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CLARENCE KING, DIRECTOR

GEOLOGY

AND

MINING INDUSTRY

OF

LEADVILLE, COLORADO

WITH ATLAS

BY

SAMUEL FRANKLIN EMMONS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1886

LETTER OF TRANSMITTAL.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF THE ROCKY MOUNTAINS,
Washington, D. C., October 1, 1885.

SIR: I have the honor to transmit herewith the manuscript of a report on the Geology and Mining Industry of Leadville, Colorado.

To yourself, and to the Hon. Clarence King, under whose direction this investigation was commenced, I am greatly indebted for the facilities and kind encouragement that have always been afforded to those engaged in its prosecution.

Very respectfully, your obedient servant,

S. F. EMMONS,
Geologist-in-Charge.

HON. J. W. POWELL,
Director United States Geological Survey, Washington, D. C.

PREFACE.

The present work was undertaken at the instance of the Hon. Clarence King, first Director of the United States Geological Survey, in 1879. It was his intention that it should form part of a series of monographs which would in time include all the important mining districts of the country, and thus furnish an accurate and permanent record of the manner of occurrence and geological relations of the metallic deposits of the United States, as well as of all substantial improvements in the methods of obtaining the metals from their ores.

In preparing such a monograph the general plan adopted was: first, to obtain an accurate knowledge of the geological structure of the region and of the various rocks of which it is made up; next, to study thoroughly the ore deposits in their varied relations to the inclosing rocks; and, finally, to investigate any methods of extraction or of reduction of the ores that presented new or unusual features, without wasting time upon what was already so well known as to require no further comment. Various circumstances rendered such modifications of this plan necessary in the present case that the various stages of the work could not always be carried on in their logical sequence. The great altitude of the region and consequent inclemency of its climate practically prevented surface work being carried on to advantage during eight months of the year. The organization of the Survey was as yet incomplete, and assistants familiar with this class of work could not immediately be obtained; moreover, a year elapsed after the inception of the work before laboratory facilities could be obtained which rendered it possible to carry on the chemical investigations that form one of its most important and essential features. The first want was accurate and detailed topographical maps, which are more than usually indispensable in the vicinity of Leadville, where the entire rock surface is covered by débris, and the geological structure had to be reconstructed by gathering into a connected whole the data derived from thousands of isolated shafts and tunnels which had penetrated below the surface accumulations.

This want was supplied by Chief Topographer A. D. Wilson, the unequaled accuracy and rapidity of whose work can only be adequately appreciated by those who have had occasion, as we had, to put it to the test of actual instrumental verification. The field work of the map of Leadville and vicinity was completed by him and his two assistants during the months of August and September, 1879, and that of the map of Mosquito Range during part of July, August, and September, 1880.

In December, 1879, I commenced the study of the ore deposits of Leadville. In this I received most invaluable aid from Mr. Ernest Jacob, graduate of the Royal School of Mines of London, who, working at first as volunteer, rendered most continuous and unwearied service during the whole continuance of the investigation To his keen insight into the intricacies of geological structure, his untiring energy in exploring every accessible prospect-hole in the region, and his accurate appreciation of the bearing of the data thus gathered, is attributable in great measure the successful unraveling of the complicated problem presented in the region represented on the map of Leadville and vicinity. So complicated a region, I make bold to say, it rarely falls to the lot of a geologist to study in detail.

In July, 1880, it was first practicable to undertake the study of the high mountain region represented on the map of the Mosquito Range. Here geological and topographical field work went hand in hand, and my party worked together with that of Mr. Wilson until heavy snows at the end of September put an end to outside work. In this field work I had the assistance of Mr. Whitman Cross, who had made a special study of microscopical petrography under Professor Zirkel, of Leipzig, and of Prof. Arthur Lakes, of the School of Mines at Golden, Colo., who devoted his summer vacation to this work. To Mr. Cross, who, like Mr. Jacob, first joined the Survey as volunteer assistant, was intrusted the final petrographical determination of all the crystalline rocks of the region, and the great value of his subsequent investigations in the field of petrography and mineralogy have fully justified the confidence thus placed in his ability.

In the autumn of 1880 the corps was increased by the addition of Mr. W. F. Hillebrand, who had already distinguished himself by his original investigations in inorganic chemistry in the laboratory of Professor Bunsen at Heidelberg; under his direction a laboratory was prepared at Denver in connection with the headquarter offices of this division of the Survey.

During the summer I was fortunate enough to secure the services of Mr. Antony Guyard, a former pupil of the École des Mines, and for twelve years chemist at the well known metallurgical works of Johnson & Mattey, London. At my request Mr. Guyard undertook the labor of making a chemical investigation of the processes of lead smelting as conducted at the various Leadville smelters. His sudden death at Paris, which was closely followed by that of his brother Stanislas, the distinguished French Orientalist, prevented the personal revision of his report which I could have desired him to make; and in that which was made by Mr. Hillebrand and myself we have not always felt justified in making modifications which might have been judged advisable could we have discussed the points with the author himself. Beyond the correction of a few clerical errors it is presented substantially in the form in which it was left by him.

In November, 1880, Messrs. Hillebrand and Guyard commenced their respective chemical investigations, the one of the rocks and ores, the other of the furnace products of Leadville, in the laboratory at Denver.

Mr. W. H. Leffingwell, with the assistance of Mr. Jacob, completed the Leadville map during the latter part of 1880 by the accurate location of various shafts and tunnels, to the number of nearly a thousand, found necessary for the determination of the geological outlines, an extremely laborious undertaking, carried on as it was at times with 15 to 20 feet of snow on the ground.

About the same time the topography and underground workings of the maps of Iron, Carbonate, and Fryer Hills were prepared under my direction by Messrs. H. Huber & Co., F. G. Bulkley & Co., and George H. Robinson & Co., respectively.

From June, 1880, to June, 1881, my time was partially taken up in the supervision and direction of experts employed under the authority of the Superintendent of the Census in making an investigation into the "Statistics and Technology of the Precious Metals" in the Rocky Mountains.

From the close of field work in the summer of 1880 to May, 1881, I was mainly occupied with Mr. Jacob in completing the examination of the mines and deposits of Leadville. In this work we received, with a single exception, the most courteous treatment from mine owners and superintendents, who not only opened their mines freely to our inspection and permitted the use of the maps of their underground workings, but also aided us materially in many cases by the information they furnished from their own every-day experience. To these gentlemen, individually and collectively, I return my most hearty thanks, as well for the services above mentioned as for the confidence thereby displayed in the disinterestedness of our motives and our wish to be of service to the mining public in general without favoring unduly any individual or corporation.

During the summer of 1881 the individual members of the corps, aided by Messrs. Morris Bien and W. B. v. Richthofen, were occupied in collating the results obtained, and in the preparation of the various maps and illustrations for the engraver, and by autumn the work was so far completed that I was enabled to embody the principal results arrived at in an abstract published in the Second Annual Report of the Director of the Survey.

During the time that has elapsed since the publication of that abstract the development of the Leadville mines has proceeded with rapid strides, and already the ores are changing from carbonates and chlorides to sulphides. In other respects also these developments have afforded most gratifying confirmation of the general accuracy of the geological outlines given on the accompanying maps and sections. Even had it been otherwise, it would have been impracticable to have changed what had long since been engraved. In the press of other work it was not possible to attempt another examination of the field, and therefore in the final revision of this long-delayed material the changes have been mainly confined to condensing and leaving out what has in a measure lost its value by the lapse of time. Where new facts have been obtained, they have been inserted in notes. The report as it now stands is therefore essentially that which was prepared four years ago, and as such it should be criticised by those who have occasion to read it.

S. F. EMMONS.

WASHINGTON, *October* 1, 1885.

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ERRATA IN ATLAS SHEETS.

SHEET VI. Blue section line BB should run through the summit of Mount Lincoln and thence to summit of Mount Cameron, instead of direct to latter from point on east spur.

VII. The line of the Mike fault should not be continued south of Empire gulch.

XII and XIV. The blue line, showing the course of the Starr ditch north of California gulch, has been omitted; the names give an approximate idea of its position.

XIII. Color on small block of Blue Limestone at Comstock tunnel (L–38) has been left out.

XV. "Ditch" just west of Sequa shaft should be "Little Evans gulch."

XXI. Section JJ, "Iowa gulch fault," should be "Iowa fault."

XXIII. Parallel linings to denote "inclines" have been omitted on Silver Wave claim.

XXV. Section FF, "California fault," should be "Dome fault."

XXX. Section GG, "White Porphyry" color under drift east from upper shaft of Yankee Doodle mine, should have been that of "vein material."

XXXI. Shaft "Carboniferous No. 7" should be "Carboniferous No. 1."

Shaft "Little Chief No. 3" (southernmost) should be "Little Chief No. 5."

Shaft "Little Pittsburgh No. 3" (near E, boundary line, and just north of dike), "No. 3" left out.

Shaft Climax No. 2 (near E, boundary line, and line of section), "No. 2" left out.

XXXV. F–10 "Leavenworth" should be "Lawrence."

M-5 "Beecher" should be "Belcher."

BRIEF OUTLINE OF RESULTS.

GEOLOGY.

The Mosquito Range, the study of whose geological structure formed a necessary basis for that of the ore deposits of the Leadville region, is the western boundary of the South Park, and has thus been considered from a topographical standpoint to form part of the Park Range. Geology shows, however, that in Paleozoic times the boundaries of the depressions now known as the Parks were formed by the Archean land masses of the Colorado Range on the east and of the Sawatch and its continuation to the north, the Park Range on the west, and that the uplift of the Mosquito Range did not occur until the close of the Cretaceous.

Prior to this uplift the various porphyry bodies, which now form a prominent feature among the rock formations of the region, were intruded into the sedimentary beds deposited during Paleozoic and Mesozoic times, spreading out between the beds and sometimes crossing them, but being most uniformly distributed at the top of the Lower Carboniferous or Blue Limestone. It was in this limestone that the greater part of the ores were deposited, and the original deposition must have taken place after the intrusion of the porphyry and before the uplift of the range.

