″ for 220′, 6⅝″ for 220′, and 5⅝″ for 210′.	
320	Mack Building	Cor. 16th st. and California.	Oct., 1890	621′+45′	5⅝″	
321	Equitable Building	Cor. Stout and 17th	Sept., 1890	610′+45′	6⅝″ for 254′, 5⅝″ for 189′, 4½″ for 167′, and 3″ for 60′.	
322	McPhee Block	Cor. Glenarm and 16th sts.	Mar., 1890	750′+45′	7″ for 250′, 5″ for 250′, and 4″ for 250′.	Shuts off 3 flows.
323	Kittridge Block	do	Fall of 1889	650′+45′	6″	
324	Railroad Building	Larimer and 15th sts.	Fall of 1887	600′+40′	6″	

[1] Use of well stopped on account of bad water in lower part. Casing pulled as far as the 600′ flow, which alone is to be utilized.

[2] Being sunk.

[3] No increase or decrease observed as yet.

[4] Flowed for 9 months from date of sinking. At first 12′ above; now 4′ below surface.

[5] At present water 12′ below surface.

[6] Distance from Western Hotel well only 8′.

[7] Flowed 11′ above surface for 10 days, then sank below.

[8] Never flowed. Water came within 18″ of surface when first sunk; now 14′ below.

[9] Has not diminished. When sunk water rose within 12′ of surface.

[10] Well flowed 20′ above surface through a 3″ pipe when first sunk; diminished to 10′ above surface April, 1890; now 4′ below.

[11] When first sunk water rose 30′ above surface, then gradually diminished to 10′ above. When Ice Co. began using their well, water sank to 6′ below; when Ice Co. shut down in Jan., 1890, well flowed as before for six weeks; then Ice Co. started again and flow ceased.

ARTESIAN WELLS OF DENVER—Continued.

Depth of flows utilized.	Original rate of discharge, head, or pressure.	Rate of discharge, head, or pressure February, 1886.	Rate of discharge, head, or pressure December, 1890.	Cost.	No.
....	Good flow..............................	....	([1])	[illegible]	[illegible]
....	120 galls. per minute	60 galls. per minute.	....	[illegible]	101
....	20 galls. per minute...............	No decrease	....	[illegible]	102
....	30 galls. per minute..............	....do	....	......	[illegible]
....	18 galls. per minute..............	....do	....		104
....	40 galls. per minute..............	....do	....	[illegible]	105
....	....		....		106
....	....	....	Pumping well	....	301
....	75 galls. per minute..............	....	Pumping[3]	....	302
....	Orig. head, 12'..................	....	Pumping well[4]	....	303
....	Raised 35' above surface until 1888.	....	do.[5]	......	[illegible]
[illegible]	....	....	do.[6]	......	[illegible]
....	50 galls. per minute	....	do.[7]	......	[illegible]
....	Never flowed..................	....	do.[8]	......	[illegible]
....	Yield, 700 galls. per hour...........	....	do.[9]	......	[illegible]
....	Orig. head, 20'..................	....	do.[10]	......	[illegible]
....	Orig. head, 30'..................	....	do.[11]	......	[illegible]
....	Orig. head, [illegible]	....	do.[12]	......	311
....	Orig. head, 11'	....	do.[13]	......	[illegible]
....	Flowed at surface	....	do.[14]	......	[illegible]
....	Orig. head, 4'..................	....	do.[15]	......	[illegible]
....	Orig. head, 20'..................	....	do.[16]	......	[illegible]
....	Orig. head, 25'..................	....	do.[17]	......	[illegible]
....	Flows 4' above surface	....	Pumps put in Nov. 22, 1890.[18]	....	317
....	Did not flow	....	Pumps not yet placed	......	[illegible]
....	Never flowed	....	Pumping[19]	......	[illegible]
....	....do	....	Pumps not yet placed[20]	....	320
....	....do	....	Pumping[21]	......	[illegible]
....	....do	....	do.[22]	......	[illegible]
....	....do	....	do.[23]	......	[illegible]
....	Flow	....	do.[24]	......	[illegible]

[12] Same remark as for McClelland well, but stopped flowing 1 month later than that. Water now 7' below surface.

[13] Well flowed 11' above surface until Ice Co. started; then sank to 4' below.

[14] Water came to surface when first sunk; at present 5' below.

[15] Well raised 4' above surface when first sunk; stopped flowing Oct., 1887.

[16] At start flowed 20' above surface; at present, 9' below.

[17] At start flowed 25' above surface; gradually diminished, and at present a 75' plunger is used. Water contains a considerable amount of soda.

[18] Throws up considerable sand. Had quite an effect on Zang well No. 2. (See No. 119.)

[19] At present water 60' below surface.

[20] At present water 45' below surface.

[21] At present water 50' below surface.

[22] At present water 13' below surface.

[23] At present water 20' below surface.

[24] When sunk came even with surface; at present 6" above.

ARTESIAN WELLS OF DENVER—Continued.

No.	Name of well.	Location.	Date of sinking.	Depth.	Casing used.	Depth below surface of flows cut.
325	Denver Tramway Co. No. 1.	Broadway and 15th st.	June, 1888	600′+50′	5⅝″	
326	Denver Tramway Co. No. 2.	Grand ave	Jan., 1890	600′+20′	5⅝″	
327	Stacy No. 2	21st and Market (or Holliday).	1887	600′+27′		
328	Windsor Hotel No. 2	Larimer and 18th	1889	530′+31′		
329	Crescent Mills	Stanton ave. and 19th	Sept., 1889	393′±0	4½″ for 200′	
330	United Oil Co. No. 2	Wewatta and 21st	1887	668′±0	5⅝″ for 150′ and 3½″ for balance.	
331	Steam Heating Co	19th and New Haven	1889	340′±0	8″	
332	Monat No. 1	Blake and 26th	1886	400′+20′	3″	
333	Monat No. 2	do	Nov., 1890	400′+20′	5⅝″ for 320′	
334	Harris	Delegany and 19th sts.	May, 1887	100′±0	4″	
335	Welch	Central and 18th	Oct., 1890	463′+30′	3″ for 100′	
336	Sewell	Kent, near Witter	Sept., 1888	425′+50′	2½″	
337	Trowbridge	Witter and Kent	Aug., 1888	473′+50′	4″	
338	Kountz	Clifton, near Scott st.	1889	900′+30′	2½″	
339	Wightman	Diamond ave., near Bert.	1889	340′+65′	4″	
340	Hurd	Howard, near Morrison.	Spring, 1887	440′+90′	3″ for 45′ and 1½″ for balance.	
341	Peabody	Howard st.	June, 1888	530′+90′	1½″	
342	Denver Brick Co. No. 3.[18]	River front	1886	325′+15′	3″	
343	Denver Brick Co. No. 4.[18]	South of Jacobs addition.	1887	480′+60′	3″	
344	Grant and 6th ave		1889	100′+45′		
345	Villa Park No. 3	Barnum's subdivision.	1888	300′+100′	3″	
346	Fletcher	Garden Place	Nov., 1889	500′—30′	3″ for 38[illegible]′	47[illegible]
347	Boivier	5th, near Central	do	500′—30′	do	
348	Morrison	Near Argo	1887	400′—20′	2½″ for 200′	
349	Anderson	do	Aug., 18[illegible]	[illegible]—2[illegible]′	2″	
350	Norber Ice Co.	do	Oct., 1890	275′—20′	5″ for 100′	
351	Gunter	West of Argo	Sept., 1889	580′+30′	4″	
352	Boston and Colorado Smelting Co.	Argo	1887	800′+30′	5[illegible]″ for 200′	
353	Fisher	Cor. Goss and Prospect aves.	1886	700′+50′	2″	
354	Davis	Goss and Greeley sts.	1889	557′+50′	5⅝″ for 300′ and 4½″ for balance.	
355	Richardson No. 1	(?)	Spring, 1886	540′	3″ for 515′	
356	Richardson No. 2	(?)	do	540′	3″	
357	Globe Smelter	Globeville	1887	505′—35′	5½″ for 425′ and 4½″ for balance.	175′, 425′, and 505′.

[1] Water at present 30′ below surface.
[2] At present 10′ below surface.
[3] Had a good flow at first, about 30′ above surface, but in 1888 fell below. In an attempt to drill deeper, drill broke, tools wedged, and well was given up.
[4] Drilled near the old well, which was abandoned.
[5] Never rose above surface; at present 10′ below.
[6] Flowed at first, but gradually diminished. At present water 30′ below surface. Bored to replace No. 1, which was abandoned.
[7] Never flowed; at present 20′ below surface.
[8] Had considerable flow at first; gradually decreased; stopped flowing in 1888; now 18′ below surface.
[9] Never flowed; now water is 18′ below surface.
[10] Never flowed; at present 12′ below surface.
[11] Never flowed; at present water 20′ below surface.
[12] Water about 60′ below surface—considerable iron in the water.
[13] Water at present about 60′ below surface.
[14] When sunk water came to within 5′ of surface; now about 18′ below.

ARTESIAN WELLS OF DENVER—Continued.

Depth of flows utilized.	Original rate of discharge, head, or pressure.	Rate of discharge, head, or pressure February, 1886.	Rate of discharge, head, or pressure December, 1890.	Cost.	No.
....	Never flowed	....	Pumping	....	325
....	do	....	do.	....	326
....	Orig. head, 30'; good flow	....	Abandoned [3]	....	327
....	....	....	Pumping [4]	....	328
....	Never flowed	....	do.[5]	....	329
....	90 galls. per minute, with 28 lbs. pressure.	....	do.[6]	....	330
....	Never flowed	....	do.[7]	....	331
....	Good flow	....	do.[8]	....	332
....	Never flowed	....	do.[9]	....	333
....	do	....	do.[10]	....	334
....	do	....	Water raised by use of small hand-pump.[11]	....	335
....	do	....	Pumping [12]	....	336
....	do	....	do.[13]	....	337
....	do	....	Pumping with small hand-pump.[14]	....	338
....	do	....	Pumping [15]	....	339
....	Strong flow	....	do.[16]	....	340
....	Flowed until Dec., 1888	....	do.[17]	....	341
....	Flowing	....	Flowing [19]	....	342
....	Flowed until fall, 188[illegible]	....	Pumping [20]	....	343
....	Rose 8' above surface	....	do.[21]	....	344
....	Never flowed	....	do.[22]	....	345
....	945 galls. daily	....	Flowing [23]	....	346
....	472 galls. daily	....	do.[24]	....	347
....	Flowed for 5 months	....	Pumping [25]	....	348
....	Never flowed	....	do.[26]	....	349
....	do	....	do.[27]	....	350
....	do	....	do.[28]	....	351
....	Flowed 4 months	....	do.[29]	....	352
....	Flowed	....	do.[30]	....	353
....	Never flowed	....	do.[31]	....	354
....	Flowed for one year	....	do.[32]	....	355
....	Flowed 2 years	....	do.[33]	....	356
175', 425', and 505'.	Flowing	....	Flowing [34]	....	357

[15] Water came within 60' of surface, where it is at present.

[16] In spring of 1888 water fell below surface; at present 4' below.

[17] Now 24' below surface.

[18] Known as Exley's wells.

[19] Flows about 1' above surface.

[20] Water at present 16' below surface.

[21] Water is very soft and cold. Well is about 75' from Cherry Creek, and there is doubt if it is artesian.

[22] Never rose above surface; at present 30' below.

[23] Water flows in tank about 12' above surface.

[24] Water flows in tank about 12' above surface.

[25] Flowed for 5 months. Water is now 60' below surface.

[26] Never came to surface; water now 90' below.

[27] Never flowed; water now 60' below surface.

[28] Never flowed; water now 60' below surface.

[29] Water below surface at present; contains considerable alkali.

[30] Flowed but a very short time; at present 30' below surface.

[31] Never flowed; now 80' below surface.

[32] At present 30' below surface.

[33] Water at present 20' below surface.

[34] Upper flow gave out in about a year; the two other flows are still in use. Water contains a quantity of sulphate of soda.

OTHER WELL RECORDS.

The following records of a few of the wells in Denver and its suburbs are added to afford an idea of individual features. The wells were carefully canvassed for the last time in December, 1890, since which date the general statement holds that the water supply has still further diminished, and many additional wells have been abandoned.

1.[1] The Anderson well, near the Colfax Avenue bridge, was sunk at first to a depth of 375 feet, in which distance water-bearing seams were cut at 154, 244, 290, 308, and 350 to 375 feet. The well was cased with 3-inch pipe to a depth of 375 feet. The pressure at first was 25 pounds, but this decreased to such an extent that the casing was taken up and the well sunk to a depth of 610 feet to cut the lower flow. After cutting this flow there was for a long time no diminution in the pressure. The original decrease was probably due to bad work in sinking, imperfect casing, and a lack of packing. The well has not been in use since 1888. It is one of the typical wells of the Denver Basin, and the strata passed through are appended below[2] as illustrating the principal features of the Arapahoe formation.

From the surface the bore passed through—

	Feet.
Gravel and surface wash	12
Clay	17
Sandstone	1
Hard clay	94
Hard sandstone	8
Clay slate	22
Sandstone (first flow of water)	14
Hard clay	24
Sandstone	2
Very tough, hard clay	50
Sandstone (second flow of water)	16
Hard clay	30
Sandstone (third flow of water)	10
Blue clay	8
Sandstone (fourth flow of water)	12
Soft clay	15
Dark, hard clay	15
Loose, white sandstone (fifth and greatest flow of water)	25
Total depth of old well	375

[1] The numbers of the full series (pp. 432–447) have here been retained.

[2] Proceedings Colorado Scientific Society, Vol. I, 1883–84, p. 76.

4. The Ester well, at No. 65 S. Twelfth street, was the last of the wells sunk in this part of the city. It was completed on December 16, 1885, at a depth of 620 feet, costing \$2 per foot. Two flows, at 400 and 600 feet, respectively, were encountered and utilized. The 400-foot flow reached the surface through a 4½-inch casing, the 600 through a 2-inch. A 3½-inch leather shoe was used as packing at the end of the latter casing, besides two leather-covered seed bags, one at 15 feet and the other at 150 feet from its end. The original discharge from the lower body of water was estimated at 40,000 gallons per day. No estimate of that from the upper horizon was made, but it was considerably less than the lower; the head was taken at 10 feet. The rate of sinking this well varied greatly. At a depth of 185 feet a 4-foot stratum of very hard stone was encountered, which was penetrated at the rate of a foot a day, the drill making 85 strokes a minute; in the clayey strata the rate was sometimes as high as 60 feet a day. The water as it comes from the well has a slight odor, which disappears after it has stood for a while.

The strata passed through in sinking the well are as follows:

	Feet.
Gravel	20
Clay	2
Gravel	21
Clay (white and blue)	42
Sandstone	5
Clay	52
Sandstone	15
Sandstone	28
Hard rock	4
Sandstone	6
Clay	6
Sandstone	12
Clay	15
Sandstone	4
Clay	32
Clay	12
Sandstone	43
Clay	20
Sandstone (water)	60
Clay	52
Sandstone	20
Clay	15
Sandstone	10
Clay	35
Gravel (coarse and fine) (water)	58

The well in December, 1890, was pumped at the rate of 24,000 gallons per day.

5. The Oakes well, on the corner of Curtis and Twelfth streets, illustrates the method of casing sometimes in use. The well was completed in 1884 and is 365 feet deep. Cost, \$1.12½ per foot. It was cased with a 2-inch iron pipe to bed rock, with 1¼-inch pipe to 329 feet and with 1½-inch pipe for the lower 36 feet. The last was perforated for 30 feet with 30 ¼-inch holes to the foot, and wrapped with a 60-mesh copper-wire gauze. A seed-bag and cement packing were used. The well was abandoned some time after 1886.

6. The Eckhart well, near the corner of Fifteenth and Stout streets, was begun in August, 1883, and was completed in seven weeks. It is 397 feet deep and is cased nearly to the bottom with 4-inch pipe. It was not sunk in the usual way, but was bored by a hand-machine turned with a lever, the cutting arrangement being composed of steel-bits shaped like the bit of a grooving-plane. The well, including the casing, cost at the rate of \$2.50 per foot. The pressure at first was reported at 32 pounds, but it had fallen to 7½ when tested a little later on. This well gradually ceased to flow, until it was found necessary to use a hydraulic ram to force the water into a reservoir in the house. The ram ceased to work about April 1, 1884, after which a pump with an 8 or 10 foot rod was used until about December 1, 1885, when this also ceased to work. The decrease in flow is supposed to be due to careless casing and packing. A 4-pound charge of giant powder was exploded in the bottom of this well, with the effect of slightly but not permanently increasing the flow.

8. The county well, at the court-house, was to have been sunk to a depth of 1,500 feet, but difficulties encountered and the delays caused thereby induced the abandonment of the attempt at 930 feet. Below 650 feet, or after passing into the Laramie, the bore showed alternate layers of sand and clays, the latter greatly in excess. The two important flows of the well are the 600-foot and the 910-foot; they are cased separately. The 600-foot flow was originally 60,000 gallons per day. In 1886 it had diminished to but little over 2,880 gallons, and in December, 1890, the water was pumped. The 900-foot flow is moderate in size and differs essentially in the quality of its water from the upper flows (vide analyses, p. 461). A curious fact was observed in connection with this flow, namely, that despite the small discharge the pressure was 57 pounds per square inch.

11. The Timmerman well, on the corner of Seventeenth and Champa streets, was never a success. The yield was clearly affected by the sinking of the Albany Hotel and Tritch wells, Nos. 10 and 15, about 400 feet to the southeast and 650 feet to the northwest, respectively, and in 1886, when the latter wells were pumped, the flow of the Timmerman well ceased altogether.

13. The Charles well, at the corner of Curtis and Fifteenth streets, was the first to reach the 600-foot flow. Its depth is 580 feet, and it is cased with 4-inch pipe for 564 feet; cost, $2,000. The pressure when the flow was first struck was 80 pounds, which was maintained for a period of about two months. Owing to other wells being sunk in the immediate neighborhood, especially the Daniels and Fischer well in the summer of 1884, and in August of the same year the McClelland well, the flow ceased altogether.

20. The Goode well, on Sixteenth street between Larimer and Holladay, was sunk in the winter of 1884. Large flows were cut at 600 and 680 feet. The 600-foot flow was originally about 25,000 gallons per day, but in February, 1886, was not utilized. The 680-foot flow had originally a head of 50 feet and discharged at the rate of 60,000 gallons per day, but in 1890 the water-level had fallen to 25 feet below the surface. This well is cased to bed rock, a distance of 50 feet with 8-inch and of 650 feet with $5\frac{5}{8}$-inch casing. No packing was used.

23. The Barkley well, on the corner of Eighteenth and Larimer streets, was completed August 4, 1883. It is 602 feet deep and is cased for 285 feet with $5\frac{5}{8}$-inch and for 538 feet with $4\frac{1}{4}$-inch casing. On the day of completion it flowed as follows:

	Gallons.
Upper flow	6,171.5
Lower flow	51,840
Total	58,011.5

Later tests gave the following results:

	Gallons.
March 9, 1884:	
Upper flow	11,520
Lower flow	64,800
Total	76,320
July 15, 1884, total	59,115
March 8, 1885, total	58,075
January 27, 1886:	
Upper flow	Ceased.
Lower flow	17,581

The decrease is supposed to have been due partly to the sinking of other wells in the vicinity and partly to clogging with sand. This well in December, 1890, was pumping 3,000 gallons per hour.

24. The Windsor Hotel well, at the corner of Eighteenth and Larimer streets, was completed August 30, 1883. The depth was originally 530 feet, but in 1886 it was considerably increased. The well was originally cased for 10 feet with a 10-inch drive-pipe, and for 480 feet with 5⅝-inch and 495 feet with 4¼-inch ordinary casing. The size below this was not learned. No packing was used. In the early well two large flows were cut, the first at 342 feet with a head of 25 feet, and the second at 515 feet with a head of 60 feet. Both were utilized. Their original discharge was about 300,000 gallons per day. This, November 10, 1883, had decreased to 182,908 gallons; November 14, 1883, to 180,417 gallons; in March, 1884, to 96,580 gallons; on May 6, 1884, to 54,697 gallons; on June 6, 1884, to 46,180 gallons; on August 5, 1884, to 21,792 gallons; and in February, 1886, to 17,581 gallons. In December, 1890, the well had long been pumped, the water-table then being 92 feet beneath the surface.

The strata passed are given as follows:

	Feet.
To bed rock	14
Soft sand at	53
Indurated clay at	65
Black shale at	138
Indurated clay at	143
Water-bearing sandstone at	181
Blue, indurated clay at	153
Water-bearing sandstone at	235
Blue, indurated clay at	245
Alternate layers of clay and sandstone to	285
Hard, white, water-bearing sandstone at	285
Blue, indurated clay at	300
Mixture of indurated clay and sand at	302
Water-bearing sandstone at	305
Soft, coarse sandstone (first large flow) at	335 to 315
Coarse gravel at	394
Blue, indurated clay at	397
Hard sandstone at	407
Blue clay at	425
Hard sand and heavy flow at	515
Loose sand and sandstone at	530

26. The well at the Union Depot was sunk in December, 1883, to a depth of about 506 feet. It is cased with 6-inch pipe to a depth of 362 feet and with 4-inch pipe to a depth of nearly 506 feet. Two large flows, the first at 365 and the second at 506 feet, have been utilized. The original pressure was 20 pounds; the discharge, 180,000 gallons per day. In February, 1886, the well had become a pumping well, the quantity of water, however, being sufficient for irrigating the grounds, running the fountains, and supplying the depot. In December, 1890, the well was not in use. Originally, when the Gas House well was flowing continuously it decreased the flow of this well about 50,000 gallons.

28. The American House well, corner of Sixteenth and Blake streets, is supplied with a Worthington Duplex pump, which is very successfully in operation.

32. The Mullen well, at the Hungarian Flour Mills, corner of Eighth and Wazee streets, was sunk in June, 1883, to a depth of 360 feet. It is given here in illustration of a feature that is occasionally met with in the Denver area. The original flow of the well was greatly decreased by the subsequent sinking of another well within a few hundred feet, but after a month's time not only its normal rate of discharge was resumed but for a while the flow showed an actual increase. It is difficult to offer a satisfactory explanation of this phenomenon; it was evidently due to local conditions. In 1890 the well had become a pumping well.

37. The well at the Milwaukee Brewery, on the corner of Twelfth and Larimer streets, was sunk in September, 1883. It is 354 feet deep and has a 4-inch casing to the depth of 286 feet. Two seed bags were used as packing. The original head was 27 feet, but the water-level in December, 1890, had fallen to 6 feet below the surface. For three years from its completion, and possibly for even a longer period, the original flow was fully maintained, supplying not only the brewery but an entire block besides. The permanency was attributed, in part, to the fact that the bottom of the hole was considerably enlarged by reaming out, made necessary by the wedging of a drill, and in part to absence of other wells in the immediate vicinity.

38 and 40. Both the Spitzer (38) and Knight (40) wells, at a distance of about 500 and 200 feet, respectively, from the well at the Western Hotel (39), showed great diminution of flows upon the sinking of the latter, that of the Spitzer well ceasing entirely. Upon casing the Western well, however, these wells regained to a considerable extent their former flows, that of the Knight well for a while becoming almost normal. The flows have always shown themselves somewhat irregular. Both these wells were long since abandoned.

45 to 49. The Denver Water Company has sunk five wells near the engine house, at the works. Three are situated in the angles of a triangle, the sides of which are approximately 250 feet each, and were so placed as to test the effect of wells near each other. In No. 1 the first water was struck at 260 feet, which yielded 8 gallons per minute. A second flow was struck at 348 feet, a third at 385, and the last flow at about 555 feet. The total depth of the well is 587 feet. The flow at completion was 108 gallons per minute, and the total pressure 26 pounds. The second well was similar in every respect, and reduced the flow from No. 1 about one-third. Well No. 3 reduced the flow from the other two, so that the total flow from the three wells was but little more than that obtained from the first well alone. Two other wells were sunk to about the same depths as the foregoing at a distance from them of about 1,800 feet. The total flow of the five wells was about 200,000 gallons per day. The casings of all the wells were perforated at every flow and provided with rubber packing.

Another instance of increase of flow after its diminution, by casing a well—the Denver and Rio Grande No. 2 (50)—subsequently sunk in the vicinity, is met with in the Water Works wells. This occurrence has been quite frequent in the Denver Basin.

52. The H. C. Brown well, at the corner of Sherman and Ellsworth streets, was sunk in the fall of 1883. It is 995 feet deep and is cased for 100 feet with 7-inch, for 600 feet with 6-inch, and for 700 feet with 4-inch casing, the last separating flows. Each of these casings was armed with a steel shoe, and was firmly driven into solid rock. No packing was used. The remainder of the well was sunk with a diamond drill, and was not cased. Flows were cut at 685 and 850 feet. The first of these was

originally used, but was cased off upon acquirement of the second. The original discharge of the well was very large, though never accurately determined. It ceased in about six months, and the water was then pumped. In 1890 the well had for some time been abandoned. The sinking of the wells at the Water Works decreased the discharge from this well very perceptibly.

53. The Fleming is one of the southernmost of the city wells, being south of the old exposition grounds. It is one of the most satisfactory wells that have been sunk in the Denver Basin. It was completed in March, 1884, is 670 feet deep, and cost $2,500. It is cased to bed rock, a distance of 64 feet with 8-inch, to a depth of 430 feet with 5⅝-inch, and to a depth of 655 feet with 4½-inch pipe. A small flow was cut at 300 feet, which rose to the top of the casing. The first large flow was cut at 430 feet, and originally discharged at the rate of 7,875 gallons a day, with a pressure of 15 pounds. The second large flow was cut at 650 feet and discharged 157,500 gallons per day, at 70 pounds pressure. Both of these flows were utilized. No decrease or variation in flow had been noticed in 1886, although in 1890 the well had apparently been abandoned.

Steel shoes were used without packing.

60. The Knox well, on the corner of Champa and Twenty-third streets, was completed in August, 1884, and is 700 feet deep; cost, $2,200. A 5⅝-inch casing was sunk to a depth of 580 feet; it was provided with a steel shoe, which was firmly driven into the rock. No packing was used. The original pressure was 24 pounds. A considerable decrease in both flow and pressure was noticed in the summer of 1886 when the water was used for sprinkling lawns and for irrigating purposes. The pressure was then about 10 pounds in the morning and 5 in the evening. When sprinkling ceased, about the 1st of November, the flow resumed its normal rate. In careful experiments seven sprinklers flowing at the same time reduced the pressure at the rate of 1¼ pounds per sprinkler. The well was somewhat affected by the Stevens well until the latter was cased. In 1890 it had been abandoned. This well is illustrative of the effects of heavy drafts for domestic, irrigating, and sprinkling purposes, and may be regarded as a type of many.

62. The Home Artesian well, on Tenth avenue between Rogers and Gilpin streets, was sunk in May, 1885. It is 685 feet deep, and is cased with 8-inch drive-pipe to bed rock and with 5½-inch casing to within 15 feet of the water-bearing sandstone. The original flow was 45,000 gallons per day; the pressure, sufficient to throw water 30 feet. This well originally supplied three blocks and was paid for by ninety shareholders, the total cost being $2,500. In 1890 data concerning it could not be obtained, but it had probably been abandoned.

63. The well at the Gas Works, near the corner of Wewatta and Nineteenth streets, was completed in June, 1884. It is 500 feet deep, and is cased for 25 feet with 10-inch, for 300 feet with 6⅝-inch, and for 449 feet with 5⅝-inch pipe. Two flows have been utilized, the first at 320 and the second at 495 feet, originally yielding, together, about 300,000 gallons per day. This had decreased to 150,000 in February, 1886, and in December, 1890, the water was pumped. A decrease of about 50,000 gallons was noticed when the Steam Heating Company's well and the well at the Union Depot were being pumped.

65. The Steam Heating Company's well, at the corner of Nineteenth and New Haven streets, was sunk in the latter part of 1883 to a depth of 325 feet. It is cased with an 8-inch drive-pipe to bed rock and with 6-inch pipe to a depth of 248 feet. A seed-bag packing was used at 245 feet in a very hard rock. The original discharge was estimated at 200,000 gallons per day. This had decreased about three-fourths in February, 1886, and in December, 1890, the well for some time had been abandoned. The well was much affected by the sinking of the Union Depot and Gas House wells. The water has a temperature of 52° F. The using of this water in conjunction with that of ordinary wells for boiler purposes illustrates the wasteful uses to which the artesian supply of the city of Denver was often put.

Intimately related to this well are wells 63, 67, and 73, respectively the wells of the Gas Works, Mr. Tiernan, and the Electric Light Company. The flows and pressures of each of these wells have been notably stronger in summer than in winter, due, it is believed, to the diminished requirements of the Steam Heating Company in summer.

73. The Electric Light Company's well, at the foot of Twenty-second street, was sunk in July, 1883, to a depth of 330 feet. It has a 6-inch drive-pipe to bed rock and a $4\frac{1}{2}$-inch casing to a depth of 285 feet. The original pressure of 30 pounds had decreased to 10 in February, 1886, and in December, 1890, the water was pumped. The early decrease was caused directly by the sinking of the wells at the Gas and Steam Heating Works in the winter of 1883. The discharge has generally been greater in the summer than in the winter. This well supplied the boilers at the works. Unusual care was taken in making tight joints in casing, and in putting this in place, and the well has been one of the most reliable in the city.

81. The Savage well, on the corner of Thirty-fifth and Holladay streets, was completed in March, 1884. It is 400 feet deep, cased to a depth of 50 feet with 4-inch and to 339 feet with 2-inch pipe. A cement packing was used. Flows were cut at 160, 220, and 370 feet. The first rose just to the top of the casing, the second had a head of 33 feet, the three together one of 50 feet. In February, 1886, this had decreased to 8 feet; the flow stopped in 1888, and in December, 1890, the water, 25 feet below the surface, was pumped. The 370-foot flow was that utilized. A sharp decrease of 12 feet took place when the Adair, or Nichols, well (No. 84 or 85) was sunk.

87. The well at the Union Pacific Hospital, near the Grant Smelter, was sunk in the latter part of 1884 to a depth of 400 feet. A flow of 5,000 gallons per day was secured at this depth, but this not being sufficient the well was further sunk to a total depth of 675 feet, where a heavy flow was cut that showed a pressure of 40 pounds. Three hundred and ninety-five feet of $5\frac{5}{8}$-inch and 640 feet of $4\frac{1}{2}$-inch casing were used without packing. This was considered one of the best wells in the city. In 1886 the flows were estimated at about 90,000 gallons per day, and the well was still in use in December, 1890.

88. The well at the Grant Smelting Works has always been one of the most satisfactory of the city wells. It was sunk in 1883 to a depth of 620 feet, and cased with $7\frac{5}{8}$-inch pipe for 387 feet and with $5\frac{5}{8}$-inch pipe for 556 feet. Three flows, at 240, 325, and 575 feet, were formerly utilized. The $5\frac{5}{8}$-inch pipe brought to the surface the water from the main flow, which

was cut at 575 feet. The $7\frac{5}{8}$-inch pipe brought up the water from the first large flow, at 325 feet, and from two small flows above, which it received through perforations. The original pressure from the main flow was 45 pounds, and from the combined upper flows 35 pounds. The main flow was in 1886 discharging at its original rate, while the upper flows had fallen off somewhat. The discharge in 1886 was estimated to be over 500,000 gallons per day. In December, 1890, the well was pumped. According to information obtained at the smelter the temperature of the water from the two flows is the same, 65° F.

98. The Hecker well, near the corner of Central and Eighteenth streets, is another illustration of the effect of casing a new well upon the flows of neighboring wells which the former had temporarily diminished.

101. The Marquis well, at the corner of Platte and Seventeenth streets, was sunk in February, 1884, to a depth of 290 feet. The work was accomplished by hand, a spring pole being used, and cost but $175. It is cased to a depth of 200 feet with 1-inch pipe and has a seed-bag packing. The original pressure was 7 pounds. No decrease had been noticed in February, 1886, but in October, 1890, the flow stopped, and in December, 1890, the water was pumped.

A daily variation in the flow was noticed during its life, the discharge being greatest at night and in the early morning. A slight increase was also noticed during the months of June and July.

108. The Shannon well, near the corner of Bert and Fay streets, about 95 feet above the Platte level, was sunk in the fall of 1883. It is 364 feet deep and is cased to bed rock with $4\frac{1}{2}$-inch casing. The original flow was 60 gallons per minute. This began to decrease soon after the well was completed, and in two months had ceased entirely. The well was then cleaned out, but did not again flow. This is supposed to be due to the sinking of a number of wells in the low ground near the Platte.

109 and 110. These wells are near 108 and have never been flowing wells, their collars being respectively 90 and 140 feet above the level of the Platte, and above those of numerous wells that had been already drilled.

115 and 116. The two Eckhart wells, on Highland avenue between Fourth and Fifth streets, were sunk respectively to the depths of 665 and

840 feet. The 665-foot well was sunk in the spring of 1883. A good flow was secured, with a pressure of about 35 pounds. The Gurley well, afterward sunk in the same vicinity and at a lower level, so affected it that it ceased to flow, and no water has been obtained from it since. The 840-foot well had cut no large flows, and, after some further work upon it, was abandoned.

118 and 119. The wells of the Zang Brewery are located near the corner of Seventh and Water streets. The first was sunk in the spring of 1883 to a depth of 300 feet. The pressure upon completion of the well was 20 pounds to the square inch, but the work had been poorly done, there was no casing employed, and the flow soon began to decrease. A 3-inch pipe was then put down nearly to the 300-foot flow. This was perforated at 180 feet, the depth at which a small flow had been cut. Rubber packing was used. The discharge, however, continued decreasing, until finally it ceased altogether.

The second well was sunk in May and June of 1883. It has a depth of 480 feet, and was cased for 350 feet with 5⅝-inch casing. It was estimated that the original discharge was about 400,000 gallons in twenty-four hours, the pressure being 25 pounds. In December, 1890, the well was pumped. The flow at 300 feet was not utilized. The water from this well has a temperature of 57° F.

128 and 129. These are located in Villa Park. The first was sunk in the summer of 1884. It ceased to flow the next spring and has since been pumped.

The second was sunk in the winter of 1884 to a depth of 763 feet. It was cased to a depth of 750 feet with stovepipe ranging in diameter from 9 inches at the top to 5⅝ at the bottom. A good flow was cut at 750 feet, the discharge from which gradually decreased until it ceased entirely. This is without doubt due to the poor casing used, as the water leaking through the casing has found its way to the surface on the hillside below, causing innumerable springs.

135. The Alkire well, near the corner of Broadway and Ellsworth street, was sunk in the early part of 1884. A good flow was cut at a depth of 700 feet. In 1886 the well was supplying a number of private houses,

and no decrease had then been noticed. In 1890 data were unobtainable, but the flow had doubtless ceased. The strata passed through are said to be as follows:

	Feet.
Gravel	96
Clay	4
Light and dark colored shale	308
Sandstone (small flow of water)	20
Shale	172
Sandstone (good flow of water)	30
Clay and shale	50
Sandstone (large flow of water)	20
Total	700

The Evans well, at the residence of ex-Governor Evans, Fourteenth and Arapahoe streets, was sunk in 1886 to a depth of 1,140 feet; cost, $3,000, exclusive of casing. It is cased to a depth of 765 feet with 3½-inch and to a depth of 1,100 feet with 2½-inch casing. The strata passed through are given as follows:

	Feet.
Gravel	25
Blue shale	339
Iron pyrites	2
White sand containing some water	370
Blue shale	110
White sand, water	10
Shale	50
White sand	90
Blue-black shale	40
White sand, water	20
Shale, mineral "blow in" at base	185
White sand	20
Brown shale	103
Black quartz, under which some unpalatable water	15
Grayish fire-clay	40
Streaks of coal	47
Clay	40
Total	1,110

At 1,100 feet a little oil came out with the coal. On account of bad water in the lower measures boring was stopped and the casing pulled to the 600-foot flow.

CHEMICAL ANALYSES OF SOME OF THE ARTESIAN WATERS OF THE DENVER WELLS.[1]

The following analyses are of artesian waters from three wells in Denver, viz: The Anderson well; Windsor well, upper flow; Windsor well, lower flow; Court-House well, lower flow.

Samples of the three were first collected by a member of the committee and forwarded to Golden. The care with which the Court-House water was collected can not be vouched for, but it is assured that every care was taken to send a correct sample in a clean vessel. Its analysis is included in this report, as the difference between this and the first three waters named is great, not only in the amount of solid residue, but in the presence of chlorine in noticeable quantity. Attention is also called to the fact that in this water only was lime found in excess over sulphuric acid. The remarkable similarity between the first three waters is seen at a glance.

In tabulating the results the probable "rational" analysis, both in grains per gallon (United States gallon of 231 cubic inches, or 58,320 grains) and in parts in 100,000, is given first. Below are added the actual results, by separate constituents. Carbonic acid is not included, as it was impossible, after much delay, to secure any suitable apparatus for gas determinations in Denver The analyses are, then, simply records of amounts of solid residues, and the analyses of those residues.

Nearly every determination was made in duplicate; several in triplicate. Qualitative tests for the higher metals as well as for sulphuretted hydrogen, iodine, and bromine failed to give the faintest reactions. Upon concentration, faint acidulation, and treatment with sulphuretted hydrogen an almost imperceptible tint was developed, but it was not identified as metallic, nor could any characteristic reaction be obtained, and it is assumed to have been merely caused by separated sulphur mixed with the small but inevitable amount of inorganic dust which settles in every atmosphere.

The soda was determined as follows: A portion of the water being evaporated to dryness in platinum, the residue was taken up with sulphuric

[1] These analyses were made by Prof. Regis Chauvenet, of the Colorado School of Mines, assisted by Mr. Charles A. Gehrmann, an advanced student at the school. The analyses were for a paper upon the Artesian Wells of the Denver Basin, published in June, 1884, by the Colorado Scientific Society as the results of an investigation made by a committee from the society. The brief statement of Professor Chauvenet accompanying the analyses is added, practically without change.

acid and again evaporated. The residue was dissolved in water, filtered from separated silica, and precipitated with barium acetate. The filtrate containing all the bases as acetates was evaporated to dryness in platinum and ignited strongly. All the bases now remain as carbonates, and it remains only to boil with water to extract the sodium carbonate and filter from the insoluble carbonates of barium, calcium, and magnesium.

This final filtrate, acidulated with hydrochloric acid, is treated in the usual way.

Actual results, by separate constituents.

ANDERSON WELL.

	Grains per gallon.	Parts in 100,000.
Solid residue	10.41	17.85
Calcium sulphate	0.87	1.49
Sodium carbonate	8.22	14.09
Sodium sulphate	.44	.75
Magnesium chloride	.10	.17
Ferrous carbonate	.03	.05
Silica	.69	1.18
	10.35	17.73
Lime (CaO)	.36	.62
Magnesia (MgO)	.04	.07
Soda (Na_2O)	5.00	8.57
Ferrous oxide (FeO)	.02	.03
Sulphuric oxide (SO_3)	.76	1.30
Silica (SiO_2)	.69	1.18
Chlorine (Cl)	.07	.12

WINDSOR WELL.

UPPER FLOW.		
Solid residue	10.03	17.20
Calcium sulphate	0.85	1.46
Sodium carbonate	7.93	13.60
Sodium sulphate	.44	.75
Magnesium chloride	.10	.17
Ferrous carbonate	.03	.05
Silica	.61	1.05
	9.96	17.08
Lime (CaO)	.35	.60
Magnesia (MgO)	.04	.07
Soda (Na_2O)	4.83	8.28
Ferrous oxide (FeO)	.02	.03
Sulphuric oxide (SO_3)	.76	1.30
Silica (SiO_2)	.61	1.05
Chlorine (Cl)	.07	.12

Actual results, by separate constituents—Continued.

WINDSOR WELL—Continued.

	Grains per gallon.	Parts in 100,000.
LOWER FLOW.		
Solid residue	10.76	18.45
Calcium sulphate	0.92	1.58
Sodium carbonate	8.48	14.54
Sodium sulphate	.44	.75
Magnesium chloride	.07	.12
Ferrous carbonate	.03	.05
Silica	.76	1.30
	10.70	18.34
Lime (CaO)	.38	.65
Magnesia (MgO)	.03	.05
Soda (Na_2O)	5.15	8.83
Ferrous oxide (FeO)	.02	.03
Sulphuric oxide (SO_3)	.79	1.35
Silica (SiO_2)	.76	1.30
Chlorine (Cl)	.05	.08

COURT-HOUSE WELL.

Solid residue	33.01	56.60
Calcium sulphate	0.36	0.62
Calcium carbonate	1.64	2.81
Sodium carbonate	15.83	27.14
Sodium chloride	14.04	24.07
Magnesium carbonate	.32	.55
Ferrous carbonate	.06	.10
Silica	.63	1.08
	32.88	56.37
Lime (CaO)	1.07	1.84
Magnesia (MgO)	.15	.26
Soda (Na_2O)	16.71	28.65
Ferrous oxide (FeO)	.04	.07
Sulphuric oxide (SO_3)	.21	.36
Silica (SiO_2)	.63	1.08
Chlorine (Cl)	8.52	14.61

WELLS IN THE COUNTRY.

The artesian wells in the country concerning which statistics have been gathered number 185, but this figure is probably somewhat below the actual total at the present day. With one or two exceptions they are within the limits of the area mapped, and for the most part are distributed along the Platte River within a mile or two of its channel. They have been drilled with the object of supplying farms, for domestic purposes, or gardens and orchards with water for irrigation. They are so widely scattered that they are uninfluenced by one another, and, moreover, there has thus far appeared no decrease in their yield that can be directly attributed to the drain upon the general supply by the wells of the city of Denver.

Doubtless the bulk of the water is derived from the Arapahoe formation, and this most often from the zone in its upper half. A well at Littleton is the only one that certainly draws its supply from the basal portion of the Denver formation, but two or three are doubtful, in their depths approaching the line of the Denver and Arapahoe. Several in the northern part of the field draw their supply from accidental water-bearing strata in the upper, clayey member of the Laramie. One only has reached the basal member of this formation—the Eureka well, in the forks of the Platte River and Plum Creek, sunk for oil (unsuccessfully) in the fall of 1890. The Pierce well, on the Denver and Rio Grande Railroad, 21 miles south of Denver, very probably takes its water from the Monument Creek formation.

The number of artesian wells in the country may at any time be increased, although, if located too far from the center of the basin—practically coincident with the Platte channel—the altitude may be such that the water will not flow at the surface.

With the exception of the Eureka well, of which the flow is reported very large and which taps the basal sandstones of the Laramie, the water-bearing strata of this formation supply but a small percentage of the artesian flows of the country. The Arapahoe, on the other hand, quite invariably affords a generous supply, as does also the Denver in the single well drawing upon it. The strata of the Denver formation are, however, liable to more rapid and more frequent changes in their composition and texture than those below, and it is quite probable that in many of the wells passing below this formation the flow encountered at Littleton was either absent or too small for practical purposes.

The total capacity of the country wells, estimated from somewhat imperfect data, was, in 1886, 1,150,000 gallons per day. This has since been greatly increased by additional wells.

The life of the country wells will doubtless be long, a population far greater than the present being required to produce an appreciable effect upon the flows.

The character of the water is practically the same as that of the water from the same horizons in Denver and its suburbs.

CHAPTER VII.

PALEONTOLOGY.

SECTION I.—THE FOSSIL PLANTS OF THE DENVER BASIN.

BY F. H. KNOWLTON.

HISTORICAL SUMMARY OF WORK ON THE FOSSIL PLANTS OF THE DENVER BASIN.

So far as I have been able to learn, the first collection of fossil plants from the Denver Basin was made by Dr. John L. LeConte in the year 1867, while attached as geologist to the survey for the extension of the Union Pacific Railway from Smoky Hill River, Kansas, to the Rio Grande.[1] He made a somewhat hasty trip from Trinidad to Denver for the purpose of investigating the coal mines in the vicinity of Denver. In the beds of clay just below the coal at Marshall's, on South Boulder Creek, he found a large number of impressions of leaves. These were submitted to Prof. Leo Lesquereux, but they were so fragmentary that he was only able to make generic determinations.

In March, 1868, Dr. F. V. Hayden published an article on the lignite deposits of the West,[2] in which he quoted a letter from Professor Lesquereux containing descriptions of 10 species of plants from Marshall's mine and of 2 species from the lignite beds near Golden. The name of the collector of these plants, of which no fewer than 8 out of the 12 species were regarded as new, was not given, but in Lesquereux's Tertiary Flora they are accredited to Dr. Hayden. It is probable that they were collected by him in the fall of 1867.

[1] Notes on the Geology of the Survey for the Extension of the Union Pacific Railway, E. D., from the Smoky Hill River, Kansas, to the Rio Grande, Phila., Feb., 1868, pp. 47–53.