In the uplift of the range both eruptive sheets and sedimentary beds, with the included ore deposits, were plicated and faulted, and by subsequent erosion an immense thickness of rocks has been carried away, laying bare the very lowest rocks in the conformable series; the outcrops are, however, frequently buried beneath what is locally called "wash," a detrital formation of glacial origin. In the Leadville region, owing to the reduplication caused by faulting, a series of outcrops of easterly dipping beds of the Blue Limestone are exposed beneath the wash, of which all are metalliferous and a considerable proportion carry pay ore.

ORE DEPOSITS.

The principal ore deposits of Leadville occur, as above indicated, in the Blue Limestone and at or near its contact with the overlying bodies of porphyry. The ores consist mainly of carbonate of lead, chloride of silver, and argentiferous galena, in a gangue of silica and clay, with oxides of iron and manganese and some barite. These materials are mainly of secondary origin, and result from the alteration by surface waters of metallic sulphides.

The study of these deposits has shown: 1, that they were originally deposited as sulphides, and probably as a mixture, in varying proportions, of galena, pyrite, and blende; 2, that they were deposited from aqueous solutions; 3, that the process of deposition was a metasomatic interchange between the materials brought in by the solutions and those forming the country rocks, consequently that they do not fill pre-existing cavities; 4, that the ore currents from which they were deposited did not come directly from below, but were more probably descending currents; and 5, that these currents probably derived the material of which the ore deposits are formed mainly from the porphyry bodies which occur at horizons above the Blue Limestone.

PRACTICAL CONSIDERATIONS.

Inasmuch as the ore currents did not come directly from below, it is not advisable to search for ore below the Blue Limestone horizon. This horizon, however, should be thoroughly prospected, and the maps and sections show its probable position in the as yet unexplored areas; the explorations, moreover, should not be confined to the upper surface of this limestone, but carried into its mass wherever there are indications of ore, and especially along the contact of transverse bodies of Gray Porphyry. The probabilities are that very considerable bodies of ore remain as yet undiscovered, and the most promising areas for prospecting are indicated. It is also probable that as the distance from the surface increases the ores will be found less altered, and that they will therefore be less easily reduced by the smelting processes now employed.

The petrography of the district is treated by Mr. Whitman Cross in Appendix A. The results of chemical investigation and the methods of research are given in Appendix B by Mr. W. F. Hillebrand, and in Appendix C Mr. Guyard has given a memoir on lead smelting as conducted at Leadville, showing the character of the plant, the composition of ores, fluxes, and furnace products, and discussing the reactions which take place in the blast furnaces.

GEOLOGY AND MINING INDUSTRY OF LEADVILLE.

PART I.

GEOLOGY.

CHAPTER I.

LEADVILLE—ITS POSITION, DISCOVERY, AND DEVELOPMENT.

Topographical description.—The city of Leadville is situated in the county of Lake, State of Colorado, on the western flank of the Mosquito Range, at the head of the Arkansas Valley. Its exact position is in longitude 106° 17′ west from Greenwich and 39° 15′ north latitude. Its mean elevation above sea-level is 10,150 feet, taken at the court-house, in the center of the city.[1]

The most striking feature in the topographical structure of the Rocky Mountains in Colorado is, as is well known to those familiar with western geography, the fact that it consists of two approximately parallel ridges, separated by a series of broad mountain valleys or parks.

The easternmost of these uplifts, the Colorado or Front Range, rises abruptly from the Great Plains, which form its base at 5,000 to 6,000 feet above the sea-level, to a crest of 13,000 to 14,000 feet. It is deeply scored by narrow, tortuous gorges, worn by mountain streams, whose clear waters debouch upon the plains and become absorbed in the sluggish, turbid currents of the Platte and Arkansas Rivers. The trend of the range is due north and south, its highest portions being mostly included within the

[1] The datum point from which the levels of the map of Leadville were reckoned is the threshold of the First National Bank, a stone building at the southeast corner of Harrison avenue and Chestnut street. The altitude of this point, as determined by connection by levels with the bench-marks of the Denver and Rio Grande Railroad, is 10,135.55 feet; by levels with the bench-marks of the Colorado Central Railroad, 10,113 feet; by depression angles from the top of Mount Lincoln, 10,112 feet. As a mean, the contour passing through it is assumed to be 10,125 feet, greater weight being given to the first figure, since the leveling by which it was arrived at was probably more carefully done than in the case of the other two. A level-line had been run from Fairplay to the top of Mount Lincoln by the members of the Hayden Survey in 1872.

boundaries of the State, beyond which at either end it becomes gradually lower, and disappears as a topographical feature beneath the plains. To the west of this range lie the mountain valleys of the North, Middle, South, and San Luis Parks, in Colorado, and the Laramie Plains, in Wyoming, each of which possesses the same general feature of being nearly completely encircled by mountain ridges. On the other hand, each has distinct topographical features of its own, which need not be entered upon here.

Beyond the parks on the west, and separating them from the great basin of the Colorado River, is a second mountain uplift, to which the general name of Park Range has been given. It has by no means the regular structure of the Colorado Range, but is made up of a series of short ranges en échelon, from which offshoots connect with the latter, forming the ridges which separate the different park basins. In the latitude of Leadville this western uplift consists of two distinct ranges, the Mosquito or Park Range—the latter being the name given in the Hayden atlas of 1877, probably because it forms the boundary of the South Park—and the Sawatch Range, which forms the water-shed between the Atlantic and Pacific waters.

The Mosquito Range is a narrow, straight ridge, about eighty miles in length, trending a little west of north, and is characterized by long, regular slopes scored deeply by glacial gorges on the east toward South Park and by an abrupt irregular inclination on the west towards the Arkansas Valley.

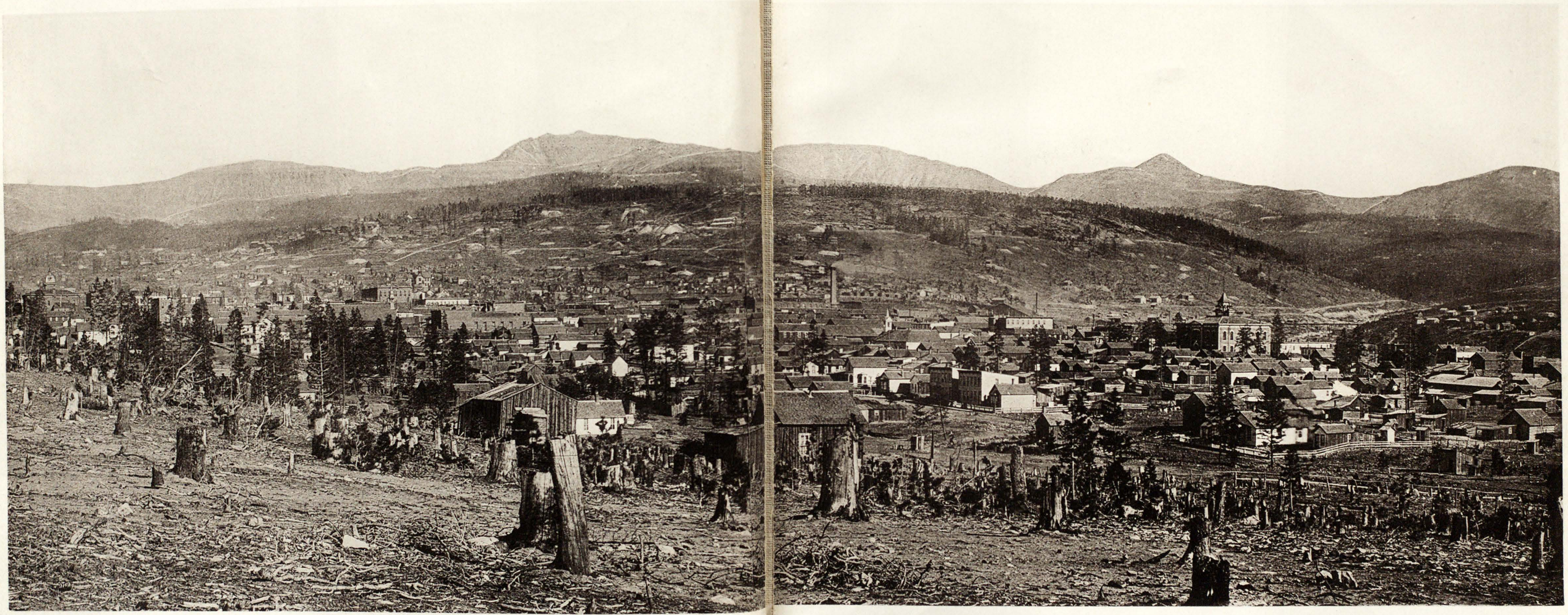
The Sawatch Range, on the other hand, is a broader, oval-shaped mountain mass, divided by the deep gorges of its draining streams into a series of massives and wanting the continuous ridge structure of the Mosquito Range. In this respect, as in its geological composition, which is the determining cause of the difference of its topographical forms, it resembles the Colorado Range. The culminating points of each range have a remarkably uniform elevation of about fourteen thousand feet above sea-level.

Between the two ranges lies the valley of the Upper Arkansas, a meridional depression 60 miles in length and about sixteen miles in width, measured from the crest of its bounding ridges. Its direction is parallel to that of the Mosquito Range, being a little east of south in its mean course, though more nearly north and south towards its head. From its southern end the Arkansas River, after receiving the waters of the South Arkansas, bends sharply to the east and cuts through the southern continuation of the Mosquito and Colorado Ranges in deep cañon valleys, the last well known to tourists as the Royal Gorge. About midway in the Upper Arkansas Valley the present bed of the stream is confined within a narrow rocky cañon, called from the prevailing rock of the surrounding hills Granite Cañon. Both above and below this cañon the foot-hills of the bordering ranges recede again, leaving a valley bottom from six to ten miles in width. But little of this area is occupied by actual alluvial soil, its surface consisting mostly of gently sloping, gravel-covered terraces. In the area above the cañon, which is about twenty miles long, the eye is at once arrested by its basin form. In the center is a relatively wide stretch of meadow land immediately adjoining the river, on either side of which mesa-like benches slope gently up to the foot-hills of the mountains, three or four miles distant, which rise abruptly from these terraces in broken, irregular outlines. The suggestion thus offered by its basin shape and terrace-like spurs that this portion of the valley was once filled by a mountain lake is confirmed, as will be seen later, by the geological facts developed during the present investigation.