[2] Am. Jour. Sci., 2d series, Vol. XLV, 1868, pp. 198–208.

This letter of Professor Lesquereux's was reproduced without change by Dr. Hayden in his Third Annual Report of the United States Geological Survey of the Territories, 1869.[1]

The next considerable collection of plants appears to have been made by Professor Lesquereux himself in July and August, 1872. From this collection he was enabled to enumerate 40 species (of which 15 were new) from Golden, 4 from Marshall's, and 7 from the Erie mines, in the Boulder Valley.[2]

In 1873 Dr. A. C. Peale appears to have first detected the presence of Dakota group plants in the Rocky Mountain region, having found obscure impressions on the south side of the South Platte River. It was not until some years later, however, that they were obtained in abundance within the area under consideration.

In 1874 Lesquereux added[3] about 10 species to the Golden flora, thus bringing the number up to over 50 species.

A complete list of all the plants of the Cretaceous and Tertiary of North America known at the time was given by Professor Lesquereux in Hayden's Annual Report for 1876.[4] This list was undoubtedly compiled from the Tertiary Flora, which also appeared in 1878, the year of the publication of this Annual Report.

The Tertiary Flora[5] was a very comprehensive work, and contains descriptions and figures of nearly all the plants belonging to what was at that time regarded as Tertiary. The volume contains plants that are now known to belong to the Laramie, Denver, Fort Union, Green River groups, and Miocene. About 88 species were accredited to Golden and a number of others to near-by localities.

The last large collection of Golden plants made before the one forming the basis of this chapter was obtained by Rev. Arthur Lakes for the Museum of Comparative Zoölogy at Cambridge, Mass. This collection was elaborated by Professor Lesquereaux.[6] It contained 873 specimens,

[1] Third Ann. Rept. U. S. Geol. Surv. Terr., 1869, pp. 196, 197, reprint of 1873.
[2] Sixth Ann. Rept. U. S. Geol. Surv. Terr., 1872 (1873), pp. 375–381.
[3] Eighth Ann. Rept. U. S. Geol. and Geog. Surv. Terr., 1874 (1876), pp. 308–315.
[4] Op. cit , 1873 (1878), pp. 487–520.
[5] Rept. U. S. Geol. Surv. Terr., Vol. VII, 1878.
[6] Bull. Mus. Comp. Zoöl. Harvard Coll., Vol. XVI, pp. 43–59.

having 1,044 more or less complete fragments of plants. There were 118 species, of which number 28 were regarded as new to science and 32 as new to the Laramie flora so called.

The collection upon which, in large part, the present chapter is based was also made by Rev. Arthur Lakes for and under the direction of Mr. S. F. Emmons. It is without doubt the largest collection ever made of the Golden plants.

Besides the collections above enumerated, smaller ones have been made by Prof. Lester F. Ward[1] for the United States Geological Survey, by Rev. A. Lakes for Princeton College, New Jersey; by Mr. George Haddon for Mr. R. D. Lacoe at Coal Creek, and by Mr. R. C. Hills, or his assistants, for Columbia College, New York. These have all been placed at my disposal and made use of in this connection.

To return to the Dakota group plants. These were found in abundance by Lieut. H. C. Beckwith, U. S. N., and Rev. A. Lakes, at Morrison, Colo. The exact date at which they were collected does not appear, but they were first described by Professor Lesquereux in 1883.[2] The entire collection is now in the United States National Museum, having been donated after the death of Lieutenant Beckwith.

LIST OF LOCALITIES IN THE DENVER BASIN AT WHICH FOSSIL PLANTS HAVE BEEN OBTAINED.

Golden, Colo.:

- Quarry No. 1; south face of South Table Mountain, 100 feet below lava cap.
- Quarry No. 2; south face of South Table Mountain, 500 yards east of quarry No. 1, and same horizon.
- Southeast corner of South Table Mountain; the lowest leaf bed on Table Mountain, being 60 feet below usual horizon and 160 feet below lava cap.
- North face of South Table Mountain, in canyon below the Tables.
- Quarry No. 3; bluff of prairie one-fourth of a mile south of Reform School and 500 or 1,000 yards southwest of South Table Mountain. Horizon about 100 feet lower than quarries Nos. 1 and 2.
- Green Mountain; northwestern base.
- Green Mountain; northwestern base; the upper seam or "Fern Ledge," about 20 feet above the lower one.

[1] Cf. Types of the Laramie Flora, 1886.

[2] Rept. U. S. Geol. Surv. Terr., Vol. VIII, Pt. III, The Cretaceous and Tertiary Floras, pp. 25-103, 1883.

Golden, Colo.—Continued.

Hoyt's coal mine, 1 mile south of Golden.

Murphy coal bank, Ralston Creek, north of Golden.

Boulder County:

Coal mines near Erie, Boulder County.

Coal mines on Coal Creek.

Marshall's coal mine.

Morrison, Colo.:

Mount Carbon; sandstone near coal seam. [Laramie.]

White sandstone. [Dakota.]

Denver, Colo.:

Sand Creek, near Denver.

Sedalia, Colo.:

Quarry No. 1; 1,900 feet east of the Douglas coal mine.

Quarry No. 2; 3,000 feet east of the Douglas coal mine.

Douglas coal mine, and 150 feet east of main coal seam.

HORIZONS INDICATED BY FOSSIL FLORA.

The fossil plants of the Denver Basin belong to three well-defined and clearly differentiated horizons, viz, the Dakota group, Laramie, and the more recently distinguished Denver beds. These horizons will be discussed in ascending order, beginning, consequently, with the Dakota.

DAKOTA GROUP.

With the exception of two species, found, according to Lesquereux, in the vicinity of Golden, only one locality within the area has afforded plants of this horizon—the hard, white sandstone at Morrison. The plants are not especially well preserved. The carbonaceous matter having almost entirely disappeared, the leaves and stems remain as outlines that are often faint and difficult to make out. It appears that only the best of this material had been seen by Lesquereux previous to the publication of the Cretaceous and Tertiary Floras, but he enumerated about 20 species, many of which were new to science. After the donation of the material to the National Museum, as above stated, it was all submitted to him with the result of adding a number of species to the flora of this place. The total number of species known from Morrison is 28. They are all enumerated in the following table (p. 470), which also shows their distribution, if any, outside of this area.

Dakota group.

Species.	Morrison, Colo.	Near Denver, Colo.	Nebraska.	Iowa.	Minnesota.	Kansas.	Amboy Clay.	Laramie.	Remarks.
Torreya oblanceolata Lx									
Sequoia Reichenbachi Heer	×							×	All Cret.
[illegible]									
Abietites dubius? Lx									
Bambusinum sp									
Salix proteæfolia Lx									
Ficus Beckwithii Lx									
magnoliæfolia Lx									
Quercus Morrisoniana Lx									
Laurus Nebrascensis Lx									
proteæfolia Lx									
[illegible]									
primigenia? Ung	×						×	×	Wide dist.
Aralia formosa Heer									
[illegible]									
Proteoides daphnogenoides Heer									
Liriophyllum populoides Lx									
Beckwithii Lx									
obcordatum Lx									
Carpites liriophylli Lx									
Magnolia speciosa Heer	×					×			Ala.
Capellini Heer									
[illegible]									
Lomatia Saportanea longifolia Lx									
Sterculia aperta Lx									
[illegible]									
Inga Cottæ? Ett									Eocene.
Sapindus Morrisoni Lx									
Leguminosites cultriformis Lx									

This little table brings out clearly a number of interesting things. It appears that 12 of the 29 species found in Colorado are confined to these two localities; that is, have never been found outside of the Denver Basin. This proportion of endemic species is very large and suggests the probability of finding much new material when the beds can be thoroughly exploited.

Of the 17 species having a more or less wide distribution, 9 are found also in Kansas, 7 in the Amboy clays of New Jersey, and 5 in Nebraska, with one or two each in Iowa, Minnesota, and the Laramie of various places. Up to the present time very little has been done toward the differentiation of horizons in the Dakota group. A few of the species are known to be common to two or more localities, but the larger part are confined to only one. This table brings out more clearly than ever before the fact that the Dakota of the Denver Basin is quite intimately connected with the Dakota of Kansas, Nebraska, etc., but much more work will be necessary before conclusive results can be obtained.

It is interesting to note the presence or absence of certain types in this flora. Thus, it has no less than 4 conifers, 2 species of Ficus, 2 of Aralia, 4 of Laurus, 3 of Magnolia, and species of that anomalous genus, Liriophyllum. Of those notable by their absence, the following genera may be mentioned: Platanus, Populus, Liriodendron, Betula, Viburnum, Protophyllum, etc.

LARAMIE AND DENVER.

At the time the earlier collections were made and when Professor Lesquereux's work was done, the differentiation between the Laramie and Denver had not been made, and inasmuch as both horizons are often plant-bearing at the same localities, it became necessary to go over all the material accessible and separate it according to this later knowledge. This work was first done for the collection belonging to the United States National Museum, and later for the material that is the property of Columbia College, New York, and Princeton College, New Jersey, with the result of throwing important light on these two floras.[1] Many corrections have been made as regards locality and a number of changes and eliminations worked out. This has been much assisted by the large recent collections.

It would be desirable to present in this connection a complete list of the species thus far detected within the area under consideration, as has been done for the Dakota plants, with a table showing their distribution within the Denver Basin as well as outside, but it has been thought inadvisable at present; many of the species are new to science and have not yet been published, and to refer to them here, without description or illustration, would be to make them nomina nuda, and otherwise complicate the synonymy. Consequently the present discussion is largely numerical, for

[1] The collection from Golden in the Museum of Comparative Zoölogy could not be completely utilized, as the catalogue had unfortunately been lost. It has since been found, but too late to be used in this connection. All of the species mentioned by Lesquereux in his report on this collection (Proc. Mus. Comp. Zoöl., Vol. XVI, No. 2) have been taken without revision, but it is more than probable that changes will be necessary when it is thoroughly examined in the light of all recent information regarding this flora.

the purpose of showing the bearing of the plants on the question of age and the differentiation of the horizons, the complete presentation being reserved for the forthcoming monograph on the Flora of the Laramie and Allied Formations.[1]

As nearly as can be made out from the scattered data available at the present time, the flora of the Laramie and Denver formations within the Denver Basin consists of 240 species. These are distributed as follows: Undoubted Laramie,[2] 98 species; undoubted Denver,[3] 150 species; Sand Creek, near Denver, 10 species; and Sedalia, 20 species. Of these 240 species 83 are confined to the Laramie, 130 to the Denver, and 3 to the other two localities. These exact figures may have to be slightly changed when the final revision is made, but that can not possibly change the essential point—namely, that these two formations are strikingly distinct, at least within the Denver Basin.

It should not be forgotten, however, that some of the species that are confined to either the Laramie or Denver within this area are found outside of it enjoying a more or less marked vertical range—that is, they are not all restricted to the Laramie or the Denver or its equivalent. It would be of interest to trace out these resemblances, but the data are not in shape to admit of this being done with satisfaction, and it also is deferred to the monograph.

Turning now to the consideration of the peculiarities of these two floras, a number of interesting facts are made out. The Laramie was especially rich in figs, about 15 species having been described. Ferns, oaks, and buckthorns (Rhamnus) were abundant. There was a single fine species of bread-fruit tree (*Artocarpus Lessiyiana* (Lx.) Kn.) and at least two palms. The conifers were rare in both formations.

The Denver flora is much richer, both in species and types. The figs continued in increased abundance, and some were of large size. The genus Plantanus was abundant both in species and individuals, as was the genus Populus.

[1] In preparation.

[2] The localities are Erie mines, Marshall mine, Coal Creek, Hoyt's coal mine near Golden, Mount Carbon near Morrison, and Murphy's coal bank, on Ralston Creek.

[3] Golden, andesite deposits, Table Mountain, Green Mountain, Denver.

The ferns numbered fully 20 species, some, as *Asplenium erosum* (Lx.), being of large size. The most abundant form is probably *Aspidium Lakesii* (Lx.), which is represented in every collection and often by hundreds of examples. There are also a curious new Hymenophyllum and a very characteristic species of Adiantum, both in fruit.

Conifers, as already stated, were very rare, almost the only one being a well-marked species of Ginkgo, known from the fruits.

The Lauraceæ is represented by numerous species of Laurus, Litsea, Cinnamomum, Persea, Daphnogene, etc. There are also representatives of the Cornaceæ, Caprifoliaceæ, Araliaceæ, Sterculiaceæ, Sapindaceæ, Aceraceæ, Juglandaceæ, Rosaceæ, Leguminosæ, Rhamnaceæ, Magnoliaceæ, Tiliaceæ, Anonaceæ, Cupuliferæ, Vitaceæ, Ebenaceæ, etc., showing that the flora was a rich and varied one.

SECTION II.—VERTEBRATE FOSSILS.

By Othniel Charles Marsh.

INTRODUCTION.

In the region of Denver are several well-marked geological horizons, which have been named from the characteristic vertebrate fossils they contain. Some of these are known far to the north, and have also been traced to the south along the eastern slope of the Rocky Mountains, marked in nearly every exposure by the remains of extinct animals that were entombed when the strata were deposited. One horizon in the immediate vicinity of Denver is classic ground to paleontologists, as here were first found the remains of the most gigantic reptiles ever discovered, living or extinct. Some of these horizons, again, are represented in the Denver region only by limited outcrops of characteristic deposits, while others are known by fragmentary fossils alone, derived from strata apparently not exposed there on the surface, but well developed in adjacent regions, where they have been carefully investigated.

The object of the present chapter is to indicate, first, the relative position of these various horizons taken as a series and their characteristic faunas; second, as still more instructive in the present connection, to give accurate figures of important type specimens of the animals that lived during these various periods, so that the strata containing their remains may be thus identified; and, in conclusion, to state briefly something of the life history of these extinct animals, and under what conditions they lived and died.

To make this succession of strata clear to the reader, the geological section represented in fig. 23 has been prepared by the writer. It is a general section designed to illustrate the vertebrate life of the Mesozoic and

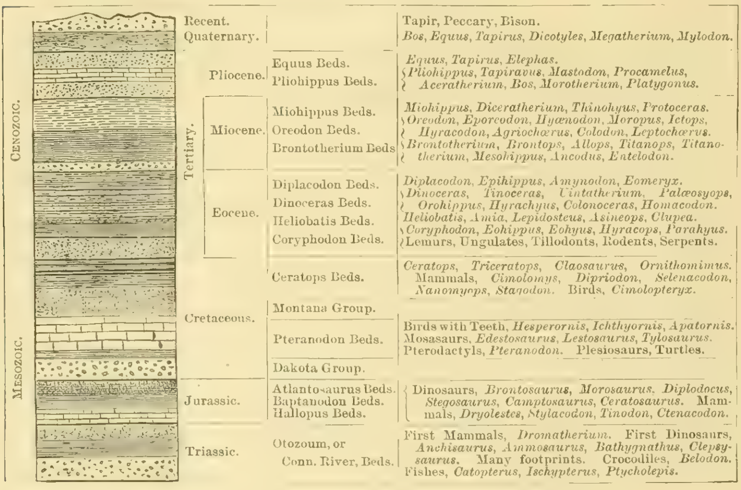


Fig. 23.—Section to illustrate horizons of vertebrate fossils.

Cenozoic, as developed in the Rocky Mountain region, and includes everything above the Paleozoic, although all the subdivisions are not indicated. In addition to showing the principal horizons from the Triassic to Recent deposits, it gives under each formation the genera of the most characteristic vertebrate fossils found in each.

PART I.

GEOLOGICAL HORIZONS.

The base of the Mesozoic in the Denver Basin appears to be represented by certain red sandstones, which rest directly against the Archean. No characteristic vertebrate fossils have yet been found in these strata, and they have usually been classed with the overlying Jurassic beds, under the general name of Juratrias. Farther to the south in New Mexico, and especially to the southwest in Arizona, this series of sandstones or their equivalents in position contain vertebrate fossils, and among these the writer has recognized both dinosaurian and crocodilian remains of Triassic types. Future exploration in the Denver region and in the same horizon farther south may bring to light characteristic fossils and determine more accurately the age of these interesting deposits.

JURASSIC.

HALLOPUS BEDS.

Immediately over the sandstones above mentioned is a large series of strata which are undoubtedly Jurassic in their upper portion, and perhaps throughout. Near the base of this series in the Canyon region are the Hallopus beds, as indicated in the section in fig. 23. These beds are of special importance biologically, owing to the fact that they contain remains of the smallest, and in many other respects the most interesting, dinosaurian reptiles yet discovered in any part of the world. The beds are of very limited extent, so far as now known. They have not yet been detected in the Denver Basin.

BAPTANODON BEDS.

The Baptanodon beds placed next in the section have also not been recognized near Denver, nor along the same horizon to the south, but are strongly developed in Utah and Wyoming on the flanks of the Uinta and Wasatch mountains, on the Laramie Plains, in the Big Horn and Wind River ranges, and at various other points farther north. They consist of marine strata, inclosing many typical invertebrate fossils in addition to the large reptile, Baptanodon, from which the horizon takes its name. As these beds occur just below the Atlantosaurus series near the Black Hills and at other points in the north, it is possible that they may be represented in the same position in the Denver region. A typical exposure of the Baptanodon beds may be seen near Lake Como, Wyoming, where the writer, in 1868, first recognized this horizon and determined its Jurassic age.

ATLANTOSAURUS BEDS.

The most important geological horizon in the Denver region is the Atlantosaurus beds, which are here extensively developed. They may be seen to good advantage in passing from Golden to Morrison, where they will be found as a series of shales and sandstones resting below either upon the red sandstone already mentioned or the succeeding strata, and covered above by the characteristic white Dakota sandstone, which in many places has protected them from erosion. These Atlantosaurus beds are of fresh-water origin, and their softer portions have suffered great denudation, thus leaving extensive valleys. This horizon is one of the most distinct and important yet found in this country, and it has now been traced, mainly by the bones of the gigantic reptiles it contains, for about 500 miles along the eastern flank of the Rocky Mountains. In the vicinity of Denver these deposits are gray or ash colored, while both to the north and south, and especially west of the mountains, they are usually variegated in color, red and yellow tints predominating. To the south of Denver the Atlantosaurus beds may be seen at various points for a hundred miles and more—at the Garden of the Gods, also near Canyon, and still farther south, at Webster Park, beyond the Arkansas River. The main Oil Creek locality, about 14 miles north of Canyon, known locally as the "Bone Yard," has long been famous, as here and in the surrounding region were found some of the most remarkable fossils of this horizon. These remains, and others from near Morrison, in the Denver Basin, will be discussed more fully later in the present chapter.

CRETACEOUS.

PTERANODON BEDS.

In the Dakota sandstone of Cretaceous age, next above the Atlantosaurus beds, only a few fragments of vertebrate remains have yet been discovered, and these beyond the limits of the Denver Basin; hence they need not be further mentioned here. The next higher horizon of special importance, which the writer has named the Pteranodon beds, from the gigantic pterodactyls found in them, is very rich in vertebrate fossils, and among these remains of marine swimming reptiles are most abundant. Here, too, were found the well-known birds with teeth. In the Denver Basin vertebrate fossils from this horizon have not been seen in place, although isolated specimens have been found. In the foothills to the north interesting discoveries have been made, one locality being on Lodge Pole Creek, Wyoming. On the plains farther east the Pteranodon beds have a great development, especially in Kansas along the Solomon, Saline, and Smoky Hill rivers, where the variegated chalk bluffs are rich in vertebrate fossils. To the south they may be seen at various points nearer the mountains, particularly in the vicinity of Pueblo and Canyon. The Pteranodon beds are in part the equivalent of No. 3, Meek and Hayden. The next horizon given in the section, fig. 23, is that of the Montana group, which is well represented in the Denver Basin, but its vertebrate fossils do not call for special mention here. Farther north in Wyoming the Fox Hills section of this group lies directly beneath the Ceratops beds, the horizon next to be considered.

CERATOPS BEDS.

The Ceratops beds placed next in the section are of special importance, from the remarkable fossils they contain and their great development in the north. They form one of the most distinct vertebrate horizons in this country. In the number and variety of their vertebrate fossils they are surpassed only by the Atlantosaurus beds, and as both horizons are so well developed in the Denver Basin special attention will be given in this chapter to the animals entombed in each of them. The exact relation of the Ceratops beds to the adjoining deposits in the vicinity of Denver will not here be discussed, but it is worthy of notice that, to the north, beds containing the same fauna have a remarkable extension, mainly as lacustrine shales and sandstones.

The most characteristic development of the Ceratops beds known to the writer from personal observation is in the northeastern part of Converse County, Wyoming, in the region represented in the accompanying map, fig. 24. The great importance of the discoveries made here, both from a biological point of view and as accurately defining the geological horizon of the Ceratops beds, made it desirable to fix definitely the position of every important specimen found, and these were carefully noted at the time each discovery was made. As the skulls of the gigantic Ceratopsidæ are most characteristic, the precise localities of 30 of these skulls are given in this map, so that the horizon and its age may thus be verified by future explorers.

FIG. 24.—Map of Converse County, Wyo., showing localities where skulls of Ceratopsidæ have been discovered. The position of each skull is indicated by a cross, and more than 30 of these specimens were found within the area bounded by the Cheyenne River and the dotted line. The localities given are based upon field notes made, at the request of the writer, by his assistant, Mr. J. B. Hatcher.

Still farther north, in the Judith Basin, in Montana, the same lacustrine strata alternate with beds in which brackish-water invertebrates and marine reptiles are found associated with the gigantic Ceratopsidæ. Along this Ceratops horizon for hundreds of miles the experienced collector can find vertebrate fossils at almost every exposure.

Fragments of vertebrate remains, evidently of this same characteristic fauna, have been found by the writer in the well-known rock columns of Monument Park, south of Denver, and careful search there would doubtless bring to light well-preserved specimens. Farther to the south, and also west of the mountains in the Wyoming Basin, typical fossils of this horizon have been observed in place at various points.

The horizon thus marked by the Ceratops fauna is indicated by a series of outcrops at various points along the eastern flank of the Rocky Mountains from Canada to New Mexico. From these exposures fossils of this fauna have already been obtained at 15 different localities, although systematic explorations have been made at only a few of the outcrops along the line thus indicated.

TERTIARY.

The Eocene formation, which has such a great development west of the Rocky Mountains and is so rich in mammalian life, is apparently not represented in the Denver Basin, nor indeed along the eastern side of the mountains to the north. It is, however, well developed to the south in Huerfano Park, and southwest, in New Mexico.

BRONTOTHERIUM BEDS.

The next higher horizon of the Tertiary, the Miocene, and the succeeding Pliocene have an extensive development along the eastern flank of the Rocky Mountains, and especially in the plains region. The series of Lower Miocene fresh-water clays and sandstones which the writer has called the Brontotherium beds form a well-marked horizon. They have been recognized at various points from southeast of Denver, in Elbert County, far to the north through Nebraska and Dakota, and have recently been found in Canada. On the plains not far from Denver they have been found, with their characteristic fossils, in depressions or pockets in the underlying Ceratops beds, and this is the case, also, at various points in the north, especially in Colorado and Wyoming, where the Brontotherium beds have suffered great denudation. Farther east, in both Nebraska and Dakota, these beds are overlain by other Miocene deposits of great thickness, known as the Oreodon beds. Both series are well developed in northeastern Colorado, at Chalk Bluffs and various other localities, and here interesting discoveries of vertebrate fossils have been made.

Southeast of Denver, the Brontotherium beds appear to be covered by later Tertiary deposits, which may include equivalents of the Oreodon series, although these have not been observed in place much south of the South Platte River. The greater part of these overlying strata are of Pliocene age.

PLIOHIPPUS BEDS.

The most important horizon in the Pliocene is that of the Pliohippus beds, which have a great extension both north and south of Denver, often remaining as table-lands far out on the plains, or as isolated buttes where they have not been entirely removed by erosion. The great Arkansas divide, especially south of the Smoky Hill River, is mainly composed of these strata, as ascertained by the writer in 1870 and 1871, by personal exploration at various points in eastern Colorado and western Kansas. Northeast of Denver these beds form high bluffs above the Miocene, and in Nebraska and Dakota this is their usual position. Pliocene vertebrate fossils have been found in the vicinity of Denver and are quite abundant at various points in the adjacent regions. The Quaternary and Recent deposits above the Pliocene also contain interesting vertebrate remains, which need not be discussed here.

These various horizons, marked by characteristic vertebrate fossils, have been determined and named by the writer mainly upon evidence secured during his own explorations in the Rocky Mountain region, beginning in 1868. In many of the strata examined no other characteristic fossils except vertebrates were to be found, and this fact should give the present determinations additional value.

PART II.

JURASSIC VERTEBRATE FOSSILS.

After this brief review of the series of geological horizons, Mesozoic and Cenozoic, represented in the region of Denver, and their chief characteristics, it remains to discuss the vertebrate life successively entombed as the various strata were deposited. The extinct animals thus preserved are of great interest in themselves, as they give conclusive evidence of many phases of ancient life as it developed from age to age in the progress of the world. They thus afford interesting data as to the higher forms of life in ages still more remote, and, more important yet, indicate the lines of descent which have continued on to the present.

During Mesozoic time the vertebrate life consisted mainly of fishes, amphibians, and reptiles, although birds and mammals were also represented. Of all these the reptiles were the dominant forms, and the title "Reptilian Age" appropriately defines the whole period. In this class the dinosaurs form in many respects the most important group, and the representatives that left their remains in the neighborhood of Denver are not surpassed in interest by those found in any other part of the world.

To make clear the descriptions that follow, it may be well to state here that dinosaurs are now divided into several distinct orders: The Theropoda, or carnivorous, bipedal forms; the Sauropoda, including huge herbivorous, quadrupedal forms; and the Predentata, consisting of herbivorous reptiles of several very different suborders, among them the Stegosauria, or plated lizards, the Ceratopsia, or horned forms, and the Ornithopoda, or bird-footed reptiles, which in many respects resemble birds. A full account of these remarkable reptiles will be found in an illustrated memoir by the writer, entitled "The Dinosaurs of North America," and published in Part I of the Sixteenth Annual Report of the United States Geological Survey. With these various dinosaurs lived other reptiles, especially crocodiles and turtles, and numerous fishes. A few birds and some diminutive mammals likewise then existed in the same region.

REPTILIA.

HALLOPUS.

Near the base of the Jurassic strata not far from Canyon, in the horizon already defined as the Hallopus beds, remains of a small carnivorous dinosaur have been found, which are worthy of special description. This diminutive reptile, which has been named by the writer *Hallopus victor*, was but little larger than a domestic fowl, although of much more slender proportions. The greater part of the skeleton is preserved, and this shows that the bones were bird-like and hollow, possibly pneumatic, and in their anatomical features of great interest. In figs. 25 and 26 below, restorations of the fore and hind legs, one-half natural size, are given, which show well the delicate proportions of the animal.

The scapula is of moderate length, and its upper portion broad and thin. The humerus is slender, with a strong radial crest. The shaft is very hollow, with thin walls, and the cavity extends almost to the distal

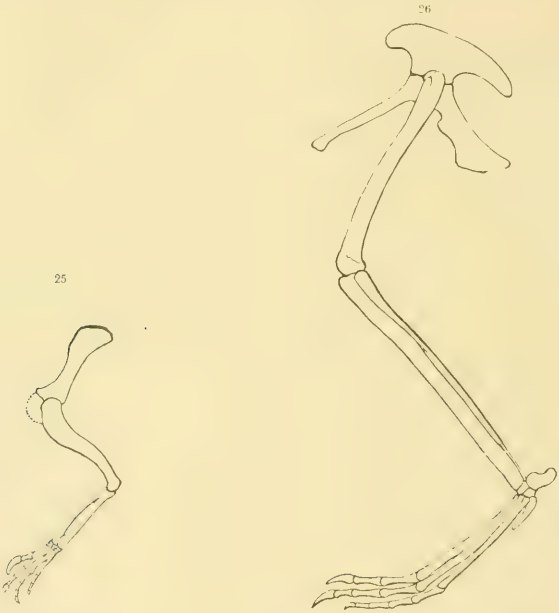


FIG. 25.—Outline restoration of left fore leg of *Hallopus victor* Marsh.
FIG. 26.—Outline restoration of left hind leg of same individual.
Both figures are one-half natural size.

end. The latter is but little expanded transversely. The radius and ulna are short, and were closely applied to each other. There were but four digits in the manus, the first being short and stout and the others slender.

All three pelvic bones aided in forming the acetabulum, as in typical dinosaurs. The ilia are of the carnivorous type, and resemble in form those of Megalosaurus. The pubes are rod-like, and projected downward and forward. The distal ends are closely applied to each other, but not materially expanded, and in the present specimen are not coossified with each other. The ischia projected downward and backward, and their distal extremities are expanded, somewhat as in the Crocodilia.

The femur is comparatively short, with the shaft curved and very hollow. The tibia is nearly straight, much longer than the femur, and its shaft equally hollow. The fibula was slender and complete, but tapered much from above downward. Its position below was not in front of the tibia, as in all known dinosaurs, but its lower extremity was outside, and apparently somewhat behind, the tibia.

The astragalus is large, and covered the entire end of the tibia, but was not coossified with it. The calcaneum is compressed transversely, and much produced backward. It was closely applied to the outside of the astragalus, and although agreeing in general form with that of a crocodile, strongly resembles the corresponding bone in some mammals. The tarsal joint was below the astragalus and calcaneum. There appears to be but a single bone in the second tarsal row, although this may be composed of two or more elements.

There were but three functional digits in the hind foot, and their metatarsals are greatly elongated. The first digit seems to be wanting, and the fifth is represented only by a remnant of the metatarsal. The posterior limbs, as a whole, were especially adapted for leaping, and are more slender than in almost any other known reptile.

There are but two vertebræ in the sacrum. The other vertebræ preserved have their articular faces biconcave. The chevrons are slender and very elongate.

This interesting reptile was found near Canyon, in the horizon that now bears its generic name. No other specimen is known.

NANOSAURUS.

In the same geological horizon in which the type of *Hallopus* was found, but at a different locality in the same vicinity, the skeleton of another dinosaur was discovered, still more diminutive, and indeed the smallest known member of the group. The remains are well preserved, and indicate clearly that this reptile was herbivorous in habit, avian in form, and in many respects the most bird-like dinosaur yet discovered. It was described by the writer in 1877, under the name *Nanosaurus agilis.* The type specimen consists of the greater portion of the skull and skeleton of one individual, with the bones more or less displaced, and all entombed in a slab of very hard quartzite. The whole skeleton was probably thus preserved in place, but, before its discovery, a part of the slab had been split off and lost. The remaining portion shows on the split surface many important parts of the skeleton, so that the main characters of the animal can be determined with considerable certainty.

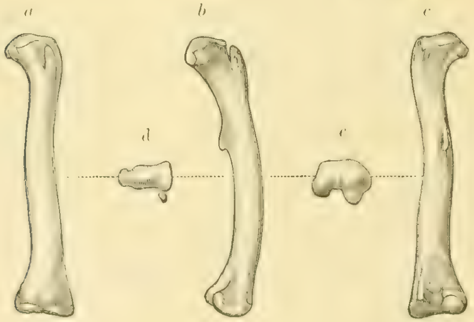


FIG. 27.—Dentary bone of *Nanosaurus agilis* Marsh; seen from the left.
FIG. 28.—Ilium of same individual; left side. Both figures are natural size.
FIG. 29.—Left femur of *Nanosaurus rex* Marsh. One-half natural size.
a, front view; *b*, side view; *c*, back view; *d*, proximal end; *e*, distal end.

A study of these remains shows that the reptile they represent was one of the typical Ornithopoda, and one of the most avian yet discovered. A dentary bone in fair preservation, shown in fig. 27, indicates that the animal was herbivorous, and the single row of pointed and compressed teeth, thirteen in number and small in size, forms a more regular and uniform series than in any other member of the group. The ilium, also, shown in fig. 28, is characteristic of the Ornithopoda, having a slender, pointed process in front, but one much shorter than in any of the larger forms. The posterior end is also of moderate size. All the bones of the limbs and feet are extremely hollow, strongly resembling in this respect those of birds. The femur was shorter than the tibia. The metatarsals are greatly elongated and very slender, and there were probably but three functional toes in the hind foot. The remains now known indicate that the animal when alive was about half the size of a domestic fowl.

A second form referred by the writer to this genus, under the name of *Nanosaurus rex*, may, perhaps, belong to the genus Laosaurus. The femur is shown in fig. 29. The animal thus represented was considerably larger than the present type species, and was found in a somewhat higher horizon in the same region.

BAPTANODON.

In the horizon marked in the section as the Baptanodon beds the most important known vertebrate is the large swimming reptile that has given the name to these deposits, and figures of its characteristic remains are given below as an aid in identifying the strata. This reptile, Baptanodon, was most nearly allied to Ichthyosaurus, but was without teeth, and the paddles had six digits, as shown in fig. 30 (p. 486). The vertebræ, one of which is represented in fig. 31, are very similar to those of Ichthyosaurus. Another interesting marine reptile from this horizon appears to be a true Plesiosaur, with teeth, and has been described by the writer as *Pantosaurus striatus*. A vertebra of the type specimen is shown in fig. 32. A small crocodile, *Diplosaurus nanus*, which the writer found in 1870 in the same beds, was the first vertebrate discovered in this horizon.

ATLANTOSAURUS.

In the succeeding Atlantosaurus beds a new and remarkable reptilian fauna makes its appearance, and the gigantic Sauropoda are the prevailing forms. In the Hallopus horizon the dinosaurs were, as already stated, the most diminutive known, but in the present beds the representatives of this group are the most gigantic land animals yet brought to light. The first genus discovered, which has been named Atlantosaurus by the writer, includes several species, all of huge dimensions. The first discovery was made in 1877, by Capt. H. C. Beckwith, U. S. N., and Prof. Arthur Lakes, and the sacrum of the type specimen is represented in fig. 33, below. This fossil, with other remains, was found in place in the upper part of the Atlantosaurus beds, on the western slope of the foothills, south of Golden.

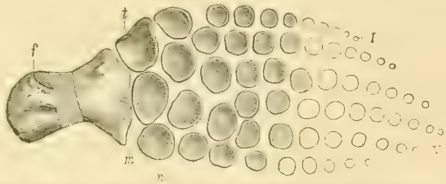


FIG. 30.—Left hind paddle of *Baptanodon discus* Marsh. One-eighth natural size.

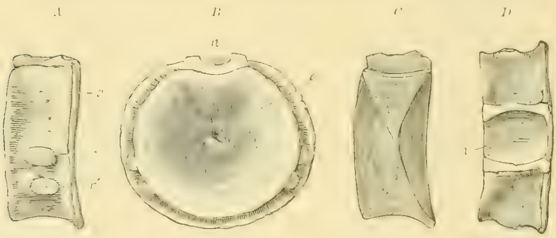


FIG. 31.—Cervical vertebra of *Baptanodon natans* Marsh. One-third natural size.
A, side view; *B*, front view; *C*, section; *D*, top view; *a*, anterior articular face; *n*, neural canal; *r*, *r'*, faces for rib.

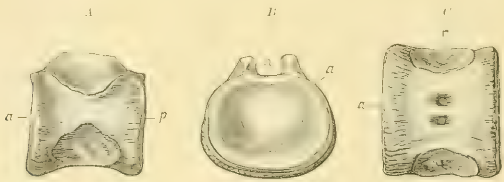


FIG. 32.—Posterior cervical vertebra of *Pantosaurus striatus* Marsh. One-half natural size.
A, side view; *B*, front view; *C*, bottom view; *a*, anterior face; *n*, neural canal; *p*, posterior face; *r*, face for rib.

Subsequent researches resulted in the discovery of other specimens near the same locality. Still later, systematic explorations were carried on by the writer at various points along the same horizon farther south, especially in the vicinity of Morrison, and at every locality interesting discoveries were made.

In the present specimen the most characteristic bones preserved are portions of the sacrum and posterior limbs. The former is represented by the last three vertebræ with their transverse processes, nearly complete, and by other fragments. The last sacral vertebra has its centrum moderately

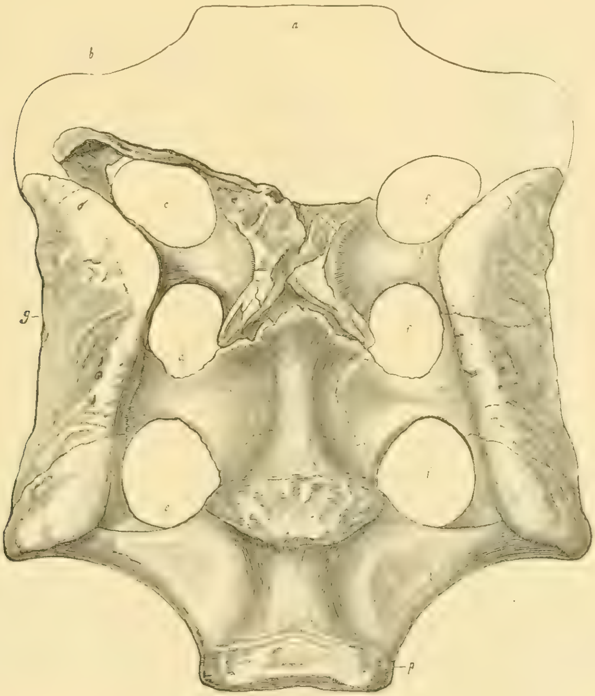


FIG. 33.—Sacrum of *Atlantosaurus montanus* Marsh; seen from below. One-eighth natural size.

a, first sacral vertebra; *b*, transverse process, or sacral rib, of first vertebra; *c*, same process of second vertebra; *d*, same process of third vertebra; *e*, same process of fourth vertebra; *f*, foramen between first and second processes; *f'* foramen between second and third processes; *f''*, foramen between third and fourth processes; *g*, surface for union with ilium; *p*, last sacral vertebra.

concave below on each side of the median line, but only near its anterior end can indications of a keel be observed. The next sacral vertebra has its inferior lateral surface so deeply concave as to materially lessen its bulk. This is also true of the next anterior centrum, and may be considered a distinctive character of these vertebræ. A more important character of the same centra is a very large cavity in each side, connected with the outer surface by an elongated foramen below the base of the neural arch. The inner surface of this cavity indicates that it was not filled by cartilage, and

FIG. 34.—Left femur of *Atlantosaurus immanis* Marsh; inner view.
FIG. 34*a*.—Proximal end of same.
FIG. 35.—The same bone; front view.
FIG. 35*a*.—Distal end of same.
All the figures are one-sixteenth natural size.
c, inner condyle; *c'*, outer condyle; *f*, groove for fibula; *h*, head; *t*, trochanter; *t'*, lower trochanter.

it was, perhaps, a pneumatic opening, designed to lessen the weight of the enormous sacral mass. The transverse processes, or more strictly speaking, the sacral ribs, of these vertebræ are very stout and of moderate length.

Their distal ends are firmly coossified, forming a powerful support for the ilium. Between these processes are large, oval openings, as shown in fig. 33.

The present remains indicate that this reptile when alive was about 50 feet in length. Its general form and proportions were very similar to those of Brontosaurus, an allied genus, the skeleton of which is represented in the restoration on Pl. XXI.

In the same series of strata, a few miles to the south, and just above the village of Morrison, various remains of a much larger species of the same genus were found in the following year, and described by the writer as *Atlantosaurus immanis.* A femur belonging to the type specimen is represented, one-sixteenth natural size, in figs. 34 and 35.

The other remains of this enormous reptile recovered show many points of interest to anatomists, which will be discussed fully by the writer elsewhere. It may, however, be stated that the head of this animal was quite small, and the neck very long and lightly built, insuring great flexibility. The vertebræ of the trunk were also lightened by large cavities in the sides, similar to those in the sacrum. The tail was powerful and much elongated. All the limb bones were massive and solid. The animal was herbivorous in habit, and its food was probably soft, succulent vegetation, which it obtained along the borders of the great fresh-water lake in which it was finally entombed. When alive, it was about 70 feet or more in length and 20 feet in height.

APATOSAURUS.

In the same stratum with the Atlantosaurus fossils the bones of an allied genus, Apatosaurus, were also found by Professor Lakes, and described by the writer in 1877. This reptile, although somewhat smaller than the one last described, was of gigantic dimensions, and similar in habit. A neck vertebra of one species is shown in fig. 36. The sacrum of the type specimen, represented one-tenth natural size in fig. 37, has but three coossified vertebræ, thus differing from that of Atlantosaurus. The pelvis of the same individual is shown in fig. 38, and this is typical of the group.

The cervical vertebræ of Apatosaurus are strongly opisthocœlian, and of moderate length. The dorsals have their centra similar, and both have deep cavities in the sides and in the neural arch resembling those in the corresponding vertebræ of Morosaurus. The lumbar vertebræ have their articular faces more nearly plane, and the last lumbar is much expanded transversely.

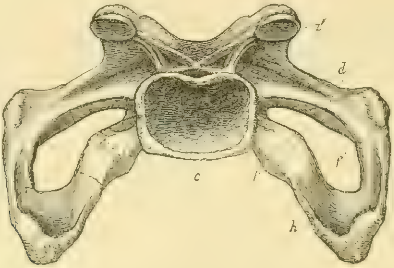


FIG. 36.—Cervical vertebra of *Apatosaurus laticollis* Marsh: back view. One-sixteenth natural size.
c, cup; *d*, diapophysis; *f'*, lateral foramen; *h*, rib; *p*, parapophysis; *z'*, posterior zygapophysis.

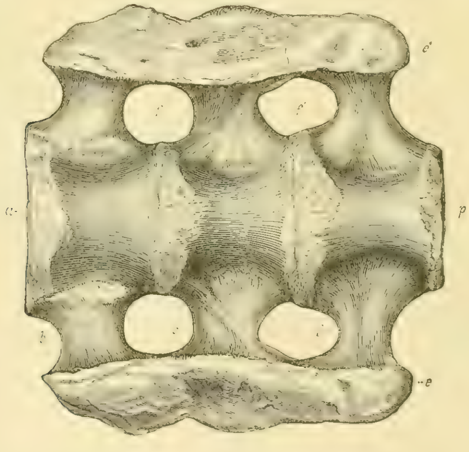


FIG. 37.—Sacrum of *Apatosaurus ajax* Marsh; seen from below. One tenth natural size.
a, first sacral vertebra; *b*, sacral rib, or transverse process, of first vertebra; *c*, same process of second vertebra; *d*, same process of third vertebra; *e*, *e'*, surfaces for union with ilia; *f*, *f'*, foramina between vertebræ; *p*, last sacral vertebra.

The sacrum is characteristic of the genus, and quite unlike any hitherto known. The type specimen on which the genus was established is well shown in fig. 37. It is short and massive, and the three vertebræ which form it are nearly equal in size and general proportions. They are firmly coossified, and their transverse processes are ankylosed to the centra. Those on each side are united distally into a solid mass, which rests on the short ilium. The articular faces of the sacral vertebræ are nearly plane. That of the anterior centrum is a transverse oval in outline, and the posterior face is more nearly round. The centra and their processes are somewhat lightened by cavities, as in the sacrum of Atlantosaurus.

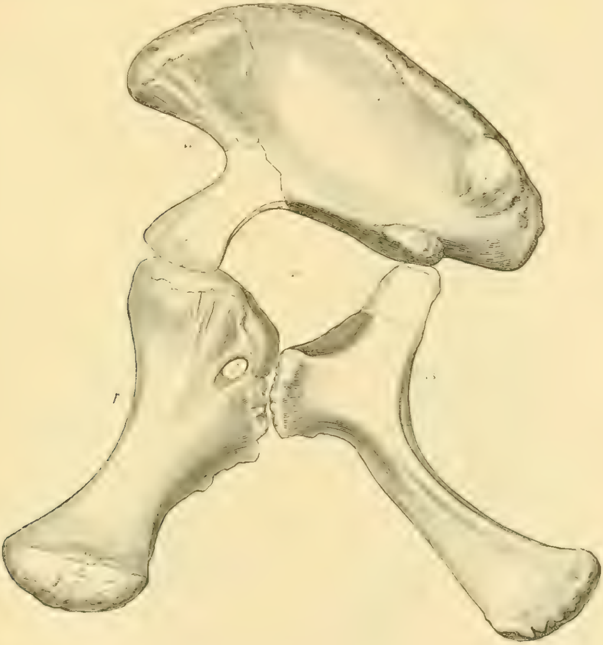


FIG. 38.—Pelvis of *Apatosaurus ajax*; seen from the left. One-sixteenth natural size. *a*, acetabulum; *f*, foramen in pubis; *il*. ilium; *is*, ischium; *p*, pubis.

The type species of the present genus is *Apatosaurus ajax* Marsh, and the known remains indicate a reptile at least 50 feet in length. A much larger species is indicated by various remains from the same locality in Colorado, among which is the huge cervical vertebra represented in fig. 36.