On the upper edge of one of these terraces, on the east side of the valley, is situated the city of Leadville. From the north bank of California gulch it extends along the foot of Carbonate hill to the valley of the east fork of the Arkansas, covering, with its rectangular system of streets and contiguous smelting works, an area of nearly 500 acres, while on the hill slopes immediately above are situated the mines which constitute its wealth. On Plate II is given the reproduction of a photograph of the city, taken from a point in its western outskirts on Capitol Hill ridge, near the junction of the two branches of the Denver and Rio Grande Railroad and about west of the Harrison smelter. Although the plate leaves much to be desired in point of distinctness and the shape of the mountain spurs back of the town are necessarily obscured by foreshortening, it serves to give a general idea of the city and its surroundings. The square building with cupola, on the extreme left, is the court-house, back of which the wooded ridge in the middle distance is Yankee Hill; a similar building to the right toward California gulch is the high school. The chimney in the middle is that of the Harrison Reduction Works, to the right of which is the Tabor mill. The slopes immediately back of the town are those of Carbonate hill, beyond which is seen the round summit of Ball Mountain, with Breece hill, as a wooded spur, extending northward from it. Still farther back the ridge slopes up in apparent continuity to Dyer Mountain, the highest point on the sky-line. To the left of Dyer Mountain is Mount Evans, $6\frac{1}{4}$ miles distant in a straight line, and on its right is Mount Sherman, forming the eastern walls of Evans and Iowa amphitheatres respectively. On a clear day the outlines of rock formations on these walls may be very distinctly seen.

Routes of approach.—The approach to Leadville, as may be seen from the above brief sketch of its topographical situation, was extremely difficult before the development of its wealth had led to the building of railroads. Three routes of travel were available. The middle one, or that most used by travelers in coming from Denver, crossed the Colorado Range near the South Platte Cañon, at an elevation of 10,000 feet, and skirting the northern rim of South Park, through the mining town of Fairplay, crossed the Mosquito Range at Mosquito pass opposite Leadville at an altitude of 13,600 feet, or, making a detour of ten or twelve miles to the southward, at Weston's pass, whose summit is only 12,000 feet above the level of the sea. This general route the Denver and South Park Railway follows, winding up the narrow and tortuous gorge of the South Platte and passing over Kenosha pass at the head of its north fork into South Park; to cross the Mosquito Range, however, it is obliged to make a longer detour to the southward and pass down the valley of Trout Creek, a tributary of the Arkansas, which, heading on the east side of the Mosquito Range, debouches into the Arkansas Valley at Buena Vista, 40 miles south of Leadville.

The southern route, before the time of railroads, generally crossed the Colorado Range at the Ute pass above Colorado Springs, and, traversing the lower end of South Park, passed into the Arkansas Valley either at Trout Creek or at Weston's pass. The Denver and Rio Grande Railway, however, has located its line — a triumph of engineering skill — directly up the valley of the Arkansas, which it follows through cañons and gorges that before were practically impassable.



LEADVILLE AND THE MUSQUITO RANGE

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The northern route starts from Golden, near Denver, and, following up the cañon of Clear Creek, crosses the Colorado Range at an altitude of 12,000 feet, either by the Argentine or by Loveland's pass. It then crosses the southern edge of Middle Park along the valley of Snake River and bends southward up the valley of Ten-Mile Creek, having thus gone around the northern end of the Mosquito Range. After crossing the relatively low divide of Frémont's pass (11,300 feet), it reaches Leadville by descending the east fork of the Arkansas. At either end of this route railroads are already built, namely, up the valley of Clear Creek to Georgetown, and from Leadville across Frémont's pass down Ten-Mile Valley to its junction with the Blue. But the advisability of completing the connecting link at such an altitude, in practical competition with the two already existing lines, seems under present conditions of development to be somewhat doubtful.

Discovery of the precious metals.—The discovery of the Leadville deposits presents so striking a picture of the life of the pioneer miner in the West, and of the large element of chance connected with it, that it seems proper to give its history with all the fullness of detail which the somewhat imperfect data obtainable will allow.

The earliest known exploration of the valley of the Upper Arkansas was that made by the expedition of Frémont in 1845. In his second expedition, in 1842, he had aimed at tracing the Arkansas River to its source, but, unwittingly leaving the main stream, had followed up the Fontaine qui bouille, now called Fountain Creek, probably passing near the present site of Denver, and struck into the mountains at some point nearly opposite that place. In 1845, however, as indicated by General Warren, he probably entered the mountains near where Cañon City now stands, and crossed the southern end of South Park, reaching the Upper Arkansas Valley through the valley of Trout Creek. Thence, following the Arkansas to its head, he crossed what was then called Utah pass and descended Eagle or Piney River to its confluence with the Grand or Blue. It seems probable, therefore, that the name of Frémont's pass, which is given to that of Ten-Mile Creek, would have been more appropriately applied to the Tennessee pass, which divides the Eagle River from the head of the Arkansas.

There is little doubt that this striking valley was afterward visited by trappers and individual explorers, but of such visits no record is left so far as is known to the writer. This region, like that of the parks, formed part of the debatable ground between the tribes of Arapahoes and Utes, who were constantly at war with each other and who made excursions to these mountain valleys simply for the purpose of hunting and without any permanent occupancy.

During the summer of 1859, at the time of the great Pike's Peak excitement, a continuous stream of emigrant wagons stretched across the plains, following up the Arkansas River to the base of Pike's Peak. As is generally the case in such mining rushes, the golden dreams of a large portion of those attracted by the marvelous stories of the wealth that existed in the streams issuing from the mountains were never realized. Many of the wagons that had crossed the plains in the early summer, carrying the triumphant device "Pike's Peak or bust," returned later over the same route with this device significantly altered to "Busted." The more adventurous and hardy of these pioneers, although disappointed in their first anticipations, pushed resolutely up through the rocky gorges towards the sources of the streams. Some of these found gold in Russell gulch, in the valley of Clear Creek, where the first mining developments were made within the State and where now stand the flourishing mining towns of Central City and Black Hawk. Others wandered across the Colorado Range into South Park, and found gold-bearing gravel deposits on its northern border, in Tarryall Creek and on the Platte in the neighborhood of Fairplay. This is, as far as can be learned, the extent of the explorations made in 1859.

In the early spring of 1860 several small parties crossed the second range into the Arkansas Valley. Among the number were Samuel B. Kellogg, now justice of the peace at Granite, and H. A. W. Tabor, later millionaire and lieutenant governor of the State of Colorado. Mr. Kellogg had already had an experience of ten years in placer mining in California when he came to Colorado in 1859. In February, 1860, he started with Tabor and his family, their wagon being the first that ever went as far as the mouth of the Arkansas. They pushed up the valley and about April 1 settled down at the site of the present town of Granite, about eighteen miles below Leadville. Here, having discovered gold in Cash Creek, whose placer deposits are worked even at the present day, they whipsawed lumber to make sluices for washing its gravels. A few days after their arrival news was brought to them of the discovery of gold in California gulch. Two parties of prospectors had, it seems, already preceded them, though their route is unknown. Foremost among their names are those of Slater, Currier, Ike Rafferty, George Stevens, Tom Williams, and Dick Wilson, from the last of whom many of the following facts were obtained: The first hole dug in California gulch was about two hundred feet above the site of the present Jordan tunnel, the second just below the present town of Oro. Owing to the richness of the ground and the number of the persons present, gold was discovered at an unusual number of points, and 14 discovery claims of 100 feet each were located. Kellogg and Tabor met the prospectors at the mouth of Iowa gulch, as they returned from locating the discovery claims, and agreed to prospect that gulch. They returned to Cash Creek for provisions, and went finally to California gulch on the 26th of April, 1860, as Iowa gulch had yielded little fruit to their labors — the geological reasons for which will be explained later.

In spite of the difficulties of communication in this wild region, the news of the rich discovery of gold spread with amazing rapidity. The day after their arrival 70 persons came into the gulch from the Arkansas Valley; by July it was estimated that there were 10,000 persons in the camp. It is said that $2,000,000 worth of gold was taken out during the first summer. Probably considerable deductions may be made from this estimate for the exaggeration that fills men's minds in moments of such excitement. The record of claims located, however, shows enormous activity in mining during this summer. In California gulch alone, 339 claims, 100 feet in width, were located. Single individuals are said to have carried away from $80,000 to $100,000 each as the result of their first summer's labor. Tabor and Kellogg worked their own claims and made about $75,000 in sixty days. The total production of the placer claims is generally stated at from $5,000,000 to $10,000,000, but a more conservative estimate places it at from $2,500,000 to $3,000,000. The climax was soon reached, and after the first year the population of this new district, whose post-office was then known as Oro

City, rapidly decreased, until within three or four years the thousands had dwindled into hundreds. Kellogg, with the restless spirit of the western prospector, wandered away in the early part of the summer into the San Juan region and did not return. Tabor started the solitary store in the place, his wife being at the time the only person of her sex in the camp. When the product of the placers had gradually decreased and the prosperity of the camp was at its lowest ebb, he moved across the range to Buckskin Joe, which was then enjoying a fitful prosperity from the rich developments of the Phillips mine; but returned later, when the discovery of vein gold in the Printer Boy mine revived for a time the waning prosperity of the gulch.

Development of mines.—In 1861 a ditch was built from Evans gulch across the head of California gulch, by means of which sluice mining was carried on, but owing to the great cost of supplies, which had to be brought in on the backs of animals, only the very richest gravels could be worked with profit, and at that time little attention was paid to vein deposits. Among the early miners it is probable that few if any suspected the existence of the real mineral wealth that the region contained, although they were much annoyed in their working by worn, iron-stained fragments of heavy rock, which they had to throw out by hand from their sluices, the water not having sufficient force to carry them down.

Report says that in August, 1861, C. M. Rouse and C. H. Cameron, of Madison, Wis., "struck carbonates," of which a small quantity was shipped to George T. Clarke, of Denver; and that samples which he sent to Chicago yielded by assay 164 ounces of silver to the ton. The Washoe Mining Company is said to have been formed on the strength of these discoveries, but no work was done upon the claims, whose location, if they really existed, is now unknown.

In June, 1868, the first gold vein, called the Printer Boy, was discovered by Charles J. Mullen and Cooper Smith, who were prospecting for J. Marshall Paul, of Philadelphia; and in August the Boston and Philadelphia Gold and Silver Mining Company of Colorado was organized, and a stamp mill was built at Oro, in California gulch, to treat the ore from this vein. A very considerable amount of gold is said to have been obtained from it, though it is difficult to obtain actual data as to its production. Estimates place its total yield at $600,000 to $800,000. The "5–20" vein was also opened at this time on the opposite side of the gulch, and also an extension of the Printer Boy, called the Lower Printer Boy. The working of these mines, which was carried on more or less continuously until 1877, imparted at times a fitful prosperity to the region. Meanwhile the location of the town of Oro had been frequently changed. It was first scattered along California gulch, then concentrated at the mouth of the gulch, near the present city of Leadville, and later moved up to the vicinity of the stamp mill, which still stands among the few cabins to which the name of Oro City is yet applied.

During this time the Homestake mine in the Sawatch Range, near Homestake Peak, opposite the head of the Arkansas, had been opened and was yielding rich silver ore. In 1875 a smelter was built at Malta, west of Oro, to treat the ore from this mine and from others which it was expected would be developed in that region. This smelter, like so many others built before any permanent production could be counted on for its supply, has never been successful.

To Mr. A. B. Wood and his associate, Mr. W. H. Stevens, both experienced and scientific miners, is due the credit of being the first to recognize the value of the now famous carbonate deposits of Leadville. Mr. Wood came to California gulch first in April, 1874, to work the Star placer claim. While examining the gravel in the gulch he was struck by the appearance of what the miners call "heavy rock," some of which he assayed. His specimens were not rich, yielding only 27 per cent. lead and 15 ounces silver to the ton; but the matter seemed to him worthy of investigation. He put prospectors at work to find the croppings of the ore deposits, and in June, 1874, the first "carbonate-in-place" was found at the mouth of the present Rock tunnel, on Dome hill. About the same time ore was discovered in a shaft sunk by Mr. Bradshaw near the bed of the gulch on the present Oro La Plata claim; but it is maintained by some that this ore was not in place, but simply "wash," accumulated from the abrasion of the adjoining croppings. Prospecting was quietly continued by Mr. Wood, but no claims were taken up, as the old placer claims — which, though abandoned, would still be in force for another year — covered all the ground adjoining the gulch. Meanwhile he studied the occurrence of the mineral and the outcrops of the limestone on either side of California gulch. In the spring of 1875 he took Mr. Stevens and Professor H. Beeger, the latter then in charge of the Boston and Colorado Smelting works at Alma, to Iron and Dome hills, and showed them in the forest that then covered the slopes the outcrops, respectively, of the Lime, Rock, and Dome claims. During this and the following summer the principal claims which constitute the valuable property of the Iron Silver Mining Company were located by Messrs. Wood and Stevens in the interest of Detroit parties. The first ore was extracted from the Rock mine, where a large mass of hard carbonate formed a cliff outcrop on the side of California gulch. This ore was rich in lead, but ran very low in silver. During the summer of 1876 ore was first taken from the croppings of Iron and Bull's Eye claims, and some rich assays, as high as 600 to 800 ounces to the ton, were obtained from it.

The first working tests of Leadville ore were made by Mr. A. R. Meyer, a graduate of European mining schools, who first came to California gulch in 1876 from Alma, acting as agent for the St. Louis Smelting and Refining Company. In the fall of that year he shipped 200 to 300 tons of ore, principally taken from the Rock mine, by wagon to Colorado Springs, and thence by rail to St. Louis. The freight to Colorado Springs cost $25 per ton and the ore averaged only seven ounces in silver to the ton; it contained, however, 60 per cent. lead, and in spite of the high cost of freight yielded a profit, owing to the high price of lead (seven cents a pound) then ruling. It having thus been proved that Leadville ore could be worked at a profit, prospecting was vigorously carried on, the next discovery being that of the Gallagher Brothers on the Camp Bird claim, supposed at that time to be the northern continuation of the Iron-Lime outcrop. This discovery was made late in the fall of 1876, and the claim now forms part of the property of the Argentine Mining Company. During this winter the Long and Derry mine was discovered by two prospectors of these names, who still own the mine and have become wealthy from its product. During the spring and summer of 1876 discoveries were made along what was then known as the second contact, on Carbonate hill, the Carbonate and Shamrock mines being the first to yield considerable quantities of pay ore.

In the following years the famous ore bodies on Fryer hill were discovered by a singular accident. At this point there is no outcrop, the whole surface of the hill being covered to an average depth of 100 feet by detrital material. Tradition has it that two prospectors were "grub-staked," or fitted out with a supply of provisions, by Tabor, half of all they discovered to belong to him. Among the provisions was a jug of whisky, which proved so strong a temptation to the prospectors that they stopped to discuss its contents before they had gone a mile from town. When the whisky had disappeared, though its influence might probably have been still felt, they concluded that the spot on which they had thus prematurely camped was as good a one to sink a prospecting hole on as any other. At a depth of 25 or 30 feet their shaft struck the famous ore body of the Little Pittsburg mine, the only point on the whole area of the hill where rock in place comes so near the surface. Discoveries rapidly multiplied in this region; immense amounts of ore were taken out, and the claims changed hands at prices which advanced with marvelous rapidity into the millions. A half interest in one claim which was sold one morning for $50,000, after being transferred through several hands, is said to have been repurchased by one of the original holders for $225,000 on the following morning.

The foundation of Mr. Tabor's wealth was laid in the first discovery on Fryer hill, but its amount was materially increased in a singular way. When the fame of the rich discovery of Fryer hill had already become known at Denver, the wholesale house from which he was in the habit of buying his provisions commissioned him to buy for them a promising claim. On his return to Leadville, in accordance with this agreement, he purchased on their account, for the sum of $40,000, the claim of a somewhat notorious prospector known as Chicken Bill, on what is now Chrysolite ground. Chicken Bill, in his haste to realize, had not waited till his shaft reached rock in place, but had distributed at its bottom ore taken from a neighboring mine, or, in the language of the miners, he had "salted" his claim. After the bargain with Tabor had been concluded he could not resist the temptation of relating to a few of his friends the part he had played in the transaction. The report of what he had done thus reached the ears of Mr. Tabor's Denver correspondents before he himself arrived to deliver the property, when they not unnaturally declined to receive it, and Mr. Tabor was obliged to keep it himself. He, with his associates, under the title of Tabor, Borden & Co., afterward bought some adjoining claims and developed their ground, from which they are said to have taken out in the neighborhood of $1,500,000, and afterward to have sold their property to the Chrysolite Company for a like sum.

In the spring of 1877, under Mr. Meyer's direction, the first smelting furnace was erected at Leadville by the St. Louis Smelting and Refining Company, now known as the Harrison Reduction Works, and others followed in rapid succession.

Growth of the city.—The nucleus of the present city of Leadville consisted of a few log houses scattered along the borders of the California gulch below the Harrison Reduction Works. In the spring of 1877 a petition for a post-office was drawn up by Messrs. Henderson, Meyer, and Wood, which necessitated the adoption of a name for the new town. Mr. Meyer proposed the names of Cerussite and Agassiz, both of which were rejected as being too scientific. Mr. Wood proposed the name of Lead City, to which Henderson objected that it might be confounded with a town of the same name in the Black Hills, and the name of Leadville was finally adopted as a compromise. The rapidity of the growth of this city borders on the marvelous. In the fall of 1877 the population of Leadville was estimated at about two hundred persons. The business houses of the town were a 10 by 12 grocery and two saloons. In the spring of 1878 a corporation was formed, which was continued for six weeks, when the town's growth justified its transformation into a city of the second class, Mr. W. H. James being the first mayor and John W. Zollars city treasurer. Within two years Leadville grew to be the second city in the State, with 15,000 inhabitants and assessable property of from $8,000,000 to $30,000,000. In 1880 it had 28 miles of streets, which were in part lighted by gas at an expense of $5,000 per annum. It had water-works, to supply all the business portion of the city, having over five miles of pipe laid. It had 13 schools, presided over by 16 teachers, and an average attendance of 1,100 pupils; a high school, costing $50,000; five churches, costing from $3,000 to $40,000; and three hospitals, in one of which 3,000 patients were treated during the year. In 1880 $1,400,000 were expended in new buildings and improvements. It had 14 smelters, with an aggregate of 37 shaft-furnaces, of which 24 were in active operation during the census year, and its producing mines may be roughly estimated at 30.

Production.—The amount that is annually added to the metallic wealth of the world by the Leadville district, the productive area of whose deposits as at present opened may be estimated at about a square mile, is truly remarkable. Its annual silver product alone is greater than that given by official estimates for any of the silver-producing nations of the world outside of the United States except Mexico. Its lead product, on the other hand, though frequently neglected in estimating the total value of its output, is nearly equal to that of all England, and, of other nations outside of the United States, it is only exceeded by that of Spain and Germany.