This species had a short, massive neck, and hence was called *Apatosaurus laticollis.* The size of the entire animal may be judged from this vertebra, which measures over 3½ feet (1.07 meters) in width. This would imply a neck not less than 5 or 6 feet wide at this point.

BRONTOSAURUS.

In the Atlantosaurus beds of the Wyoming Basin the genus Brontosaurus is well represented by two or more gigantic species, one of which

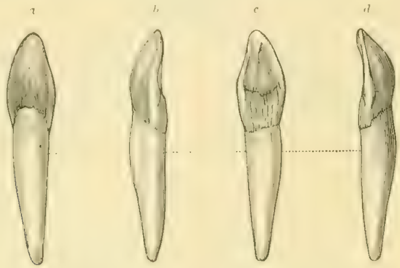
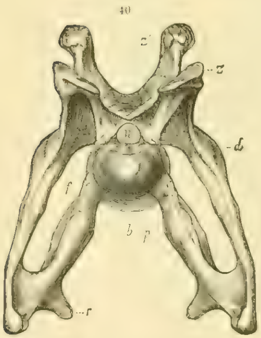


FIG. 39.—Tooth of *Brontosaurus excelsus* Marsh. Natural size.
a, outer view; *b*, posterior view; *c*, inner view; *d*, front view.



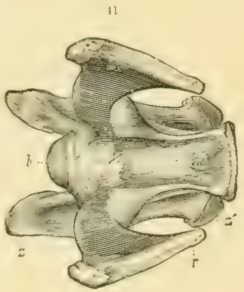


FIG. 40.—Sixth cervical vertebra of *Brontosaurus excelsus;* front view.
FIG. 41.—The same vertebra; bottom view.
Both figures are one-twelfth natural size.
b, ball; *d*, diapophysis; *f*, lateral foramen; *n*, neural canal; *p*, parapophysis; *r*, cervical rib; *z*, anterior zygapophysis; *z′*, posterior zygapophysis.

is shown in the restoration on Pl. XXI. Various remains apparently identical with this species have been found in the Denver region, and likewise near Canyon, in the same horizon. The great perfection of the remains of this genus from the western localities has enabled the writer to make a careful study of the whole skeleton, and thus determine many important points in the anatomy of the Sauropoda hitherto unknown. In fig. 39, opposite, a tooth of Brontosaurus is represented, and this may be regarded as typical of the Sauropoda in general. A cervical vertebra of the same species is shown in figs. 40 and 41, and this indicates the delicate,

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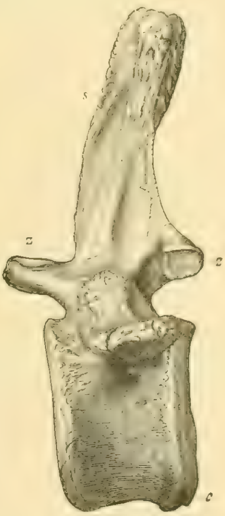

FIG. 42.—Dorsal vertebra of *Brontosaurus excelsus;* side view. One-twelfth natural size.
FIG. 43.—Fourth caudal vertebra of *Brontosaurus excelsus;* side view. One-eighth natural size.
b, ball; *c*, cup; *c′*, face for chevron; *d*, diapophysis; *f*, foramen in centrum; *p*, parapophysis; *s*, neural spine; *z*, anterior zygapophysis; *z′*, posterior zygapophysis.

bird-like neck of this huge reptile. In fig. 42 a dorsal vertebra of the same individual is represented, which also shows how the trunk vertebræ were lightened in a corresponding manner. The sacrum in this genus was quite hollow, and was composed of five coalesced vertebræ. The anterior caudal vertebræ, and even the ribs, were more or less lightened by cavities, but the rest of the caudal vertebræ and all of the limb bones were quite solid.

RESTORATION OF BRONTOSAURUS.

In the restoration given on Pl. XXI the diminutive head will first attract attention, as it is smaller in proportion to the body than in any vertebrate hitherto known. The entire skull is less in diameter or actual weight than the fourth or fifth cervical vertebra.

A careful estimate of the size of Brontosaurus, as here restored, shows that when living the animal must have weighed more than 20 tons. The very small head and brain, and slender neural cord, indicate a stupid, slow-moving reptile. The beast was wholly without offensive or defensive weapons, or dermal armature.

In habits Brontosaurus was more or less amphibious, and its food was probably aquatic plants or other succulent vegetation. The remains are usually found in localities where the animals had evidently become mired.

The present genus, Brontosaurus, together with the genera Atlantosaurus, Apatosaurus, and Barosaurus, form a distinct family of the Sauropoda, which the writer has called the Atlantosauridæ.

DIPLODOCUS.

In the same horizon in the Denver Basin remains of another peculiar genus, Diplodocus, are quite abundant, especially the teeth. This genus, described by the writer in 1884, represents a distinct family of the Sauropoda, and one of much interest. The skull and nearly every part of the skeleton are now known. The type specimen was found by M. P. Felch, near Canyon, Colo. Other remains of the same genus have been found near Lake Como, in Wyoming.

The skull of Diplodocus is of moderate size. The posterior region is elevated and narrow. The facial portion is elongate, and the anterior part expanded transversely. The nasal opening is at the apex of the cranium, which from this point slopes backward to the occiput. In front of this aperture the elongated face slopes gradually downward to the end of the muzzle, as represented in fig. 44.

Seen from the side, the skull of Diplodocus shows five openings: A small oval aperture in front, a large antorbital vacuity, the nasal aperture,

FIG. 44.—Skull of *Diplodocus longus* Marsh, side view. One-sixth natural size.

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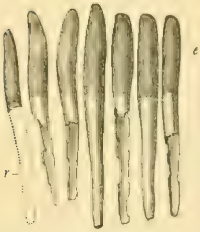

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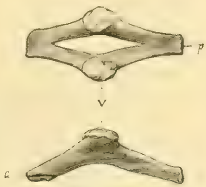

FIG. 45.—Maxillary teeth of *Diplodocus longus;* side view. One-half natural size. *e*, enamel; *r*, root.

FIG. 46.—Chevron of *Diplodocus longus;* top and side views. One-tenth natural size. *a*, anterior end; *p*, posterior end; *v*, faces for articulation with vertebræ.

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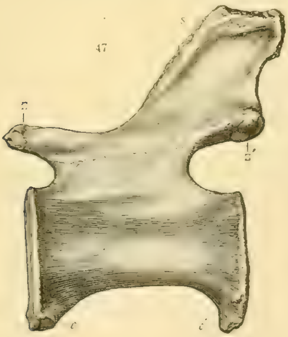

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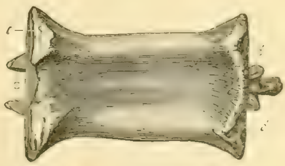

FIG. 47.—Twelfth caudal vertebra of *Diplodocus longus;* side view.

FIG. 48.—The same vertebra; bottom view.

Both figures are one-sixth natural size.

c, anterior face for chevron; *c'*, posterior face for chevron; *s*, neural spine; *z*, anterior zygapophysis; *z'*, posterior zygapophysis.

the orbit, and the lower temporal opening. The first of these has not been seen in any other Sauropoda; the large antorbital vacuity is characteristic of the Theropoda also; while the other three openings are present in all the known Dinosauria.

The lower jaws of Diplodocus are more slender than in any of the other Sauropoda. The dentary, especially, lacks the massive character seen in Morosaurus, and is much less robust than the corresponding bone in Brontosaurus. The short dentigerous portion in front is decurved, and its greatest depth is at the symphysis. The articular, angular, and surangular bones are well developed, but the coronary and splenial appear to be small.

The dentition of Diplodocus is the weakest seen in any of the known Dinosauria, and strongly suggests the probability that some of the more specialized members of this great group were edentulous. The teeth are entirely confined to the front of the jaws, and those in use were inserted in such shallow sockets that they were readily detached. Specimens in the Yale University Museum show that the entire series of upper or lower teeth could be separated from the bones supporting them without losing their relative position. In fig. 45 a number of these detached teeth are shown.

The vertebral column of Diplodocus, so far as at present known, may be readily distinguished from that of the other Sauropoda by both the centra and chevrons of the caudals. The caudals are deeply excavated below, as shown in fig. 48, while the chevrons have both anterior and posterior branches, as seen in fig. 46.

The type specimen of Diplodocus, to which the skull here figured belongs, indicates an animal intermediate in size between Atlantosaurus and Morosaurus, probably 40 or 50 feet in length when alive. The teeth show that it was herbivorous, and the food was probably succulent vegetation.

MOROSAURUS.

Another genus of the Sauropoda, represented by several species of large size, has also been found in the Denver region, and especially in the same horizon farther south. Like Brontosaurus, however, it is much more abundant in the Wyoming Basin, west of the mountains. This genus, described by the writer in 1878, is the type of a distinct family, the Morosauridæ.

The head in this genus was very small. The skull resembles somewhat that of Brontosaurus, but the jaws are more massive and the teeth larger. The vertebræ were similar in general form to those of Brontosaurus, but were less lightened by cavities, especially in the trunk. The sacrum was much less excavated, and the caudals were all solid.

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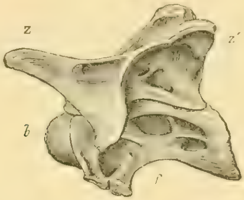

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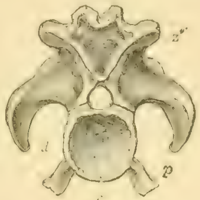

Fig. 49.—Fourth cervical vertebra of *Morosaurus grandis* Marsh; side view.

Fig. 50.—The same vertebra; back view.

Both figures are one-eighth natural size.

b, ball, *c*, cup, *d*, diapophysis; *f*, foramen in centrum; *p*, parapophysis; *z*, anterior zygapophysis; *z'*, posterior zygapophysis.

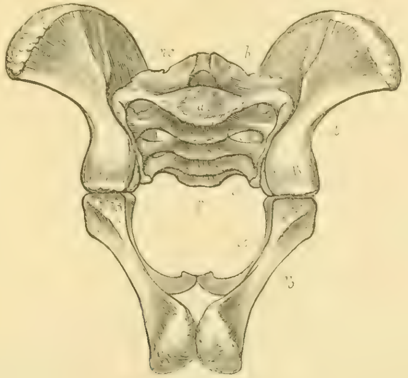

Fig. 51.—Pelvic arch of *Morosaurus grandis*; seen from in front. One-sixteenth natural size.

a, first sacral vertebra; *b*, sacral rib, or transverse process of first sacral vertebra; *c*, the same process of second sacral vertebra; *e*, same process of last sacral vertebra; *il*, ilium; *is*, ischium; *nc*, neural canal; *p*, fourth, or last, sacral vertebra; *pb*, pubis.

The scapula has a large anterior projection on its shaft, while the ischia are twisted and were directed backward, characters not seen in the Atlantosauridæ.

A cervical vertebra of this genus is shown in figs. 49 and 50, above, and in fig. 51 the entire pelvic arch, with the sacrum in position, is likewise represented.

The type species of the present genus, *Morosaurus grandis*, was about 40 feet in length when alive. *Morosaurus agilis*, found near Canyon, was much smaller. The genus Camarasaurus Cope, which includes some of the gigantic forms of the Sauropoda, was apparently a form nearly allied to Morosaurus, and perhaps belonged to the same family.

STEGOSAURUS.

Although the Sauropoda are by far the most abundant dinosaurs in this horizon, there are other large herbivorous forms well represented, and among these the Stegosauria are the most remarkable. The type genus, Stegosaurus, described by the writer in 1877, is now well known, and is represented by several species, two of which, at least, occur in the Denver region, where the type was found. West of the mountains, especially in the Wyoming Basin, remains of this genus are also numerous in the Atlantosaurus beds. One species from that region, *Stegosaurus ungulatus*, is restored on Pl. XXII. This figure will indicate the general form and appearance of all the species of the genus, although they differ much in minor details.

The skull of Stegosaurus is long and slender, the facial portion being especially produced. Seen from the side, with the lower jaw in position, it is wedge-shaped, with the point formed by the premaxillary, which projects well beyond the mandible, as shown in fig. 52. The anterior nares are large and situated far in front. The orbit is very large and placed well back. The lower temporal fossa is somewhat smaller. All these openings are oval in outline and are on a line nearly parallel with the top of the skull. In this view the lower jaw covers the teeth entirely. A single tooth is shown below, in fig. 53.

The brain of this reptile was much elongated, and its most striking features were the large size of the optic lobes and the small cerebral hemispheres. The latter had a transverse diameter only slightly in excess of the medulla. The cerebellum was quite small. The optic nerve corresponded in size with the optic lobes. The olfactory lobes were of large size. A cast of the brain is shown in fig. 54, on the opposite page.

In Stegosaurus the brain was one of the smallest known in any land vertebrate, living or extinct. A still more remarkable feature, however, is seen in the sacrum, where there is a very large chamber formed by an enlargement of the spinal canal. This chamber is ovate in form, and strongly resembles the brain-case in the skull, although very much larger,

FIG. 52.—Skull of *Stegosaurus stenops* Marsh; side view. One-fourth natural size.

a, anterior narial opening; *an*, angular bone; *ar*, articular; *b*, orbit; *c*, lower temporal fossa; *d*, dentary; *fp*, postfrontal; *j*, jugal; *l*, lachrymal; *m*, maxillary; *n*, nasal; *oc*, occipital condyle; *pd*, predentary; *pf*, prefrontal; *pm*, premaxillary; *po*, postorbital; *q*, quadrate; *s*, splenial; *sa*, surangular; *so*, supraorbital; *sq*, squamosal.

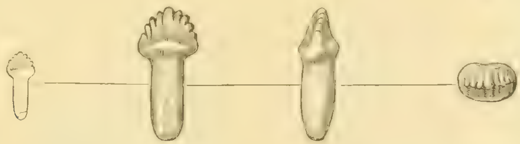

FIG. 53.—Tooth of *Stegosaurus ungulatus* Marsh. *a*, natural size; *b*, *c*, *d*, twice natural size. *b*, outer view; *c*, end view; *d*, top view.

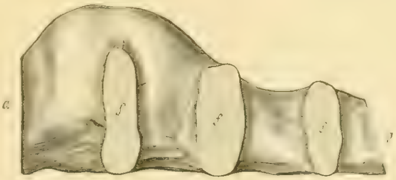

FIG. 54.—Brain-cast of *Stegosaurus ungulatus*; side view.

c, cerebral hemispheres; *cb*, cerebellum; *m*, medulla; *ol*, olfactory lobes; *on*, optic nerve; *op*, optic lobes.

FIG. 55.—Cast of neural cavity in sacrum of *Stegosaurus ungulatus*; side view.

a, anterior end; *f*, foramen between first and second vertebræ; *f'*, same between second and third vertebræ; *f''*, same between third and last vertebræ; *p*, exit of neural canal in last sacral vertebra.

Both figures are one-fourth natural size.

being at least twenty times the size of the cavity which contains the brain. This large, vaulted chamber is mainly contained in the first and second sacral vertebræ, although the canal is considerably enlarged behind this cavity. Figs. 54 and 55 show the comparative size of the brain cavity and the chamber in the sacrum. The physiological effects of a posterior nervous center so many times larger than the brain itself is a suggestive subject which need not here be discussed. It is evident, however, that in an animal so endowed the posterior part was dominant.

The dermal armor of Stegosaurus is one of its most remarkable features, and suggested the generic name. A plate and spine are shown in figs. 56 and 57, and the series are in place in the restoration, Pl. XXII.

In the restoration of Stegosaurus given on Pl. XXII, the animal is represented as walking, and the position is adapted to that motion. The

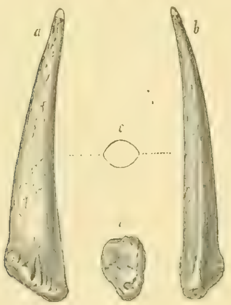

Fig. 56.—Dermal spine of *Stegosaurus ungulatus*.
a, side view; *b*, front view; *c*, section; *d*, inferior view of base.
Fig. 57.—Dermal plate of *Stegosaurus ungulatus*.
a, side view; *b*, end view of base; *d*, thin margin; *e*, rugose base; *f*, surface marked by vascular grooves.
Both figures are one-twelfth natural size.

head and neck, the massive fore limbs, and, in fact, the whole skeleton, indicate slow locomotion on all four feet. The longer hind limbs and the powerful tail show, however, that the animal could thus support itself, as on a tripod, and this position could have been very easily assumed in consequence of the massive hind quarters.

In the restoration as here presented the dermal armor is the most striking feature, but the skeleton is almost as remarkable, and its high specialization was evidently acquired gradually as the armor itself was developed. Without the latter many points in the skeleton would be inexplicable, and there are still a number that need explanation.

The small, elongated head was covered in front by a horny beak. The teeth are confined to the maxillary and dentary bones, and are not visible in the figure here given. They are quite small, with compressed fluted crowns, and indicate that the food of this animal was soft, succulent vegetation. The vertebræ are solid, and the articular faces of the centra are biconcave or nearly flat. The ribs of the trunk are massive, and placed high above the centra, the tubercle alone being supported on the elevated diapophysis. The neural spines, especially those of the sacrum and anterior caudals, have their summits expanded to aid in supporting the massive dermal armor above them. The limb bones are solid, and this is true of every other part of the skeleton. The feet were short and massive, and the terminal phalanges of the functional toes were covered by strong hoofs. There were five well-developed digits in the fore foot and only three in the hind foot, the first toe being rudimentary and the fifth entirely wanting.

In life, the animal was protected by a powerful dermal armor, which served both for defense and offense. The throat was covered by a thick skin in which were imbedded a large number of rounded ossicles, as shown in the restoration, Pl. XXII. The gular portion represented was found beneath the skull, so that its position in life may be regarded as definitely settled. The series of vertical plates which extended above the neck, along the back, and over two-thirds of the tail, is a most remarkable feature, which could not have been anticipated, and would hardly have been credited had not the plates themselves been found in position. The four pairs of massive spines characteristic of the present species, which were situated above the lower third of the tail, are apparently the only part of this peculiar armor used for offense. In addition to the portions of armor above mentioned, there was a pair of small plates just behind the skull, which served to protect this part of the neck. There were also, in the present species, four flat spines, which were probably in place below the tail, but as their position is somewhat in doubt, they are not represented in the present restoration.

All these plates and spines, massive and powerful as they now are, were in life protected by a thick, horny covering, which must have greatly increased their size and weight. This covering is clearly indicated by the vascular grooves and impressions which mark the surface of both plates and spines, except their bases, which were evidently implanted in the thick skin.

CAMPTOSAURUS.

Another group of dinosaurs, the Ornithopoda, is well represented in the Atlantosaurus beds, on both the eastern and western sides of the Rocky Mountains. This suborder includes the smaller herbivorous forms, which have many bird-like features. The genus Nanosaurus, already

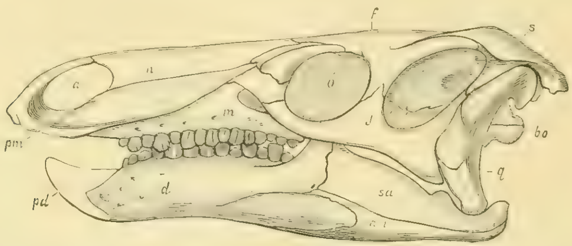

FIG. 58.—Skull of *Camptosaurus medius* Marsh; seen from the left side. One-fourth natural size.
a, anterior narial opening; *an*, angular bone; *bo*, basioccipital; *d*, dentary; *f*, frontal; *j*, jugal; *m*, maxillary *n*, nasal; *o*, orbit; *pd*, predentary; *pm*, premaxillary; *q*, quadrate; *s*, squamosal; *sa*, surangular.

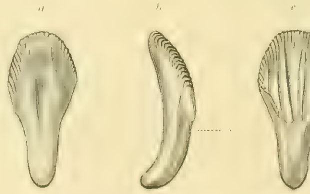

FIG. 59.—Fifth lower tooth of *Camptosaurus medius*. Natural size.
a, outer view; *b*, posterior end view; *c*, inner view.

described, is the smallest member of the group, or, in fact, of all the dinosaurs, while Camptosaurus includes some species of quite large dimensions. All this group are bipedal in locomotion, and thus quite unlike the gigantic forms previously described from this horizon, which were all quadrupedal. The general form and structure of the animals of this order are indicated by the restoration on Pl. XXIII, which represents the skeleton of one of the typical species of the genus Camptosaurus. In fig. 58, above, is shown the skull of another species, and in fig. 59 a tooth of the same individual is also represented. Other allied genera of this group from the same horizon are Dryosaurus and Laosaurus, the latter containing several species of very small, bird-like forms. A restoration of one of these (*Laosaurus consors*) is shown in Pl. XXIV.

The restoration given on Pl. XXIII is based upon the type specimen of *Camptosaurus dispar*, one of the most characteristic forms of the great group Ornithopoda, or bird-footed dinosaurs. The reptile is represented on this plate one-thirtieth natural size. The position chosen was determined after a careful study, not only of the type specimen, but of several others in excellent preservation belonging to the same species or to others nearly allied. It is therefore believed to be a position frequently assumed by the animal during life, and thus, in some measure, characteristic of the genus Camptosaurus. The present species, when alive, was about 20 feet in length and 10 feet high in the position here represented.

CERATOSAURUS.

The Jurassic dinosaurs above described from the Atlantosaurus beds have all been herbivorous forms, but in the same horizon there are abundant remains of carnivorous species that preyed upon them. These are members of the order Theropoda, and the most important genera are Allosaurus and Ceratosaurus, both large of size and ferocious in habit. A small, bird-like form (Cœlurus) of this order lived at the same time, and although of much scientific interest can not be discussed here. All these carnivorous dinosaurs were bipedal in locomotion, and their general form and appearance are suggested by the restoration of Ceratosaurus, shown in Pl. XXV.

The genus Ceratosaurus is the best known of this group, and may be taken as a typical form. The skull of the type species is shown in fig. 60, and the pelvis of Allosaurus in fig. 61.

The skull of *Ceratosaurus nasicornis* is very large in proportion to the rest of the skeleton. The posterior region is elevated, and moderately expanded transversely. The facial portion is elongate, and tapers gradually to the muzzle. Seen from above, the skull resembles in general outline that of an alligator. The nasal openings are separate and lateral, and are placed near the end of the snout, as shown in fig. 60.