In the magnitude of its product Leadville has been only surpassed in the United States by the famous Comstock lode in the Washoe district of Nevada, and the surprising rapidity of its development in the few years of its existence has been even more remarkable than that of the latter, which produced forty-eight millions of gold and silver during the five years succeeding its discovery. The third district of comparable importance in the magnitude of its product from a comparatively restricted area is the Eureka district of Nevada, which, according to Mr. Curtis, has, in the first fourteen years of its existence, produced sixty millions of gold and silver and 225,000 tons of lead.[1]

Owing to the want of any general law compelling producers to furnish an exact and sworn statement of the amount of their annual product, it is impossible to obtain anything more than an approximate estimate of the metallic production of a mining district like Leadville. Such an estimate varies necessarily in the closeness of its approximation, with the care with which it is made, with the accuracy with which the records of individual mines and smelters have been kept, and with the readiness shown

[1] J. S. Curtis, Silver-lead Deposits of Eureka. Washington, 1884.

under varying circumstances to furnish these records to those who may be gathering statistics.

The′ most trustworthy estimates of production are those that were obtained for the year ending May 31, 1880, by those engaged in collecting statistics of the production of the precious metals for the Tenth Census. This is due to the fact that not only was the force of experts sufficient to visit personally all the important mines and smelting works, but the law gave them the authority to demand, if necessary, an accurate transcript of their records, and the data thus gathered were subjected to a critical analysis during compilation by those technically familiar with the various branches of mining industry. Moreover, it was a most favorable epoch in the development of the district for obtaining an accurate record, since the larger mines were being systematically worked, the record of their product was kept with relative accuracy, and as yet but little ore was shipped out of the district for reduction and thus rendered difficult to trace.

The Census figures of production for this period are as follows:

Leadville products during census year, 1879–'80.

	Gross weight.		Contents.					
			Gold.		Silver.		Lead.	
	Tons.	*Kilos.*	*Ounces.*	*Kilos.*	*Ounces.*	*Kilos.*	*Ounces.*	*Kilos.*
I. Ore extracted	152, 241	138, 110, 797	1, 716	53. 36	10, 603, 331	329, 763. 5	(?)	....
II. Ore smelted	140, 623	127, 571, 118	3, 913. 7	121. 81	9, 717, 819	302, 224	(?)	....
III. Bullion produced by Leadville smelters.	28, ?83	25, 657, 921	3, 830. 2	119. 11	8, 053, 946	250, 478	28, 226	25, 606, 212

In the above table, I gives the amount of ore extracted from the various mines during the year and the contents of the same in silver and gold, as determined by assay àt the mines.

II gives the amount of ore smelted during the year and its assay value in silver and gold, including that sent out of the district for reduction, as determined by the returns from smelters and sampling works.

III gives the bullion produced during the census year by the smelters situated at Leadville and its contents in lead, silver, and gold.

It thus appears that the Leadville ores contained during the year an average of 69½ ounces of silver per ton, and that the bullion produced therefrom contained an average of 285 ounces of silver per ton. The apparent discrepancy in the amount of gold given under the various heads may arise in part from the fact that it is generally present in such minute quantities in the ore that the assayers at the mines do not always make an estimate of it, and in part from small lots of gold-bearing ore either from Leadville itself or from adjoining districts that have escaped notice in making up the returns from mines, or in segregating outside ore in returns from sampling works and smelters. It was not possible to obtain an accurate estimate of the average percentage of lead contained in all the ores extracted. It appears, however, from data obtained from the eight principal smelters running at that time that the average yield per ton of ores treated by them during the year was 398.8 pounds or 19.94 per cent. of lead bullion, containing 65.64 ounces or 0.225 per cent. of silver.

The various newspapers of Leadville have published monthly statements of the bullion product of the district, upon which the annual official statements made by the Director of the Mint and other estimates of the product of the district have been based. These figures often bear internal evidence of incompleteness or inaccuracy, and from want of any evidence of the relative care with which they have been made, it is difficult to know, in cases of discrepancy between them, which is the most trustworthy. Nevertheless, in the absence of any other complete data, these must be assumed as the nearest approximation available.

The following table of the product of the district, since the discovery of silver-lead deposits, has been compiled from these sources, using mainly the figures of the Leadville Herald, which have been the most continuously collected and published. In the case of shipments of ore to be reduced outside the district, of which only the price received is in many instances given, the weight of the metals contained in these shipments has been assumed arbitrarily to average the same as those in which the relative weights are known, which evidently cannot give the exact amount in every case, but which would be probably as nearly correct as an arbitrary assumption of probable averages for each year. The value of the total product is calculated according to the mint valuation ($1.2929 per ounce of silver), which, as is well known, is in the case of silver considerably higher than the fluctuating market value, and increases the value given for the total product by about seven million dollars above that which would be obtained by using the market value, if it were possible to obtain it in each case. The price of lead is assumed at 4½ cents a pound as an average for the whole period involved:

Production of Leadville mines from 1877 to 1884, inclusive.

	Gold.		Silver.		Lead.		Value.
	Ounces.	*Kilograms.*	*Ounces.*	*Kilograms.*	*Tons.*	*Kilograms.*	*Dollars.*
Reduced at Leadville	77, 197	2, 401	42, 089, 722	1, 308, 990	203, 831	184, 912, 426	74, 358, 395
Shipped out of the district	25, 825	803	9, 012, 644	280, 293	102, 867	93, 319, 399	21, 506, 343
Total	103, 022	3, 204	51, 102, 366	1, 589, 283	306, 698	278, 231, 825	95, 864, 738

In the time that has elapsed since the census year, although, owing partly to decline in value of the metals and partly to a lower average tenor of the ore, the total value of the annual product has decreased, the amount of ore extracted from the mines of the district has very considerably increased, this having been in the census year (1879–1880) 152,241 tons, and in the year 1884, according to the report of the Director of the Mint, 232,000 tons.

CHAPTER II.

GENERAL GEOLOGY OF THE MOSQUITO RANGE.

ROCKY MOUNTAINS IN COLORADO.

The simplest expression of the geological structure of the Rocky Mountains in Colorado is that of two approximately parallel uplifts or series of ridges of Archean rocks, upon whose flanks rest at varying angles a conformable series of sedimentary formations extending in age from the earliest Cambrian to the latest Cretaceous epochs, the latter being locally overlaid by unconformable Tertiary beds.

The eastern uplift is generally known as the Colorado or Front Range and the western as the Park Range, the series of depressions or mountain valleys between them having received the name of parks.

The most prominent fact thus far recognized in the geological history of this region is that a great physical break or non-conformity in the strata is found between the Cretaceous and Tertiary formations; in other words, that at this period occurred the great dynamic movement which uplifted the Rocky Mountain region essentially into its present position. As the beds of the Paleozoic and Mesozoic systems have been thus far found to be practically conformable throughout the region, it may be assumed that no important dynamic movement took place during these eras, and that deposition went on continuously, except when continental elevations of the whole region may have caused a temporary recession of the waters of the ocean for a limited period, and thus produced a gap or gaps in the geological series without causing any variation in angle of deposition in the at present successive beds.

Eastern uplift.—The Colorado or Front Range is the more extensive and more important of the two Archean uplifts, and along its eastern flanks is exposed, by the denudation of the overlying Tertiary formations, an almost continuous fringe of upturned Paleozoic and Mesozoic beds.

The most significant geological fact to be observed in connection with these exposures of upturned beds is that the formation which is immediately adjacent to the Archean varies from place to place. At one point Triassic beds, sloping away at varying angles from the flanks of the mountain, rest directly upon the Archean beds; at another point the lower beds of the Cretaceous; at still another, and this more rarely, the Carboniferous limestones are exposed resting against the Archean, while above them, always conformable, are found the Triassic, Jurassic, and Cretaceous formations as one follows the section in an ascending geological sense. At one or two points only along the eastern flanks Silurian beds are exposed beneath the Carboniferous.

It has been customary with many of the early geological explorers to consider the uplift of these mountain ranges to be that of a simple anticlinal fold in the sedimentary strata, which once arched over the underlying nucleus of crystalline rocks; this was once considered the typical structure of a mountain range. In practical field geology, however, it is found that the symmetrical form resulting from this typical structure of mountain range is one of the rarest occurrences, at least in the Rocky Mountain region. The one great instance of such a perfect anticlinal range is that of the Uinta Mountains, which presents exceptional features distinguishing it from the majority of mountain ridges of the Rocky Mountain system; this has a peculiarly normal anticlinal structure in the first place, and in the second place its trend is east and west, whereas all the other great mountain ridges of the Cordilleran system have a direction varying between north and south and northwest and southeast.

The facts just noticed with regard to the sedimentary beds which rest against the eastern flanks of the Rocky Mountains, it will be readily seen, exclude the possibility of the typical anticlinal structure above mentioned. If we suppose a conformable series of sedimentary beds to have been folded into a long anticlinal fold and the crest of this fold subsequently planed off by erosion, so that the core of the fold is exposed, the projection or horizontal section made thus by the planing off of its crest would necessarily show a continuous line of outcrops along either side of the axis of the fold, in which the lowest bed of the conformable series would invariably be seen at the contact of the underlying rocks which, when these beds were deposited, formed the floor of the then existing ocean. In other words, if the Rocky Mountain uplift were a typical anticlinal uplift, the sandstones of the Cambrian period, which are the lowest beds of the conformable series exposed, would be found continuously along the eastern flanks of the Rocky Mountains wherever erosion had swept away the obscuring Tertiaries so that the edges of the folded rocks could be seen.

Since it is evident, then, that the entire series of these beds could not at any time have arched over the present Archean exposures, the alternative presents itself that these exposures represent an ancient continent or island along whose shores they were deposited, a hypothesis which is borne out by the lithological character of the beds themselves, which bear abundant internal evidence, in ripple-marks, in prevailing coarseness of sediment, and in the abundance of Archean pebbles in the coarser beds, that they are a shore-line deposit. The varying completeness in the series of sedimentary beds exposed at different points would in this case be explained by unequal local erosion or elevation, by which the contact, now of a lower, now of a higher horizon, with the original Archean cliff would be laid bare.

Inasmuch as the same evidence of shore-line conditions is found wherever the sedimentary beds adjoining the larger masses of Archean have been carefully studied, and as, moreover, in no part of the higher regions of these Archean ridges have relics of sedimentary beds been found, not even of the later Tertiary formations, as would be expected had they originally arched over these ridges, it is evident that these Archean islands have never been entirely submerged since they first appeared above the ocean level.

The Colorado Range formed the most extensive of these ancient landmasses, and its outlines probably did not vary essentially from those of the present Archean areas. Extending from Pike's Peak northward to the boundary of the State, its dimensions were approximately one hundred and fifty miles in length by about thirty-five to forty miles in width. To the eastward it presented a continuous and regular shore line, broken only by a single narrow bay, separating the Pike's Peak mass from the mainland, and now known as Manitou Park. On the west, toward the parks, its original outlines are as yet less certainly known, but though less regular they probably had a general parallelism with the eastern shore line. North and south this line of elevation was continued by a series of islands and submerged reefs to the Black Hills of Dakota on the one hand and into the present Territory of New Mexico on the other.

The Parks.—That the present valleys, known respectively as the North, Middle, and South Parks, have been more or less submerged in Paleozoic and Mesozoic and again in Tertiary times, and that at one time they formed a connected series of bays or arms of the sea, is proved by the sediments of those eras that are still found in them. Although the geology of the park region has not been studied in sufficient detail to afford complete data in regard to its past history, enough is known to furnish its general outlines.

In some respects the present conditions of these depressions are those that prevailed in the earliest Paleozoic times; in others they have experienced more or less change. Then as now the outlet or opening of the North Park was toward the north, of the Middle Park toward the west, and of the South Park toward the south. On the other hand, up to the close of the Cretaceous the North and Middle Parks were connected and formed a single depression; the present mountain barrier between the Middle and South Parks did not extend as far as their western boundaries, and a water connection existed between them, whose outlines cannot now be given exactly, owing to faulting and subsequent denudation; again, the waters of the South Park extended westward to the flanks of the land mass now forming the Sawatch Range. It seems probable that in earlier Paleozoic times only the North and South Parks were sufficiently submerged to receive the sediments that were washed down from the neighboring land masses, but that, as time went on, the waters became deeper or the sea bottom subsided, so that in Cretaceous times sediments were deposited continuously through the three valleys. In Tertiary times again, after they had been raised above the ocean-level, fresh-water lakes occupied the parks, and in their basins sedimentary beds were deposited, which have since been so extensively eroded off that the age or extent of these lakes cannot readily be determined.

Western uplift.—The western boundary of the park area consisted of two or more distinct ridges or islands, forming, however, a general line of elevation nearly parallel with that of the Colorado Range. These are the Park Range proper, on the west side of the North Park, and the Sawatch Range, now separated from the South Park by the Mosquito Range. Between these was the Archean mass of the Gore Mountains, which formed, with the southern extremity of the Park Range, the western wall of the Middle Park, of whose geological relations but little is definitely known.

The present topographical boundary of the South Park on the west is the Mosquito Range, which has for this reason been also called the Park Range. Geologically, however, this name is less appropriate than topographically, since prior to Cretaceous times no Mosquito Range existed, but the rocks which now form its crest still rested at the bottom of the sea. The Sawatch range forms the normal southern continuation of the Park Range as an original Archean land-mass; hence it seems advisable to avoid the use of the name Park Range in this latitude.

The Archean land-mass of the Sawatch in Paleozoic times, judging from the almost continuous fringe of Cambrian beds encircling it, as shown on the Hayden maps, which may be assumed to represent a tolerable approximation to its original outlines, was an elliptical-shaped area, trending a little west of north, with a length of about seventy-five miles and an extreme breadth of about twenty miles. Through the eastern portion of this area, and parallel with its longer axis, runs the valley of the Upper Arkansas River, now an important feature in the topography, but which during Paleozoic and Mesozoic times did not exist.

The relative height of these mountain masses above the adjoining valleys must have been far greater then than now, since the sedimentary beds which surround them must have been formed out of the comminuted material abraded from their slopes. It is probable, however, that they were not the only land masses at that time, and future geological studies in this region will doubtless decipher many yet unopened pages in its past history. The great area of volcanic rocks to the southwest, whose culminating points are the San Juan Mountains, may very likely conceal the remains of a former land mass of equal, if not greater, dimensions than this. The present Archean areas to the south, in the Wet Mountain and Sangre de Cristo Ranges, may also, in part at least, have been land masses at those times. Moreover, the not infrequent occurrence of Cretaceous beds lying directly upon the Archean at points far away from any well-defined ancient shore line, suggest elevations and subsidences of which the geological studies thus far made in Colorado furnish no record. The areas already mentioned were, however, the most important elevations, since they are the only ones of which it may now be said with tolerable certainty that they have been permanent land surfaces through the long cycles that have elapsed since the commencement of the Paleozoic era. Their consideration, therefore, is all that is necessary for the purposes of the present study.

Mountain structure.—It is no longer assumed, as it was in the early days of geology, that the elevation of mountains is the result of a vertically acting force or a direct upthrust from below. On the contrary, the generally received contraction theory, which is the one that best accords with all observed facts of geological structure, supposes that it is horizontally acting forces that have uplifted them. According to this theory, during the secular cooling of the earth from a molten mass, a solid crust was first formed on its exterior. As cooling and consequent contraction of the whole mass went on, this first-formed crust, in order to adapt itself to the reduced volume of its nucleus, also contracted; but, as it was more or less rigid, this contraction resulted in the formation of wrinkles or ridges on its surface, which there is considerable evidence to show occupied essentially the same lines that the present mountain systems of the world do. Whatever the determining cause that originally fixed these lines, the earth's crust along them would have been compressed, plicated, and probably fractured, and, in subsequent dynamic movements resulting from continued contraction, they would have constituted lines of weakness along which the effects of these movements would have found most ready expression.

Whether the consolidation of the entire earth-mass is already completed, or whether there still remains a molten nucleus towards its centre, is a purely speculative question, upon which geologists are not yet in entire accord, and whose discussion would not be appropriate in a memoir like the present, which has to do with observed facts and with theories only so far as they are necessary for a proper comprehension of these facts. It is an observed fact that in the great mountain systems are found the most intense expression of the compression of the crust, in plications and in great faults. It is also an observed fact that along these lines of elevation and of consequent fracturing of the crust, have occurred the most extensive extrusions and intrusions of molten or eruptive rock, whatever may have been their source—whether from a fluid center or from a fluid envelope between a solid center and a solidified crust, or from subterranean lakes of molten rock at different and varying points beneath the crust. It may likewise be considered a fact of observation that the tangential or horizontal thrust which the contraction theory requires most readily accounts for the plication and faulting of the sedimentary beds which geological study discloses. This thrust may be best conceived as the expression of two forces of compression: a major force acting at right angles to the longitudinal axis of the mountain system, or east and west, and a minor force acting in a direction parallel with that axis, or north and south.

The geological structure of the Rocky Mountains forms as marked a contrast to that of the regions adjoining it on either side as do its topographical features. On the Great Plains, which stretch in an almost unbroken slope from their eastern base to the Mississippi River, or, it might be said, to the western foot of the Appalachians, the strata which form the surface lie in broad undulations, whose angles of dip are so gentle as to be scarcely perceptible to the eye, and which are apparently broken by no important displacements.

In the Colorado Plateau region, which extends from their western edge to the base of the parallel line of uplift of the Wasatch, the beds seem as horizontal as when they were originally deposited, but along certain lines abrupt changes of level are brought about by sharp monoclinal folds, accompanied by or passing into faults, and having great longitudinal extent.

In the intervening mountain region the strata are compressed against the original land masses and flexed until the limit of tension is reached, when by great displacements, often measured by thousands of feet, their edges are pushed past and over each other, the movement of both folds and faults showing that the force which produced them was acting from either side toward the center of the original land masses.

As contrasted with the Basin region west of the Wasatch uplift, the folds of the Rocky Mountains show a greater plasticity in the sedimentary strata by their relative sharpness, the anticlines and synclines in the former having more gentle and equal slopes, while in the latter they often have the form of an **S**, with one member almost bent under the other into an isocline.

Compared with the remarkably compressed folds of the Appalachians, on the other hand, where the isocline may be considered the type structure, the flexures of the Rocky Mountains show that the sedimentary rocks are far from possessing the great plasticity and compressibility that they have in the former. The contrast between the eastern and western mountain systems, in respect to the relative plasticity of their strata, is so marked that it would seem that the reason therefor must be readily apparent. It is not that the beds in the former are thinner; on the contrary, the corresponding Paleozoic formations are many times thicker in the Appalachians than in the Rocky Mountains. It is to be remarked, however, that in the former eruptive rocks are comparatively rare, especially those of Mesozoic and Tertiary age, while in the Rocky Mountains they are most abundant and in the western part of the Basin region they form the greater part of the surface; to this fact may probably be ascribed, as will be shown later, the less plastic condition of the earth's crust in the latter regions.

In the character of these eruptive rocks, again, there is a marked contrast between the Rocky Mountains and the Basin region of Nevada. In the latter they almost exclusively belong to the Tertiary volcanics, approaching in character the lavas of modern volcanoes, the older and more crystalline varieties, corresponding to the Mesozoic porphyries of Europe, having been rarely observed on the surface. In the Rocky Mountain region, on the other hand, while the Tertiary eruptive rocks are often developed on a very large scale, the earlier and more crystalline varieties seem to have an equal and even greater importance, if not in the actual amount of surface they occupy, certainly in the influence which they have had upon the concentration of mineral formation.

In that portion of the Rocky Mountain region under consideration there is a noticeable connection between the structural lines and those along which eruptive action has been most active. The latter correspond with the lines of weakness, of greatest folding and faulting. Leaving out of consideration the dikes which traverse the Archean rocks, which, though numerous, are of relatively small mass, the eastern uplift gives evidence of little eruptive activity, it being shown only by a few isolated outflows of Tertiary lavas. Along the line of the parks, on the other hand, both earlier and later eruptions are so frequent that their outcrops form an almost continuous line from north to south parallel with the western uplift, while along the west base of the latter the Elk Mountains, the head of White River, and the Elk Head Mountains in Wyoming have apparently been the scenes of most violent and repeated eruptions during both Mesozoic and Tertiary times.