Seen from the side, this skull appears lacertilian in type, the general structure being light and open. From this point of view, one special feature of the skull is the large, elevated, trenchant horn-core situated on the nasals. Other features are the large openings on the side of the skull, four in number. The first of these is the anterior nasal orifice; the second, the very large, triangular, antorbital foramen; the third, the large oval orbit, and the fourth, the still larger lower temporal opening.

The parietal bones are of moderate size, and there is no pineal foramen. The median suture between the parietals is obliterated. The frontal bones are rather short, and are closely united on the median line. The nasal bones are more elongate than the frontals, and firmly coossified.

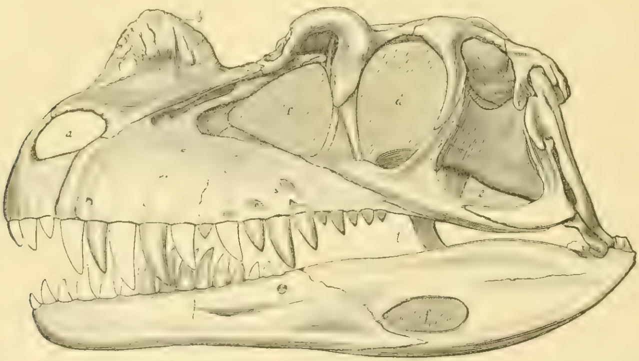

Fig. 60.—Skull of *Ceratosaurus nasicornis* Marsh; side view. One-sixth natural size.
a, nasal opening; *b*, horn-core; *c*, antorbital opening; *d*, orbit; *e*, lower temporal fossa; *f*, foramen in lower jaw; *t*, transverse bone.

These bones support the large, compressed, elevated horn-core, on the median line. The lateral surface of this elevation is very rugose, and furrowed with vascular grooves. It evidently supports a high, trenchant horn, which must have formed a most powerful weapon for offense and defense.

The premaxillaries are separate, and each contained three functional teeth. The maxillary bones are large and massive, as shown in fig. 60. They are each provided with fifteen functional teeth, which are large, powerful, and trenchant, indicating clearly the ferocious character of the animal when alive.

The cervical vertebræ of Ceratosaurus differ in type from those in any other known reptiles. With the exception of the atlas, all are strongly opisthocœlian, the cup on the posterior end of each centrum being unusually deep. In place of an equally developed ball on the anterior end, there is a perfectly flat surface. The size of the latter is such that it can be inserted only a short distance in the adjoining cup, and this distance is accurately marked on the centrum by a narrow articular border, just back of the flat anterior face. This peculiar articulation leaves more than three-fourths of the cup unoccupied by the succeeding vertebra.

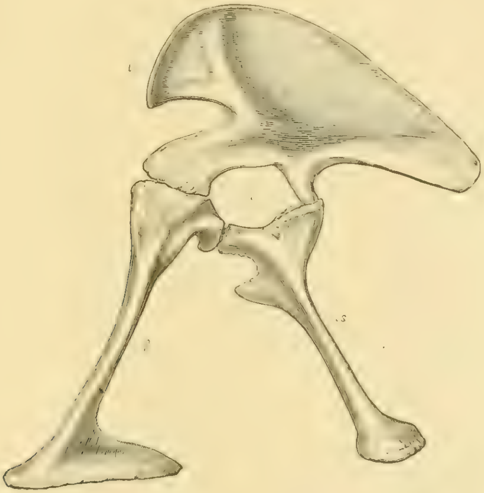

FIG. 61.—Pelvis of *Allosaurus fragilis* Marsh; side view, seen from the left. One-twelfth natural size. *a*, acetabulum; *il*, ilium; *is*, ischium; *p*, pubis.

The pubes have their distal ends coossified, and expand into an elongate, massive foot, which is one of the most characteristic parts of the skeleton. It is probable that this foot in connection with the distal ends of the ischia served to support the body in sitting down. That some Triassic dinosaurs sat down on their ischia is proved conclusively by the impressions in the Connecticut River sandstone. In such cases the leg was bent so as to bring the heel to the ground. The same action in the present reptile would bring the foot of the pubes to the ground, nearly or quite under the center of gravity of the animal. The legs and ischia would then naturally aid in keeping the body balanced. Possibly this position was assumed habitually by these ferocious biped reptiles in lying in wait for their prey.

The most interesting feature in the extremities of this dinosaur is in the metatarsal bones, which are completely ankylosed, as are the bones of the pelvis. There are only three metatarsal elements in each foot, the first and fifth having apparently disappeared entirely. The three metatarsals remaining, which are the second, third, and fourth, are proportionally shorter and more robust than in the other known members of the Theropoda, and being firmly united to each other, they furnish the basis for a very strong hind foot. The phalanges of the hind feet are of moderate length, and most of them are quite hollow. The terminal phalanges evidently supported strong and sharp claws.

The unique cervical vertebræ, the coossification of the pelvic bones, and the union of the metatarsals, as in modern birds, distinguish Ceratosaurus widely from all other dinosaurs, and make it the type of a well-marked family, the Ceratosauridæ. The nearest allied form is apparently Ornithomimus, from the Laramie, recently described by the writer.

The type specimen of Ceratosaurus was about 22 feet long when alive, and 12 feet high, as restored on Pl. XXV. It was found by M. P. Felch in the Atlantosaurus beds of the Upper Jurassic, near Canyon, Colo. The associated fossils were mainly other dinosaurs, especially Sauropoda and Ornithopoda, together with various small mammals.

OTHER VERTEBRATES.

In addition to the dinosaurs here described, many other reptiles lived in this region during Jurassic time, and not a few left their remains in the deposits now known as the Atlantosaurus beds. Among these were various crocodiles of moderate size, and some nearly as large as existing species. The genera appear to be distinct from those now living. One of the most interesting is Diplosaurus, the type specimen of which, found at Morrison in 1887, is represented in the diagram, fig. 62, on the opposite page. All these crocodilians had biconcave vertebræ, and also seem to have been protected by a dermal covering of bony plates, as in existing species.

The turtles appear to have been more abundant, and still more distinct from living forms. The most characteristic genus is Glyptops, and a skull and carapace of one species are represented in figs. 63 and 64, below. The

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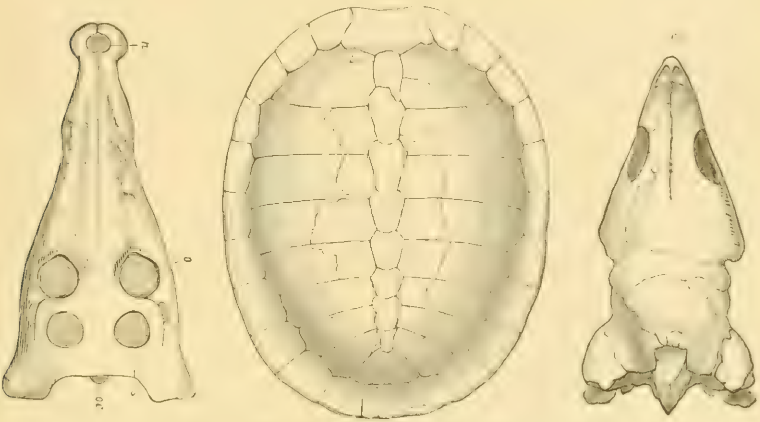

FIG. 62.—Skull of *Diplosaurus felix* Marsh; top view. One-fourth natural size.
n, nasal aperture; *o*, orbit; *oc*, occipital condyle; *s*, supratemporal fossa.
FIG. 63.—Skull of *Glyptops ornatus* Marsh; top view. Natural size.
FIG. 64.—Carapace of same species; top view. One-fourth natural size.

generic name refers to the sculptured surface of the skull, which is not known in any living form of this order, although this character is not unusual

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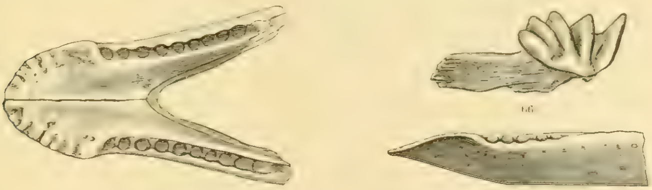

FIG. 65.—Jaws of *Macelognathus vagans* Marsh; seen from above. One-half natural size.
FIG. 66.—The same specimen; side view.
FIG. 67.—Tooth of *Ceratodus güntheri* Marsh. Natural size.

in the carapace of many species, living and extinct. Numerous remains of the above species have been found in the Denver region, especially near Morrison and Canyon.

In the Wyoming Basin, west of the mountains, the same species are abundant, and with them have been found remains of a very remarkable reptile (Macelognathus), figs. 65 and 66, and also a pterodactyl (*Dermodactylus montanus*). A batrachian (*Eobatrachus agilis*) and a peculiar fish (*Ceratodus güntheri*), fig. 67, have likewise been found in this horizon. A single bird (*Laopteryx priscus*), discovered near Como, Wyo., has also been described by the writer. All these species are probably represented in the

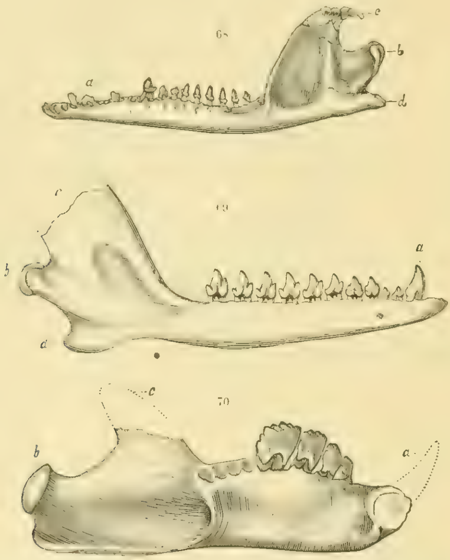

FIG. 68.—Left lower jaw of *Stylacodon gracilis* Marsh; outer view. Three times natural size.
FIG. 69.—Right lower jaw of *Diplocynodon victor* Marsh; outer view. Twice natural size.
FIG. 70.—Left lower jaw of *Ctenacodon serratus* Marsh; inner view. Three times natural size.
a, canine; *b*, condyle; *c*, coronoid process; *d*, angle.

Denver region, and may be brought to light at any time. Many other forms of much scientific interest, but known only from fragmentary remains, have been found in this horizon.

JURASSIC MAMMALS.

The most important of the remaining vertebrate fossils from the Atlantosaurus beds are the diminutive mammals, of which a few only have been found on the eastern side of the mountains, but on the western slope, and especially near Lake Como, a large number have been discovered, and described by the writer. In figs. 68, 69, and 70, on the opposite page, are shown the lower jaws of three of these small mammals, all from different localities in this horizon.

In the Atlantosaurus beds east and west of the mountains various invertebrate fossils have been found, but they are apparently all of fresh-water species, and hence of little value as evidence of geological age. The most abundant of these are Unios, and a typical locality is on Oil Creek, north of Canyon, just above the well-known strata containing vertebrate fossils. Remains of plants also occur in this horizon, but those yet found throw no light on the problem of age, which the characteristic vertebrate fossils have fully determined.

PART III.

CRETACEOUS VERTEBRATE FOSSILS.

PTERANODONTIA.

PTERANODON.

The next horizon in this region that contains important vertebrate remains is known as the Pteranodon beds, and its general position is shown in the section, fig. 23, where the characteristic genera found in these strata are also recorded. The gigantic toothless pterodactyls belonging to the order Pteranodontia are of special interest, and the skull of the typical genus, Pteranodon, is represented below in figs. 71 to 74.

These huge flying reptiles, when alive, had a spread of wing of from 15 to 25 feet, and their remains are now quite abundant in the chalk deposits of this horizon, especially in Kansas. With them are found the remarkable birds with teeth, of the genera Hesperornis and Ichthyornis (Pl. XXVI), described by the writer. In the same strata the remains of the mosasaurs are the most numerous of all the vertebrate fossils there entombed, while plesiosaurs and turtles are also represented, and fossil fishes are especially abundant.

DINOSAURS.

CERATOPSIDÆ.

The next horizon rich in vertebrate fossils is the Ceratops beds, so named by the writer from the gigantic horned dinosaurs that are especially abundant in these deposits, and characteristic of the horizon wherever it has been found. The entire vertebrate fauna of these strata is of great interest, and is only surpassed in this respect by that of the Atlantosaurus beds above described. The dinosaurs are here still the dominant forms, but are more highly specialized than those of the Jurassic horizon. Other reptiles were also abundant, including plesiosaurs, crocodiles, turtles, and serpents, while amphibians and fishes were much more numerous. Bones

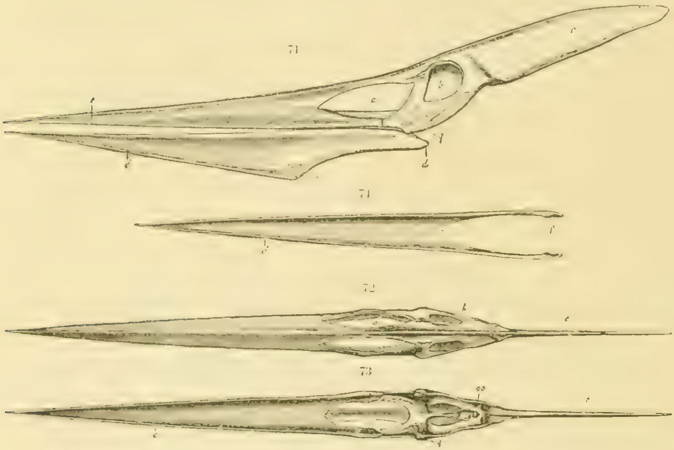

FIG. 71.—Skull and lower jaw of *Pteranodon longiceps* Marsh; side view.
FIG. 72. The same skull; top view.
FIG. 73.—The same skull; bottom view.
FIG. 74.—Lower jaw of *Pteranodon longiceps*; top view.
All the figures are one-eighth natural size.
a, antorbital aperture; *b*, orbit; *c*, sagittal crest; *d*, angle of jaw; *e*, lower margin of upper jaw; *e'*, upper margin of lower jaw; *f*, articulation of lower jaw; *oc*, occipital condyle; *q*, quadrate bone; *s*, symphysis of lower jaw.

of several birds have been found, while remains of small mammals of primitive types are abundant in many localities.

The gigantic horned dinosaurs, as the most characteristic forms in this horizon, will first claim attention, and the skull of one of the best-known genera of the group is well shown in fig. 75. A front view of the same skull is represented in fig. 76, and the posterior view of another in fig. 77. A tooth of Triceratops is given in fig. 78, showing the double roots, the only case among the Reptilia. Another interesting specimen, although only a fragment of the skull with the horn-cores, is shown in figs. 79 and 80. This specimen was found near Denver by George L. Cannon, jr., who has secured other important specimens from the same horizon. Still others of interest were found by George H. Eldridge, while

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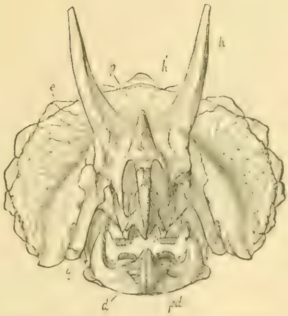


FIG. 75.—Skull and lower jaw of *Triceratops prorsus* Marsh; seen from the left side. About one-sixteenth natural size.
FIG. 76.—Skull of *Triceratops prorsus;* seen from the front.
FIG. 77.—Skull of *Sterrholophus flabellatus* Marsh; seen from behind.
Both figures are one-twentieth natural size.
d, dentary; *e*, epoccipital; *h*, horn-core; *h'*, nasal horn-core; *p*, parietal; *pd*, predentary; *q*, quadrate; *r*, rostral bone; *s*, squamosal.

working out the geology of this region. The restoration of the skeleton on Pl. XXVII shows the general form and position of one of these reptiles when alive.

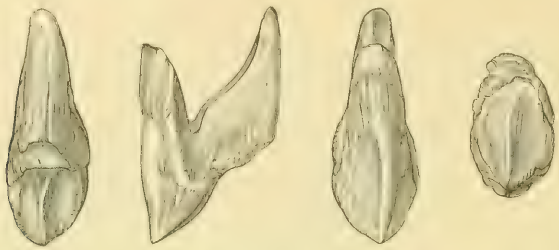


Fig. 78.—Maxillary tooth of *Triceratops serratus* Marsh. Natural size.
a, outer view; *b*, side view; *c*, inner view; *d*, seen from below.

Fig. 79.—Fragment of skull, with horn-cores, of *Ceratops alticornis* Marsh; front view.
Fig. 80.—Left horn-core of same specimen; side view.
Both figures are one-eighth natural size.

The skull of Triceratops, the best-known genus of the family, has many remarkable features. First of all, its size, in the largest individuals, exceeds that of any land animal hitherto discovered, living or extinct, and is surpassed only by that of some of the Cetaceans.

Another striking feature of the skull is its armature. This consisted of a sharp, cutting beak in front, a strong horn on the nose, a pair of very large, pointed horns on the top of the head, and a row of sharp projections around the margin of the posterior crest. All these had a horny covering of great strength and power. For offense and defense they formed together an armor for the head as complete as any known. This armature dominated the skull, and, in a great measure, determined its form and structure. In some species the armature extended over portions of the body.

The skull itself is wedge-shaped in form, especially when seen from above. The facial portion is very narrow and much prolonged in front. In the frontal region the skull is massive and greatly strengthened to support the large and lofty horn-cores which formed the central feature of the armature. The huge, expanded, posterior crest, which overshadowed the back of the skull and neck, was evidently of secondary growth, a practical necessity for the attachment of the powerful ligaments and muscles that supported the head.

The front part of the skull shows a very high degree of specialization, and the lower jaws have been modified in connection with it. In front of the premaxillaries there is a large massive bone not before seen in any vertebrate, which has been called by the writer the rostral bone (*os rostrale*). It covers the anterior margins of the premaxillaries, and its sharp inferior edge is continuous with their lower border. This bone is much compressed and its surface very rugose, showing that it was covered with a strong, horny beak. It is a cartilage ossification, and corresponds to the predentary bone below. The latter, in this genus, is also sharp and rugose, and likewise was protected by a strong, horny covering. The two together closely resemble the beak of some of the turtles, and as a whole must have formed a most powerful weapon of offense.

The frontal bones are quite short, and early unite with each other and with the adjoining elements, especially those behind them. The frontal or central region of the skull is thus greatly strengthened to support the enormous horn-cores which tower above. These elevations rest mainly on the postfrontal bones, but the supraorbitals and the postorbitals are also absorbed to form a solid foundation for the horn-cores.

These horn-cores are hollow at the base, and in general form, position, and external texture agree with the corresponding parts of the Bovidæ. They vary much in shape and size in different species. They were evidently covered with massive, pointed horns, forming most powerful and effective weapons.

The orbit is at the base of the horn-core, and is surrounded, especially above, by a very thick margin. It is oval in outline, and of moderate size.

The enormous posterior crest is formed mainly by the parietals, which meet the postfrontals immediately behind the horn-cores. The posterior margin is protected by a series of special ossifications, which in life had a thick horny covering. These peculiar ossicles, which extend around the whole crest, have been called the epoccipital bones. In old animals they are firmly coossified with the bones on which they rest.

The lateral portions of the crest are formed by the squamosals, which meet the parietals in an open suture. Anteriorly they join the postfrontal elements which form the base of the horn-cores, and laterally they unite with the jugals. The supratemporal fossæ lie between the squamosals and the parietals.

The teeth of Triceratops and its near allies are very remarkable in having two distinct roots. This is true of both the upper and lower series These roots are placed transversely in the jaw, and there is a separate cavity, more or less distinct, for each of them. One of these teeth from the upper jaw is represented in fig. 78. The teeth in this family are entirely confined to the maxillary and dentary bones. The rostral bone, the premaxillaries, and the predentary are edentulous.

The atlas and axis of Triceratops are coossified with each other, and at least one other vertebra is firmly united with them. These form a solid mass, well adapted to support the enormous head. The cup for the occipital condyle is nearly round and very deep. The rib of the second vertebra is coossified with it, but the third is usually free. The centrum of the fourth vertebra is free, and the remaining cervicals are of the same general form, all having their articular faces nearly flat.

The anterior dorsal vertebræ have very short centra, with flat articular ends, and resemble somewhat those of Stegosaurus, especially in the neural arch.

The posterior trunk vertebræ have also short, flat centra.

The sacrum was strengthened by the union of several vertebræ, ten being coossified in one specimen of Triceratops. The middle or true sacral vertebræ have double transverse processes, diapophyses being present, and aiding in supporting the ilium. This character has been seen hitherto in the Dinosauria only in Ceratosaurus and some other Theropoda.

Besides the armature of the skull the body, also, in the Ceratopsidæ was protected. The nature and position of the defensive parts in the different forms can not yet be determined with certainty, but various spines, bosses, and plates have been found that clearly pertain to the dermal covering of Triceratops or nearly allied genera. Several of these ossifications were probably placed on the back, behind the crest of the skull, and some of the smaller ones may have defended the throat, as in Stegosaurus.

In the restoration on Pl. XXVII the animal is represented as walking, and the enormous head is in a position adapted to that motion. The massive fore limbs, proportionally the largest in any known dinosaur, correspond to the head, and indicate slow locomotion on all four feet.

The skull is, of course, without its strong horny covering on the beak, horn-cores, and posterior crest, and hence appears much smaller than in life. The neck seems short, but the first six cervical vertebræ are entirely concealed by the crest of the skull, which in its complete armature would extend over one or two vertebræ more.

No attempt is made in this restoration to represent the dermal armor of the body, although in life the latter was more or less protected. Various ossifications indicating such dermal armature have been found with remains of this group, but the exact position of these specimens can be, at present, only a matter of conjecture.

This restoration gives a correct idea of the general proportions of the entire skeleton in the genus Triceratops. The size, in life, would be about 25 feet in length and 10 feet in height.

This specimen was found by J. B. Hatcher in the Ceratops beds of Converse County, Wyo.

CLAOSAURUS.

Another large herbivorous dinosaur, Claosaurus, has left its remains in the same horizon as the gigantic Ceratopsidæ, but owing to their smaller size and more delicate proportions they are much less conspicuous, and hence appear to be less abundant. The best-known species of the present genus is *Claosaurus annectens*, and a restoration of the type specimen will be found on Pl. XXVIII. This animal was bipedal in locomotion and had very small anterior limbs. The head was comparatively large and the tail long and massive.

The skull of Claosaurus is long and narrow, with the facial portion especially produced. The anterior part is only moderately expanded transversely. Seen from the side, fig. 81 (p. 517), the skull shows a blunt, rugose muzzle, formed above by the premaxillary and below by the predentary, both probably covered in life with a thick, corneous integument.

Behind the upper part of this muzzle is an enormous lateral cavity, which includes the narial orifice, but was evidently occupied in life mainly by a nasal gland, somewhat like that in the existing Monitor, and also seen in some birds. This cavity is bounded externally by the nasal bone and the premaxillary. The median septum between the two narial orifices was only in part ossified, the large oval opening now present in the skull probably having been closed in life by cartilage.

The orbit is very large and subtriangular in outline. It is formed above by the prefrontal, frontal, and postfrontal, and below mainly by the jugal. There are no supraorbital bones. A distinct lachrymal forms a portion of the anterior border.

The lower jaws are long and massive. The predentary bone is robust and especially fitted for meeting the strong beak above. The dentary bones are large and powerful, with elevated coronoid processes. The angular and surangular bones are, however, quite short and not especially strong.

The teeth of Claosaurus are confined entirely to the maxillary and dentary bones. In each, the teeth are very numerous and are arranged in vertical series, so that they succeed each other as the functional teeth are worn away. This is seen in fig. 82, which shows the form of the teeth and their relations to each other in the same series. The number of teeth in

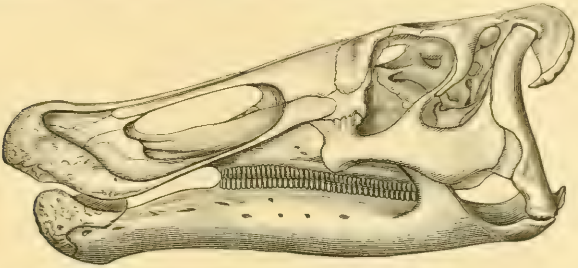


FIG. 81.—Skull of *Claosaurus annectens* Marsh, seen from the left. One-tenth natural size.

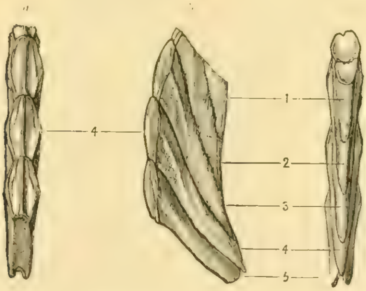


FIG. 82.—Series of five lower teeth of *Claosaurus annectens*. One-half natural size. *a*, inner view; *b*, side view; *c*, outer view.

each series depends upon the position, those near the middle of the jaw having the greatest number, sometimes six or more. The teeth of the upper jaw have the external face of the crown covered with enamel and ridged. In the lower jaw this is reversed, the ridged face of the crown being on the inside. This arrangement greatly increased the cutting power of the jaws. The food was probably soft vegetation.

The animal restored in Pl. XXVIII was nearly 30 feet in length when alive, and about 15 feet high in the position represented. The remains were obtained by J. B. Hatcher and A. L. Sullins in the Ceratops beds of Converse County, Wyo.

ORNITHOMIMUS.

Besides the large herbivorous dinosaurs from the Ceratops beds, above described, there were also carnivorous forms that served to limit

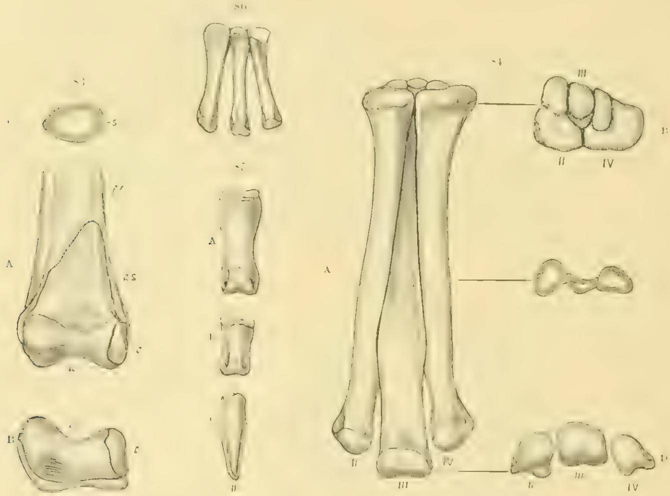


FIG. 83.—Left tibia of *Ornithomimus velox* Marsh. A, front view; B, distal end; C, transverse section.

FIG. 84.—Left metatarsals of same specimen. A, front view; B, proximal ends; C, transverse section; D, distal ends.

FIG. 85.—Phalanges of second digit of same foot; front view. A, first phalanx; B, second phalanx; C, third, or terminal, phalanx.

FIG. 86.—Left metacarpals of same species, perhaps of smaller individual; front view.

All the figures are one-third natural size.

a, astragalus; *as*, ascending process of astragalus; *c*, calcaneum; *f'*, face for fibula; II, second metatarsal; III, third metatarsal; IV, fourth metatarsal.

their numbers, and among these the genus Ornithomimus is especially important. Several species of this genus are now known from this horizon, some quite large and very destructive in habit, and others of moderate dimensions. One of the latter species, the type of the genus *Ornithomimus velox*, was discovered in 1889 in the Denver beds, at Green Mountain, near Denver, by George L. Cannon, jr. The remains show that Ornithomimus was one of the most highly specialized of dinosaurs, and in the structure of the feet the most bird-like of any yet discovered, as shown in figs. 83 to 86, on the opposite page.

On the distal part of the tibia represented in fig. 83, the astragalus is seen in place, with a very large ascending process, larger than in any dinosaur hitherto known. The calcaneum is also shown in position, but the slender fibula is absent. This bone was complete, but of little functional value. The tibia and all the larger limb bones were hollow, with thin walls, as indicated in the section, fig. 83, C. The almost exact correspondence of these different parts in some recent birds and the present reptile will be manifest to every anatomist.

The most striking feature of the foot belonging with the reptilian tibia is shown in the metatarsals represented in fig. 84, A. These are three in number, and are in the same position as in life. They are the three functional metatarsals of the typical Ornithopoda and of birds. The distal ends of these bones correspond in size and relative position in the two groups, but here, in the present specimen, the reptilian features cease, and those of typical birds replace them. In all the reptiles known hitherto, and especially in dinosaurs, the second, third, and fourth metatarsals are prominent in front, at their proximal ends, and the third is usually the largest and strongest. In birds, the place of the third is taken above by the second and fourth, the third being crowded backward and very much diminished in size.

This character is well shown in the second, third, and fourth metatarsals of a young turkey, with the tarsal bones absent. In the reptilian metatarsals seen in fig. 84 the same arrangement is shown, with the tarsals in place. The second and fourth metatarsals have increased much in size in the upper portion, and meet each other in front.

The third metatarsal, usually the largest and the most robust throughout, here diminishes in size upward, and takes a subordinate, posterior position, as in birds. The correspondence between the metatarsals of the bird and reptile are here as strongly marked as in the tibiæ and their accompanying elements, above described.

In fig. 85 the three phalanges represented belong with the second metatarsal, and were found together in place.

The three metacarpals represented in fig. 86 were found together in position, near the remains of the hind limb here described.

Another larger species is based upon the nearly complete pelvis, with various vertebræ, and some other parts of the skeleton. The most striking feature of the pelvis is the fact that the ilium, ischium, and pubis are firmly coossified with each other, as in recent birds. This character has been observed hitherto among dinosaurs only in the genus Ceratosaurus, described by the writer from the Jurassic of Wyoming. The present pelvis resembles that of Ceratosaurus in its general features, but there is no foramen in the pubis.

CRETACEOUS MAMMALS.

In addition to the varied reptilian fauna now known from the Ceratops beds, the many small mammals recently discovered in this horizon are worthy of special mention. All are low in type and diminutive in size, and among them, so far as at present determined, there were no representatives of the carnivores, rodents, or ungulates, that form so large a proportion of the mammalian life in the succeeding Tertiary period. In figs. 87 to 92 (p. 521), are given illustrations of a few of the mammalian fossils already described by the writer from the Ceratops beds. They were all found in Converse County, Wyo.

The small mammals represented by these remains and all others known from this horizon appear to have been either monotremes or marsupials, the true placental mammals not being known until the Tertiary.

In this brief review of the vertebrate fauna of the Ceratops beds, only a few of the principal forms have been mentioned, and those which are most characteristic. The large number of well-preserved specimens now known from this horizon show conclusively that this vertebrate fauna is very extensive, and includes so many groups of animals that, taken together, they establish beyond reasonable doubt the Cretaceous age of the period in which they lived.

PART IV.

CENOZOIC FOSSILS.

The remaining horizons represented in the Denver Basin by vertebrate remains may be briefly treated, as the fossils they contain are better known and the succession of the important types are more clearly understood.

As the Eocene is not represented, the first noteworthy fauna above the Ceratops beds is that in which the remains of the Brontotheriidæ are so abundant. These huge ungulates belong to the perissodactyl, or odd-toed, mammals, and they were the largest land animals during early

Fig. 87.—Upper molar tooth of *Cimolomys digona* Marsh.
Fig. 88.—Third or fourth lower premolar of *Halodon serratus* Marsh.
Fig. 89.—Upper molar of *Allacodon lentus* Marsh.
Fig. 90.—Lower jaw of *Telacodon præstans* Marsh.
Fig. 91.—Upper cutting premolar of *Oracodon anceps* Marsh.
Fig. 92.—Premolar of *Stagodon validus* Marsh.

a, natural size; *b-e*, twice natural size, except fig. 89, which is three times natural size.
b, outer view; *c*, end view; *d*, inner view; *e*, top view.

Miocene time. The characteristic genera of this family found on the plains east of the Denver Basin, or farther north along the South Platte River, are Brontotherium, Brontops, Megacerops, Symborodon, and Titanops, with others less known. The skulls of two of these genera, found at the latter locality, are represented below in figs. 93 and 94. In Pl. XXIX is given the restoration of the most perfect skeleton yet discovered. This figure will indicate the general form and appearance of these hoofed mammals, which once roamed in great herds over the region near the lake basin where their remains are now preserved. The specimen here restored was found in the Brontotherium beds of northern Nebraska.

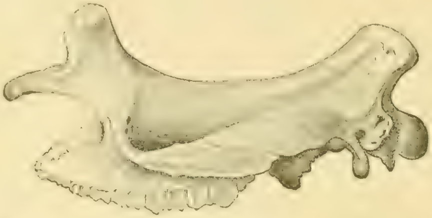


FIG. 93.—Skull of [illegible] Marsh; side view. One-twelfth natural size.

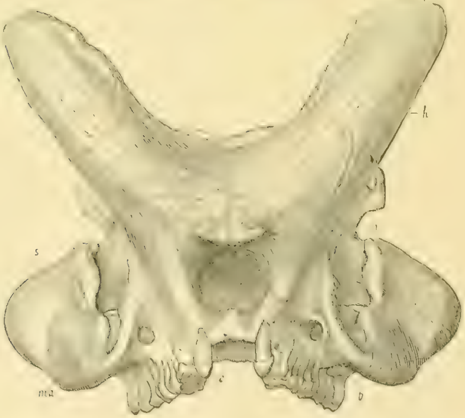


FIG. 94.—Skull of *Titanops curtus* Marsh; front view. One-eighth natural size. *b*, antorbital foramen; *c*, canine; *h*, horn-core; *ma*, malar; *n*, nasal; *s*, zygoma.

The largest reptile in this horizon is the huge tortoise represented in figs. 95 and 96 (p. 523).

Among the even-toed mammals, or Artiodactyls, that lived about the same time, the genus Entelodon was one of the most interesting, and in Pl. XXX is represented the restored skeleton of one of the largest species known from the Lower Miocene. The skull of another species is shown in fig. 97. The type specimen was discovered in northeastern Colorado, where so many other extinct mammals have been found.

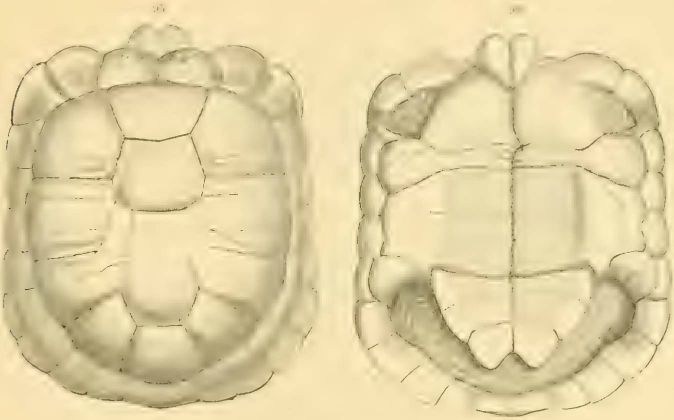


FIG. 95.—*Testudo brontops* Marsh; top view.
FIG. 96.—The same specimen; bottom view.
Both figures are one-twelfth natural size.

The Oreodon beds next above are especially rich in such remains, and the skull of one typical form is shown in fig. 98 (p. 524). In these

FIG. 97.—Skull of *Entelodon clavus* Marsh; with brain-cast; top view. About one-fifth natural size.

Miocene strata the horse family is well represented, and typical specimens of the genus Mesohippus are given in fig. 101, with two other series from the Pliocene for comparison.

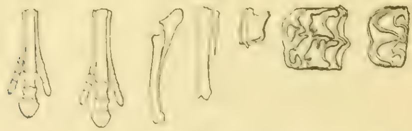
The Pliocene strata in the plains region, already alluded to, contain a rich series of mammals, among which remains of horses and rhinoceroses are especially abundant. The largest of all these mammals was the Mastodon, the remains of which occur in place, and also have been found

FIG. 98.—Skull of *Eporeodon major* Leidy; seen from the left. One-third natural size.

in surface deposits at many points. The skeleton of one species of this genus is restored in Pl. XXXI, which will show the form and proportions of this typical proboscidian.

99

100



101

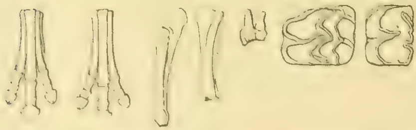


FIG. 99.—Limb bones and teeth of *Pliohippus pernix* Marsh. Pliocene.
FIG. 100.—The same series of *Protohippus avus* Marsh. Pliocene.
FIG. 101.—The same series of *Mesohippus celer* Marsh. Miocene.

Among the extinct horses of this horizon the genera Pliohippus and Protohippus are characteristic, and their remains are almost always to be found by careful search in any favorable locality. Figs. 99 and 100 indicate parts typical of these genera.

Several species of rhinoceros have been found in this horizon, and all appear to have been destitute of horns. The skull of one of the most abundant species is represented in fig. 102.

Above this horizon, the Equus beds and the Quaternary contain many vertebrate fossils of interest, all closely allied to the fauna of to-day.

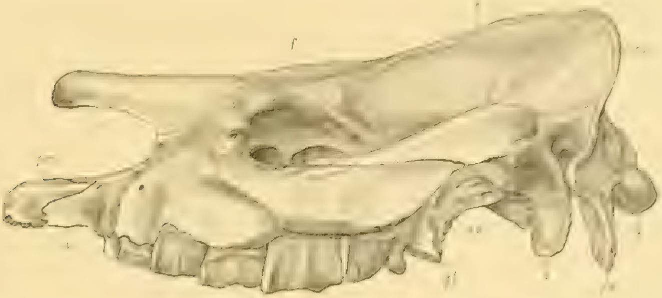


FIG. 102.—Skull of *Aceratherium acutum* Marsh; seen from the left. One-fifth natural size. *f*, frontal; *m*, maxillary; *ma*, malar; *n*, nasal; *o*, occipital condyle; *p*, parietal; *pa*, paroccipital, *pm*, premaxillary; *pt*, pterygoid; *s*, squamosal; *so*, supraocipital.

PART V.

CONCLUSION.

To this short review of the typical vertebrate fossils of the Denver region a few words may be added about the conditions under which these various animals lived and died. Nearly all those here discussed were essentially land animals, but not a few of them, especially of the Reptilia, lived near the water, and there met their fate. The preservation of their remains was probably, without exception, due to their entombment beneath the waters of the great fresh-water lakes which existed in this region during Mesozoic and Cenozoic time.

The climatic conditions under which they lived are clearly indicated by the animals themselves. The gigantic herbivorous dinosaurs of the Jurassic were denizens of a tropical climate, in which rank vegetation supplied them with food and served to protect them from their carnivorous enemies. This climate was clearly a feature of the whole of Jurassic time, and especially characteristic of the zenith of the reptilian age.

In the Cretaceous period that followed, the huge flying reptiles and the gigantic marine saurians, many of them veritable sea serpents in form and habit, clearly prove that the tropical climate still continued in this region. That it prevailed later during this age, the gigantic Ceratopsidæ and their many reptilian contemporaries demonstrate by the abundance of their remains deposited in this region, and especially farther north. Their sudden extinction, which left no survivors, is equal proof of a great change in climate, if not of important geölogical convulsions, at the close of the epoch in which they lived.

Throughout Tertiary time, as indicated by the rich and varied mammalian life, a warm, temperate climate prevailed in the Denver region, and this continued with various changes and a gradually declining temperature until the approach of the Glacial period began to affect all land vertebrate life. The survivors of that epoch and their descendants constitute the existing fauna of to-day.

LIST OF VERTEBRATE FOSSILS.

The following is a list of the more important vertebrate fossils, especially types known to the writer, which are characteristic of Mesozoic or Tertiary horizons represented in the Denver Basin, and have been found within or near that area. Some of the more important localities are also indicated. The original descriptions of the types described by the writer will be found in the American Journal of Science.

Hallopus beds: Near Canyon, Colo.

Hallopus victor.
Nanosaurus rex.
Nanosaurus agilis.

Atlantosaurus beds: Near Morrison and Canyon, Colo.

Atlantosaurus (Titanosaurus) montanus.[1]
Atlantosaurus immanis.[1]
Apatosaurus ajax.[1]
Apatosaurus laticollis.[1]
Brontosaurus excelsus.[1]
Diplodocus longus.[1]
Diplodocus lacustris.[1]
Morosaurus grandis.[1]
Morosaurus agilis.[1]
Stegosaurus armatus.[1]
Stegosaurus stenops.[1]
Camptosaurus medius.
Laosaurus gracilis.
Allosaurus fragilis.
Labrosaurus ferox.
Ceratosaurus nasicornis.
Diplosaurus felix.[1]
Glyptops ornatus.
Ceratodus Güntheri.
Dryolestes gracilis.

[1] These forms were found near Morrison; the others are from near Canyon, but quite a number are common to both regions.

Pteranodon beds: Wallace County, Kans.

Pteranodon occidentalis.
Edestosaurus rex.
Holosaurus abruptus.
Lestosaurus simus.
Hesperornis regalis.
Ichthyornis victor.

Ceratops beds: Near Denver, Colo.

Ceratops alticornis.
Triceratops galeus.
Triceratops horridus.
Claosaurus annectens.
Ornithomimus velox.
Crocodilus humilus.
Compsemys victus.
Trionyx foveatus.
Lepidotus occidentalis.

Brontotherium beds: Weld County, Colo.

Brontotherium gigas.
Brontotherium ingens.
Megacerops Coloradensis.
Titanops curtus.
Ammodon potens.
Entelodon crassus.
Entelodon clavus.
Mesohippus celer.
Meleagris antiquus.
Testudo brontops.

Pliohippus beds: Cheyenne County, Colo.

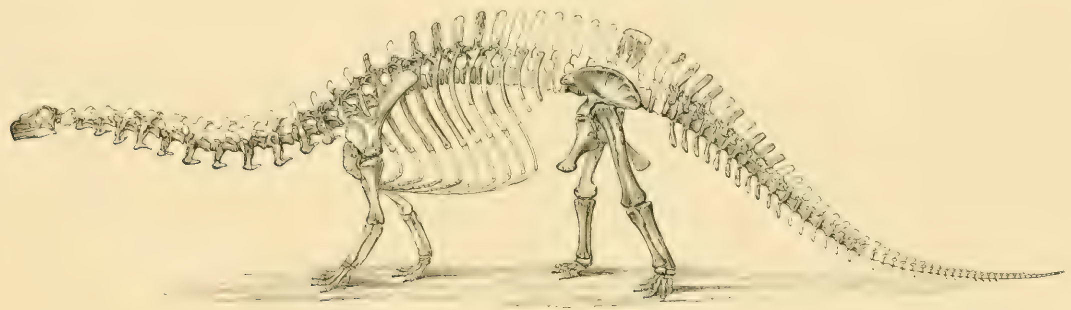
Pliohippus pernix.
Mastodon obscurus.
Aceratherium acutum.

YALE UNIVERSITY, *August 1, 1895.*

PLATE XXI.

PLATE XXI.

JURASSIC DINOSAURS.—SAUROPODA.



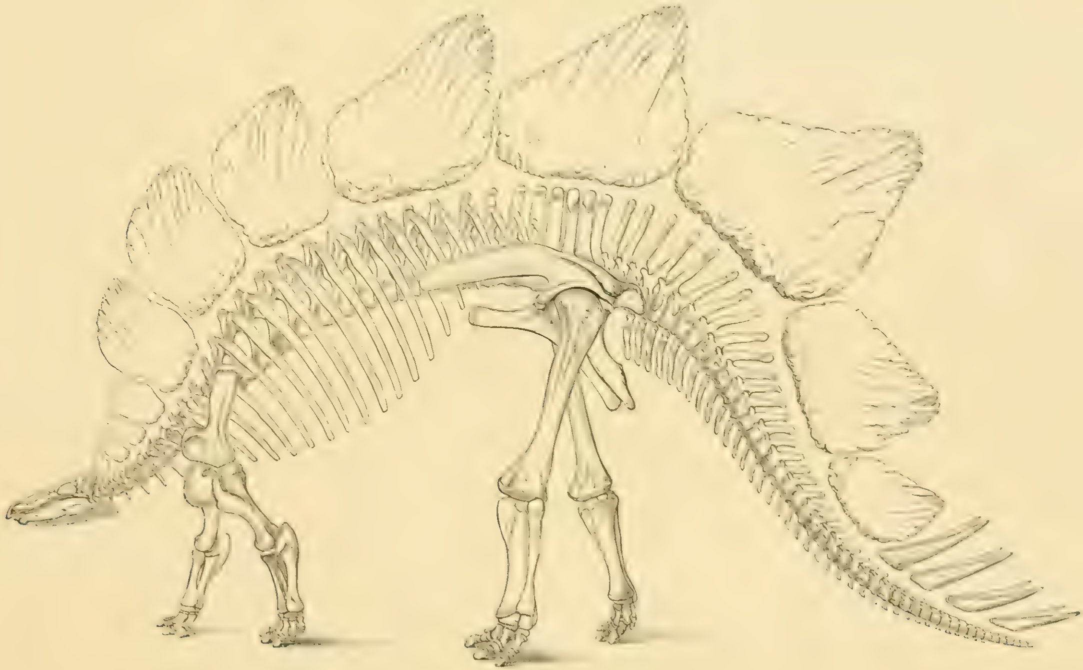
RESTORATION OF BRONTOSAURUS EXCELSUS Marsh.