MOSQUITO RANGE.

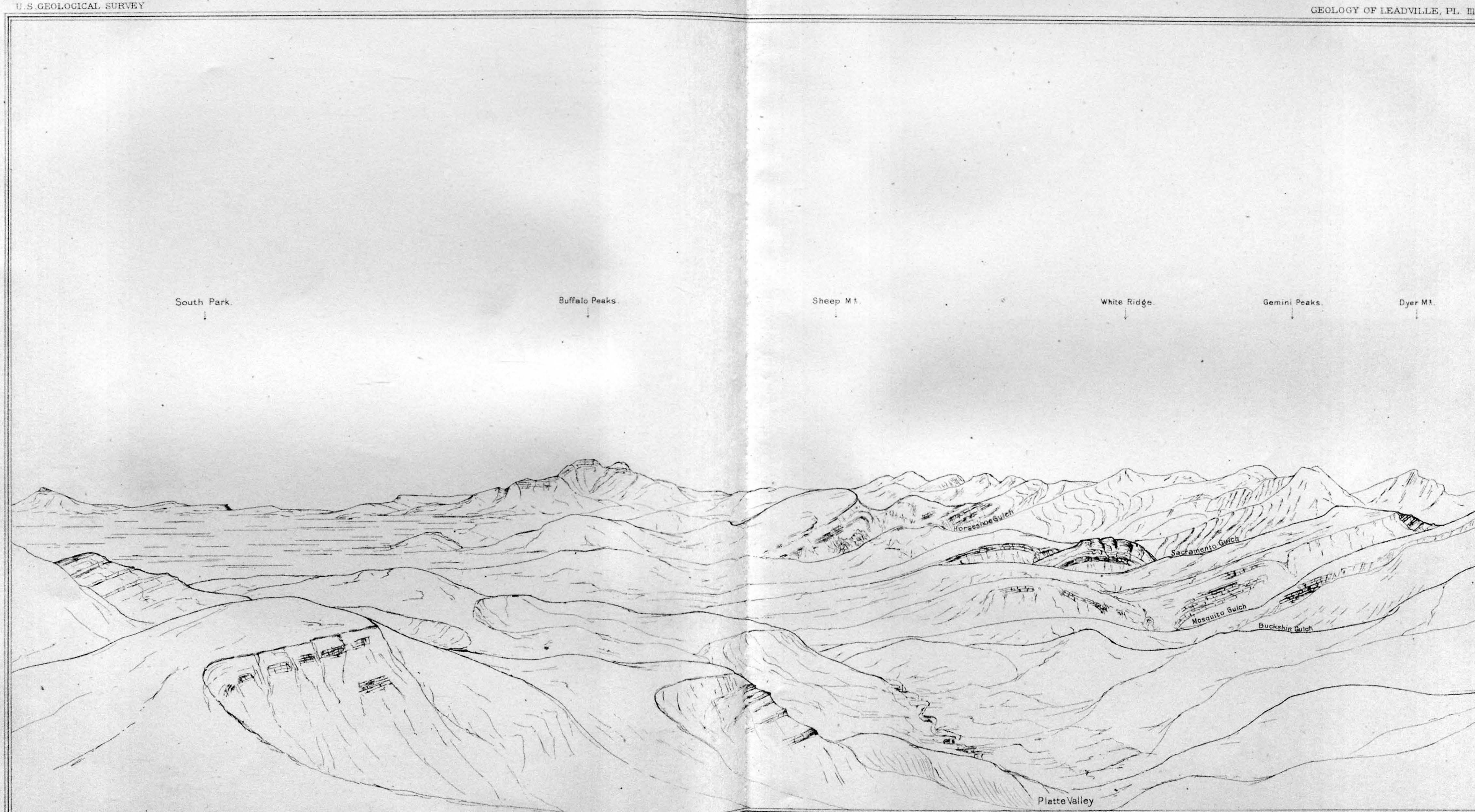
Topography.—That portion of the Mosquito Range the study of whose geological structure was considered necessary for a proper comprehension of the ore deposits of Leadville is shown in relief on Atlas Sheet V. It comprises a length of 19 miles along the crest of the range, and in width includes its foot-hills, bordering the Arkansas Valley on the west and South Park on the east, a slope in the one case of seven and one-half miles and in the other of about nine miles in a direct line. This is essentially an alpine region, scarcely a point within the area of the map being less than 10,000 feet above sea level.

In this area the range has a sharp single crest trending almost due north and south, the échelon structure being, however, developed on the northern and southern limits of the map respectively. To the west this crest presents abrupt escarpments, descending precipitously into the great glacial amphitheaters which exist at the head of almost all the larger streams flowing from the range. The spurs have extremely irregular, jagged outlines, resulting from the numerous minor hills which rise above the average slope. Within a few miles of the valley bottom, however, their form suddenly changes, and from sharp serrated ridges they become broad, gently sloping mesas or table-lands. On the eastern side, though the descent into the glacial amphitheaters is almost as precipitous, the average slope is much less steep, and the spurs as a rule descend in long sweeping curves, widening out gradually as they approach the valley.

The spurs on either side of the range are thickly covered with a forest growth of alpine character, reaching from the valleys of the streams up to an average altitude of 11,700 feet, the upper limit varying somewhat with the more or less favorable conditions of the surface, and extending apparently somewhat higher on the western than on the eastern slopes.

In the northern portion of this area, between the heads of the Arkansas and Platte Rivers, the main crest of the range, which has hitherto followed an almost straight line, takes a bend en échelon, and is continued on a line removed about two miles to the eastward, resuming, however, its original line just beyond the limits of the map. The massive formed by the three peaks, Mounts Cameron, Bross, and Lincoln, the last the highest point within the area mapped, lies still to the eastward of this crest and is topographically an almost independent uplift. Sheep Mountain and the ridge which extends southeastward from it also form an apparently abnormal feature in the topography of the eastern slope.

The sketch given in Plate III shows the general outlines of the eastern slopes of the Mosquito Range and the basin of the South Park, as seen from a western spur of Mount Silverheels. The sky-line of the western half is the crest of that portion of the range included in the map which lies south of Mosquito Peak, the low gap is that of Weston's pass, beyond which is the Buffalo Peaks group. The various gulches south of the Mount Lincoln massive are indicated by name, and the lines of outcrop on their walls are somewhat strengthened to show the geological structure, which will be explained in detail in Chapter IV. Buffalo Peaks are 25 miles distant from the point of view, and the volcanic hill in the extreme left-hand corner of the sketch, seen across the South Park plain, is over 40 miles distant. The little hill on the edge of the plain, and on a line with the eastern spur of Buffalo Peaks, which forms the continuation of the Sheep Mountain ridge, is Black Hill, which lies just beyond the extreme



Julius Bien & Co. lith.
S. F. Emmons, Geologist-in-Charge.

SOUTH PARK AND EASTERN SLOPES OF MOSQUITO RANGE FROM SILVERHEELS.

southeast corner of the Mosquito map. The base of this hill is 10,000 feet above the level of the sea.

It were scarcely possible to select an alpine region more admirably adapted to illustrate the interdependence of topographical and geological structure than that chosen for this study. The gentle slopes of the eastern spurs follow the inclination of the easterly dipping beds of Paleozoic rocks which form their surface, and which remain in broad sheets, like the covering of a roof, to protect the underlying Archean schists from erosion. Where they have been cut through, first by the erosive action of glaciers and later by the corrasive action of mountain streams, to their stratified structure is due the formation of the almost perpendicular cliffs which form the cañon walls of their streams. The generally abrupt slope immediately west of the crest is due to a great fault extending along its foot, in virtue of whose movement the western continuation of the sedimentary beds, which slope up the eastern spurs and cap the crest itself, are found at a very much lower elevation on the western spurs; while the jagged outline of the western spurs is due to a series of minor faults and folds, crossing them nearly at right angles. The secondary uplift of the Sheep Mountain ridge on the eastern slopes is the expression of a second great line of fault and flexure, whose direction, like that of the ridge itself, forms an acute angle with that of the main crest. The elevation of the Mount Lincoln massive is the result of a combination of the forces which have uplifted the Mosquito Range and of those which have built up the transverse ridge which separates the South from the Middle Park.

In the later topography of the range the results of the action of a system of enormous glaciers are seen in the immense amphitheaters which form the heads of its main streams, and in the characteristic V-shaped transverse outlines of the valleys descending from them. Finally, the mesa-like character of the lower end of the western spurs toward the Arkansas Valley is due to the existence beneath their surface of comparatively undisturbed beds deposited at the bottom of a lake formed at the head of that valley by the melting of the ice at the close of the first portion of the Glacial period.

The evidence furnished by the deposits of this lake affords an interesting confirmation of the deduction already made by geologists from the study of the glacial drift in Europe and in the Eastern States, and by Messrs. King and Gilbert from their study of the lake deposits of the Basin regions of Utah and Nevada; namely, that the Glacial period presented two maxima of cold, with an intervening warmer period during which the ice was partially melted and vegetation flourished. The general character of the stratified deposits of the Arkansas Lake shows that they must have been carried down during a time of great floods and that they are formed largely of rearranged moraine material. The thickness of these deposits proves the the existence during a long period of a lake which during part of the year was not frozen; their position shows that the shores of the lake extended several miles to the eastward of the Arkansas Valley. Finally, the facts that these beds are deeply buried beneath surface accumulation of detrital material and that the moraines of now extinct glaciers extend out beyond the original shore-line of the lake and rest above its beds, prove that subsequent to the draining of the lake another set of glaciers, formed during a later period of cold, covered the slopes of these mountains and carved out to a greater depth the present valleys.