One-ninetieth natural size. Jurassic, Wyoming.

PLATE XXII.

PLATE XXII.

JURASSIC DINOSAURS.—STEGOSAURIA.



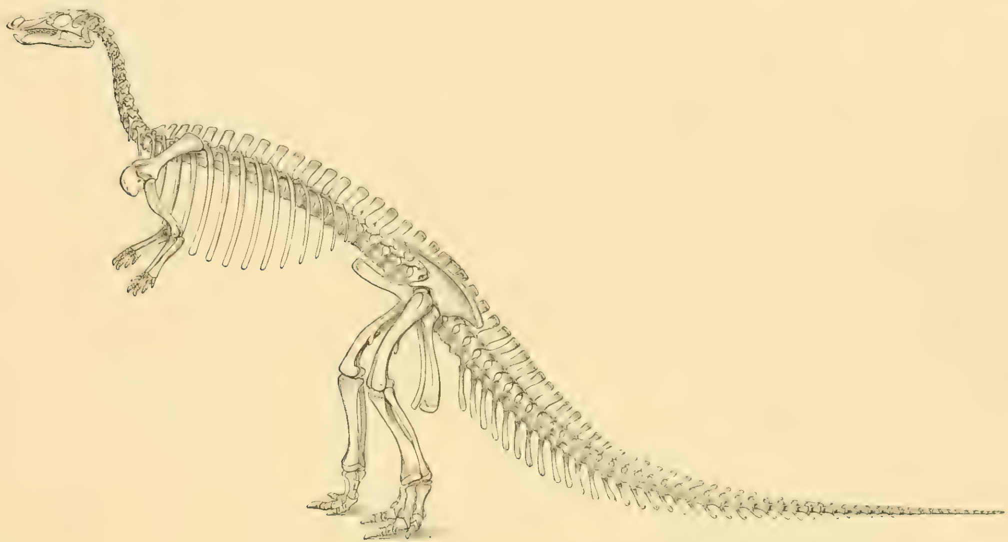
RESTORATION OF STEGOSAURUS UNGULATUS Marsh

One-thirtieth natural size. Jurassic, Wyoming.

PLATE XXIII.

PLATE XXIII.

JURASSIC DINOSAURS.—ORNITHOPODA.



RESTORATION OF CAMPTOSAURUS DISPAR Marsh.

One-thirtieth natural size. Jurassic, Wyoming.

PLATE XXIV.

PLATE XXIV.

JURASSIC DINOSAURS.—ORNITHOPODA.

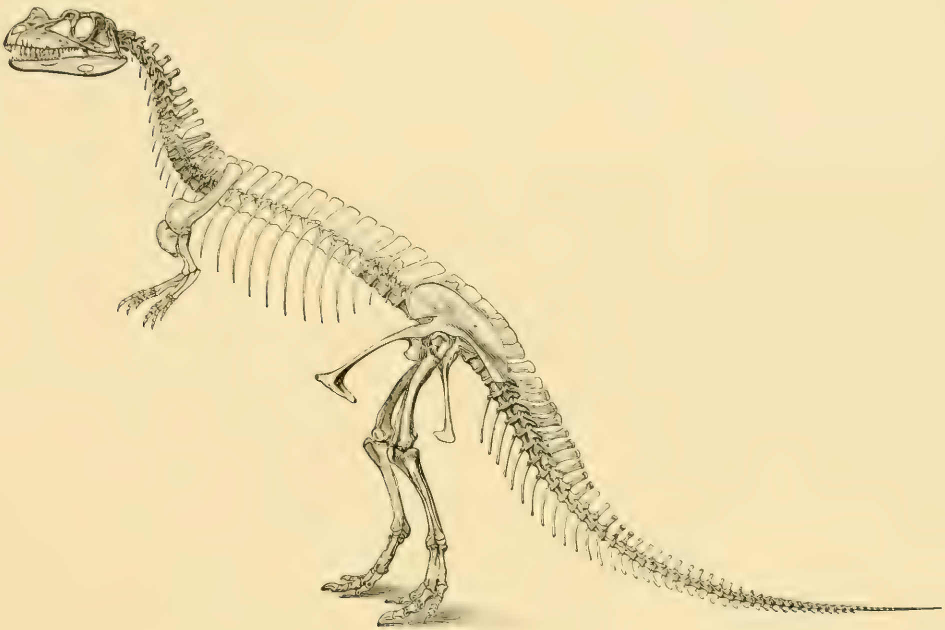
RESTORATION OF LAOSAURUS CONSORS Marsh.

One-tenth natural size. Jurassic, Wyoming.

PLATE XXV.

PLATE XXV.

JURASSIC DINOSAURS.—THEROPODA.



RESTORATION OF CERATOSAURUS NASICORNIS Marsh.

One-thirtieth natural size. Jurassic, Colorado.

PLATE XXVI.

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PLATE XXVI.

CRETACEOUS BIRDS.—ODONTORNITHES.

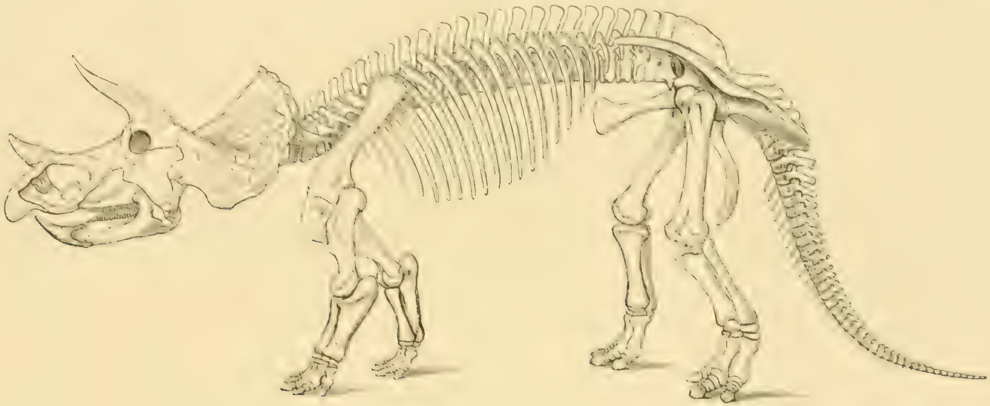
Fig. 1.—RESTORATION OF ICHTHYORNIS VICTOR Marsh.
One-half natural size. Cretaceous, Kansas.

Fig. 2.—RESTORATION OF HESPERORNIS REGALIS Marsh.
One-eighth natural size. Cretaceous. Kansas

PLATE XXVII.

PLATE XXVII.

CRETACEOUS DINOSAURS.—CERATOPSIA.



RESTORATION OF TRICERATOPS PRORSUS Marsh

One-fortieth natural size. Cretaceous, Wyoming

PLATE XXVIII.

PLATE XXVIII.

CRETACEOUS DINOSAURS.—ORNITHOPODA.

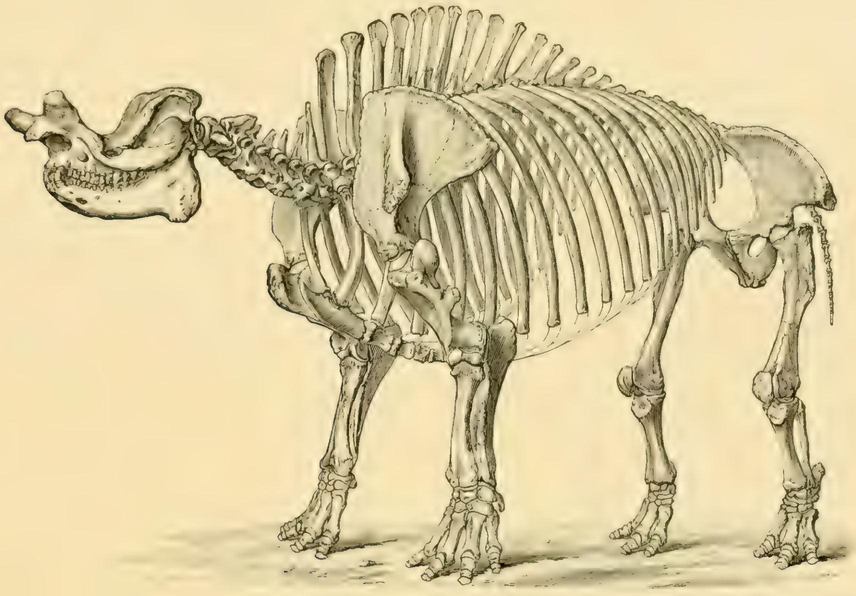
RESTORATION OF CLAOSAURUS ANNECTENS Marsh.

One-fortieth natural size. Cretaceous, Wyoming.

PLATE XXIX.

PLATE XXIX.

TERTIARY MAMMALS.—BRONTOTHERIIDÆ.



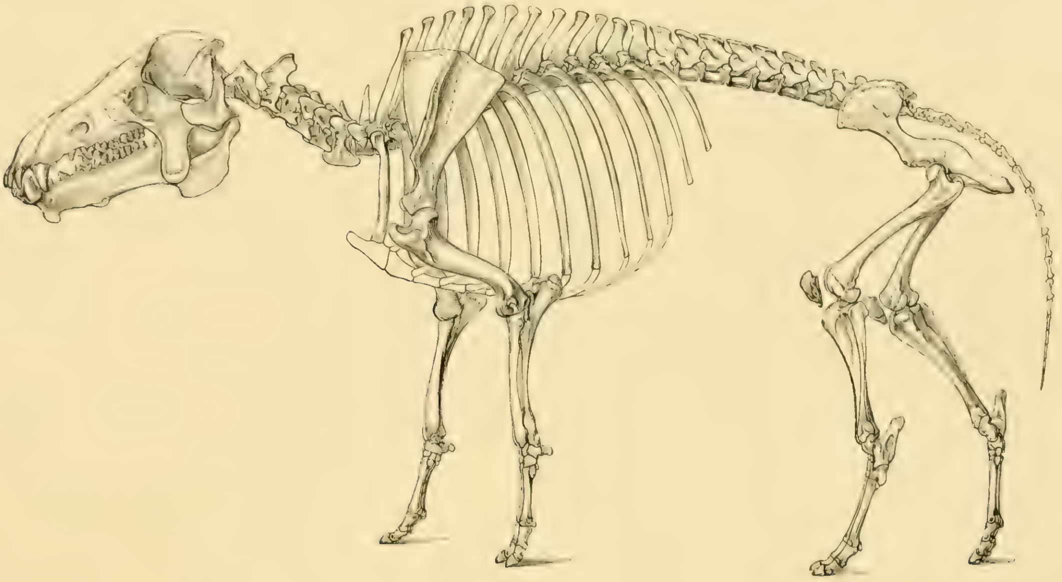
RESTORATION OF BRONTOPS ROBUSTUS Marsh

One twenty fourth natural size. Miocene. Nebraska.

PLATE XXX.

PLATE XXX.

TERTIARY MAMMALS.—ENTELODONTIDÆ.



RESTORATION OF ENTELODON CRASSUS Marsh.

One-twelfth natural size. Miocene, Colorado.

PLATE XXXI.

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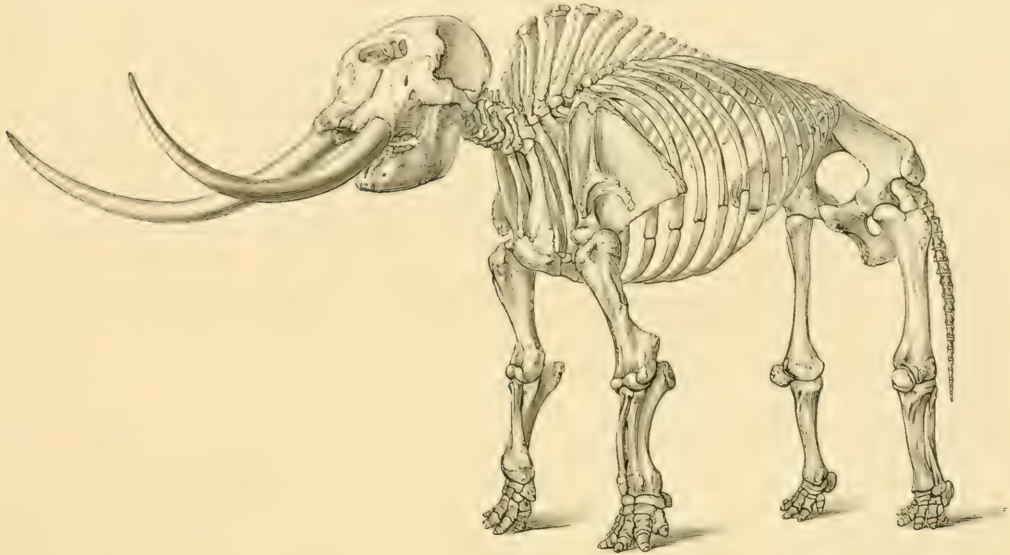
PLATE XXXI.

QUATERNARY MAMMALS.—PROBOSCIDEA.



RESTORATION OF MASTODON AMERICANUS Cuvier.

One-thirty-second natural size Quaternary, New York

INDEX.

D.

ADVERTISEMENT.

[Monograph XXVII.]

The statute approved March 3, 1879, establishing the United States Geological Survey, contains the following provisions:

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization: And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

Except in those cases in which an extra number of any special memoir or report has been supplied to the Survey by special resolution of Congress or has been ordered by the Secretary of the Interior, this office has no copies for gratuitous distribution.

ANNUAL REPORTS.

I. First Annual Report of the United States Geological Survey, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Second Annual Report of the United States Geological Survey, 1880–'81, by J. W. Powell. 1882. 8°. lv, 588 pp. 62 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881–'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882–'83, by J. W. Powell. 1884. 8°. xxxii, 473 pp. 85 pl. and maps.

V. Fifth Annual Report of the United States Geological Survey, 1883–'84, by J. W. Powell. 1885. 8°. xxxvi, 469 pp. 58 pl. and maps.

VI. Sixth Annual Report of the United States Geological Survey, 1884–'85, by J. W. Powell. 1885. 8°. xxix, 570 pp. 65 pl. and maps.

VII. Seventh Annual Report of the United States Geological Survey, 1885–'86, by J. W. Powell. 1888. 8°. xx, 656 pp. 71 pl. and maps.

VIII. Eighth Annual Report of the United States Geological Survey, 1886–'87, by J. W. Powell. 1889. 8°. 2 pt. xix, 474, xii pp. 53 pl. and maps; 1 p. l. 475–1063 pp. 54–76 pl. and maps.

IX. Ninth Annual Report of the United States Geological Survey, 1887–'88, by J. W. Powell. 1889. 8°. xiii, 717 pp. 88 pl. and maps.

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"*Provided*, That hereafter the reports of the Geological Survey in relation to the gauging of streams and to the methods of utilizing the water resources may be printed in octavo form, not to exceed one hundred pages in length and five thousand copies in number; one thousand copies of which shall be for the official use of the Geological Survey, one thousand five hundred copies shall be delivered to the Senate, and two thousand five hundred copies shall be delivered to the House of Representatives, for distribution."

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1. Pumping Water for Irrigation, by Herbert M. Wilson.

GEOLOGIC ATLAS OF THE UNITED STATES.

The Geologic Atlas of the United States is the final form of publication of the topographic and geologic maps. The atlas is issued in parts, progressively as the surveys are extended, and is designed ultimately to cover the entire country.

Under the plan adopted the entire area of the country is divided into small rectangular districts, bounded by certain meridians and parallels. The unit of survey is also the unit of publication, and the maps and descriptions of each rectangular district are issued as a folio of the Geologic Atlas.

Each folio contains topographic, geologic, economic, and structural maps, together with textual descriptions and explanations, and is designated by the name of a principal town or of a prominent natural feature within the district.

Two forms of issue have been adopted: A *library* edition, bound between heavy paper covers and stitched; and a *field* edition, similarly bound, but unstitched.

Under the law a copy of each folio is sent to certain public libraries and educational institutions. A limited number of copies are reserved for distribution to persons specially interested in the region represented. This distribution is at first gratuitous, but when the remaining number of copies of any folio reaches a certain minimum a charge equivalent to cost of publication will be made. In such cases prepayment is obligatory. The folios ready for distribution are listed below.

No.	Name of sheet.	State.	Limiting meridians.	Limiting parallels.	Area, in square miles.	Price, in cents.
1	Livingston*	Montana	110°–111°	45°–46°	3,354	25
2	Ringgold*	Georgia Tennessee	85°–85° 30′	34° 30′–35°	980	25
3	Placerville*	California	120° 30′–121°	38° 30′–39°	932	25
4	Kingston*	Tennessee	84° 30′–85°	35° 30′–36°	969	25
5	Sacramento*	California	121°–121° 30′	38° 30′–39°	932	25
6	Chattanooga*	Tennessee	85°–85° 30′	35°–35° 30′	975	25
7	Pikes Peak*	Colorado	105°–105° 30′	38° 30′–39°	932	25
8	Sewanee*	Tennessee	85° 30′–86°	35°–35° 30′	975	25
9	Anthracite-Crested Butte*	Colorado	106° 45′–107° 15′	38° 45′–39°	465	50
10	Harpers Ferry*	Virginia West Virginia Maryland	77° 30′–78°	39°–39° 30′	925	25
11	Jackson*	California	120° 30′–121°	38°–38° 30′	938	25
12	Estillville*	Virginia Kentucky Tennessee	82° 30′–83°	36° 30′–37°	957	25
13	Fredericksburg*	Maryland Virginia	77°–77° 30′	38°–38° 30′	938	25
14	Staunton*	Virginia West Virginia	79°–79° 30′	38°–38° 30′	938	25
15	Lassen Peak*	California	121°–122°	40°–41°	3,634	25
16	Knoxville*	Tennessee North Carolina	83° 30′–84°	35° 30′–36°	925	25
17	Marysville*	California	121° 30′–122°	39°–39° 30′	925	25
18	Smartsville*	California	121°–121° 30′	39°–39° 30′	925	25
19	Stevenson*	Alabama Georgia Tennessee	85° 30′–86°	34° 30′–35°	980	25
20	Cleveland*	Tennessee	84° 30′–85°	35°–35° 30′	975	25
21	Pikeville*	Tennessee	85°–85° 30′	35° 30′–36°	969	25
22	McMinnville*	Tennessee	85° 30′–86°	35° 30′–36°	969	25
23	Nomini	Maryland Virginia	76° 30′–77°	38°–38° 30′	938	25
24	Three Forks	Montana	111°–112°	45°–46°	3,354	50
25	Loudon	Tennessee	84°–81° 30′	35° 30′–36°	969	25
26	Pocahontas	Virginia West Virginia	81°–81° 30′	37°–37° 30′	951	25
27	Morristown	Tennessee	83°–83° 30′	36°–36° 30′	963	25

* These folios can now be sent only on prepayment of price stated in the last column.

STATISTICAL PAPERS.

Mineral Resources of the United States [1882], by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1883 and 1884, by Albert Williams, jr. 1885. 8°. xiv, 1016 pp. Price 60 cents.

Mineral Resources of the United States, 1885. Division of Mining Statistics and Technology. 1886. 8°. vii, 576 pp. Price 40 cents.

Mineral Resources of the United States, 1886, by David T. Day. 1887. 8°. viii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1887, by David T. Day. 1888. 8°. vii, 832 pp. Price 50 cents.

Mineral Resources of the United States, 1888, by David T. Day. 1890. 8°. vii, 652 pp. Price 50 cents.

Mineral Resources of the United States, 1889 and 1890, by David T. Day. 1892. 8°. viii, 671 pp. Price 50 cents.

Mineral Resources of the United States, 1891, by David T. Day. 1893. 8°. vii, 630 pp. Price 50 cents.

Mineral Resources of the United States, 1892, by David T. Day. 1893. 8°. vii, 850 pp. Price 50 cents.

Mineral Resources of the United States, 1893, by David T. Day. 1894. 8°. viii, 810 pp. Price 50 cents.

On March 2, 1895, the following provision was included in an act of Congress:

"*Provided*, That hereafter the report of the mineral resources of the United States shall be issued as a part of the report of the Director of the Geological Survey."

In compliance with this legislation, the report Mineral Resources of the United States for the Calendar Year 1894 forms Parts III and IV of the Sixteenth Annual Report of the Survey, and Mineral Resources of the United States for the Calendar Year 1895 forms Part III of the Seventeenth Annual Report of the Survey.

The money received from the sale of these publications is deposited in the Treasury, and the Secretary of that Department declines to receive bank checks, drafts, or postage stamps; all remittances, therefore, must be by POSTAL NOTE or MONEY ORDER, made payable to the Director of the United States Geological Survey, or in CURRENCY for the exact amount. Correspondence relating to the publications of the Survey should be addressed

TO THE DIRECTOR OF THE
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

WASHINGTON, D. C., *November, 1896.*

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Series.

United States. *Department of the interior.* (*U. S. geological survey.*)

Department of the interior | — | Monographs | of the | United States geological survey | Volume XXVII | [Seal of the department] | Washington | government printing office | 1896

Second title: United States geological survey | Charles D. Walcott, director | — | Geology | of the | Denver basin | in | Colorado | by | Samuel Franklin Emmons, Whitman Cross, and George Homans Eldridge | [Vignette] |

Washington | government printing office | 1896

4°. 556 pp. 31 pl.

Author.

Emmons (Samuel Franklin), **Cross** (Whitman), and **Eldridge** (George Homans).

United States geological survey | Charles D. Walcott, director | — | Geology | of the | Denver basin | in | Colorado | by | Samuel Franklin Emmons, Whitman Cross, and George Homans Eldridge | [Vignette] |

Washington | government printing office | 1896

4°. 556 pp. 31 pl.

[UNITED STATES. *Department of the interior.* (*U. S. geological survey.*) Monograph XXVII.]

Subject.

United States geological survey | Charles D. Walcott, director | — | Geology | of the | Denver basin | in | Colorado | by | Samuel Franklin Emmons, Whitman Cross, and George Homans Eldridge | [Vignette] |

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4°. 556 pp. 31 pl.

[UNITED STATES. *Department of the interior.* (*U. S. geological survey.*) Monograph XXVII.]