Geological history.—Although now so prominent a feature in the topography of the Rocky Mountains, the Mosquito Range, from the sources of the Arkansas River to the southern end of the main Arkansas Valley, is geologically a part of the Sawatch uplift. It was from the abrasion of the land surfaces exposed in the Archean island which occupied the present position of the Sawatch range that the sediments which constitute its stratified beds were doubtless in a great measure formed. In the seas that surrounded this island during Paleozoic and Mesozoic times was deposited a conformable and, as far as present evidence shows, an almost continuous series of coarse sandstones and conglomerates, alternating with dolomitic limestones and calcareous and argillaceous shales. The geology of the Rocky Mountains has not yet been studied in detail over a sufficiently extended area to afford data for tracing the history of the elevations and subsidences to which the region as a whole may have been subjected, or of the alternate recessions and advances of ocean waters during this long lapse of time. The examination of these beds made during the present investigation furnishes some evidence of a shallowing of these seas, and perhaps even of the existence of some land surfaces subjected to erosion during part of this time. Still, the absence of non-conformity in the successive strata deposited and their great uniformity throughout the area studied show that no violent dynamic movement took place before the great disturbance at the close of the Cretaceous, which extended throughout the whole of the Rocky Mountain system and was doubtless the main factor in producing its present elevation.

During this long period of conformable deposition there was an accumulation in this area of 10,000 to 12,000 feet of sedimentary beds. Toward the latter part of this period, possibly very near its close, there was an exhibition of intense eruptive activity, during which enormous masses of molten rock were intruded through the underlying Archean floor into the overlying sedimentary deposits, crossing the beds to greater or less elevations and then spreading out in immense sheets along the planes of division between the different strata. It is not possible at present to define all the points at which these eruptive masses forced their way up, although they were doubtless very numerous and widely spread throughout the region; but the negative evidence obtained proves that the intrusive force must have been almost inconceivably great, since comparatively thin sheets of molten rock were forced continuously for distances of many miles between the sedimentary beds. That the eruptions were intermittent and continued during a considerable lapse of time is proved by the great variety of eruptive rocks now found and by the fact that a given rock in one place precedes and in another follows a second. It might naturally be thought that this eruptive activity must have been coincident with or immediately subsequent to a great dynamic movement; but that it preceded the movement at the close of the Cretaceous, which caused the uplift of the Mosquito Range as well as of the other Rocky Mountain Ranges, is proved by the fact that these interbedded sheets of eruptive rocks, porphyries and porphyrites, are found practically conformable with their bounding strata, and, like them, folded into sharp folds and cut off by faults. The intrusion between the strata of such vast masses of rock—which in some cases reached a thickness of from 1,000 feet to 2,000 feet, and of which in other cases successive beds varying from 50 feet to 200 feet in thickness are now found intercalated between alternate strata to the number of 15 or 20 in a single section—must necessarily have produced great irregularities in the once level surface of the then existing crust; but these irregularities were largely obliterated by the dynamic movements which followed, and the only traces still remaining are variations in the strike of the inclosing beds, which show a tendency to curve around any concentration of eruptive masses.

At some time during the long period which intervened between the final deposition of the latest sediments of the Cretaceous epoch and the succeeding deposition of Tertiary strata, and during which the waters of the ocean gradually receded from the Rocky Mountain region, the pent-up energy of the force of contraction of the earth's crust, which had accumulated during ages of comparative geological tranquillity, found expression in intense and prolonged dynamic movements of the rocky strata forming the immediate crust of the earth in this region. These dynamic movements in their simplest form may be conceived as a pushing together from the east and from the west of the more recent stratified rocks against the relatively rigid mass of the already existing Archean land masses, and a consequent folding or crumpling of the beds in the vicinity of the shore-lines, where, owing to the break in the continuity of the strata and the more irregular character of the floor upon which they rested, the conditions were more favorable to the crumpling movement than they would be, for instance, in the open plains, where a great thickness of level and hitherto undisturbed beds offers no lines of weakness to favor a commencement of folding. It is here a question only of the movement of the distinctly stratified beds, because it is in these alone that the resulting flexures can be accurately studied and mapped out; but it is evident that the crystalline and already violently contorted beds which formed the Archean land masses must have also partaken in the resulting movements, and their axial regions have been lifted up to a great elevation, of which the present height of the culminating peaks of the Rocky Mountains, formed as they are in the majority of cases exclusively of Archean rocks, is only a very much modified expression. Contemporaneously with the east and west movements (the expression of the major force of contraction in this region), there acted also a minor force of contraction in a north and south direction, whose effects can now be seen along the eastern foot-hills in gentle lateral folds, their axes approximately at right angles to the trend of the range, and whose presence is indicated by a sudden bend or curve in the line of sedimentary outcrop, where at one point, owing to a local synclinal, the beds have been more or less preserved from erosion, and again where, owing to the crossing or coincidence of crests of the folds, like those of waves crossing each other, is found an otherwise unexplainable steepening in the dip of the strata.

It must be borne in mind that, while this great dynamic movement is defined as occupying a certain lapse of geological time and its principal effects were brought about within that time, it is not to be regarded as a sudden convulsion, like that of an earthquake, though such disturbances may have occasionally occurred. On the contrary, it must be conceived to have been rather a slow and gradual movement, extending over a period of time of which human experience can form no adequate conception. Moreover, as will be shown in the detailed study of the region, it can be proved that in a modified degree this movement has been continued into so recent a period as that following the Glacial epoch, and may very probably be going on at the present day, although, owing to the great area involved, it has been impossible to obtain any demonstrable proof of its actual existence.

Mineral deposition.—It was during the period which intervened between the intrusion of the eruptive rocks and the dynamic movements which uplifted the Mosquito Range that the original deposition of metallic minerals in the Leadville region took place. These original deposits were probably in the form of metallic sulphides, though as now found they are largely oxidized compounds, and therefore the result of a secondary chemical action; although during this secondary action they may have been to a slight degree removed from their original position, their relation as a whole to the inclosing rocks must remain essentially the same. Their manner of occurrence and the probability that they were derived, in great part at least, from the eruptive rocks themselves prove that they must be of later formation than the latter, while the fact that they have been folded and faulted together with the inclosing rocks, both eruptive and sedimentary, shows that they must have been formed prior to the dynamic movements, and that they are therefore older than the Mosquito Range itself. These deposits were formed by the action of percolating waters, which, having taken up certain ore materials in their passage through neighboring rocks, deposited them in a more concentrated form in their present position. This process may have taken place while the sedimentary beds were still covered by the waters of the ocean, and the waters therefore have been derived from it; whether this was actually the case or not cannot be known until the age of the eruptive rocks is more exactly determined. However, as it is already known by the estuarine character of its fauna that the latest Cretaceous formation must have been deposited in an already shallowing ocean, it seems probable that the area occupied by the Mosquito Range may have already emerged from the ocean at this time.

Structural results of the dynamic movements.—Before proceeding to a detailed geological description of the region included in the Mosquito map (Atlas Sheets VI and VII), which represents the results of the dynamic movements and of subsequent erosion, it may be well to give a brief summary thereof, thus reversing the natural order, for the benefit of those readers who may not have time or inclination to follow all the details of Chapter IV.

The average or major strike of the sedimentary beds and of the axes of the principal folds is northwest magnetic, or N. 30° W., but in some cases a strike due north and south is observed. In these two directions are seen the influence of the shore lines of the Sawatch island, against which the sedimentary strata were compressed; for, while this area lies mainly along the eastern shore line which has a north and south direction, in the northern part the beds had already commenced to sweep round to the westward along the northern shore line of the island. To the south of this area the crest of the Mosquito Range itself marks the eastern limit of Paleozoic beds, while from South Peak, near Weston's pass, northward this limit bends to the northwest toward the mouth of the east fork of the Arkansas. Beyond this line to the west everything is Archean; to the east of it Archean exposures are found only where denudation has removed their previous covering of Paleozoic and later beds; it may be assumed, therefore, to represent approximately the original shore line of the Paleozoic ocean.

The uplift of the Mosquito Range was not the simple pushing up of the beds into a monoclinal fold, as might appear at first glance from the seemingly regular dip of the beds from the crest down its eastern slopes, but a somewhat irregular plication of them into anticlinal and synclinal folds, and their fracturing by faults, which have the same general direction as the axes of the folds without coinciding exactly with them, and which often pass into folds at their extremities. The anticlinal folds have as a rule a very steep inclination, sometimes nearly vertical, on the west side of the axis and a more gentle slope to the east, thus approaching the form of the isocline. It is along this steeper slope that the fracturing has generally taken place, and the fault may thus follow the axis of a syncline or of an anticline, according as it runs to the one side or the other of this steep slope.

The north and south direction of the main crest of the range is evidently determined by the great Mosquito fault, which, starting at some as yet unknown distance beyond the northern boundary of the map, follows the foot of the steep slope west of the crest to the region of the Leadville map, where for a short distance it bends somewhat further to the westward and is thence continued southward in the Weston fault, which passes into a synclinal fold south of Weston's pass.

From the Mosquito fault just north of Mosquito Peak branches off the next most important fracture plane, the London fault, which runs in a southeasterly direction across the eastern spurs of the range. The line of this fault passes just east of the axis of a most pronounced anticlinal fold across London Mountain and Pennsylvania hill to Sheep Mountain, on the sides of which the folding can be most distinctly traced along the cañon walls. To the south of Sheep Mountain it apparently coincides with the axis of the anticlinal fold which forms Sheep ridge, and with it gradually dies out and passes under the level plain of the South Park.

The geological structure of the Mosquito Range is simplest toward the south and becomes more complicated as one goes north, reaching the extreme of complexity opposite Leadville. Near Buffalo Peaks, a few miles beyond the southern limits of the map, it seems to be a simple monoclinal fold, the western slopes being entirely of Archean granite, and the crest formed by Cambrian quartzites dipping gently eastward and resting unconformably on the Archean.

At the southern edge of the map an anticlinal and synclinal fold comes in to the east of the monocline. Here the range has a double crest en échelon, divided by the longitudinal valley of Weston's pass, which runs northwest magnetic following the direction of the strike. The ridge of South Peak to the west of the pass is formed by a monocline of easterly-dipping Cambrian and Silurian beds. The valley of the pass itself is formed by a compressed synclinal fold in Carboniferous strata, along the eastern side of which runs the Weston fault, bringing up the Archean and Cambrian on its east side. The ridge bounding the valley on the east, which is the southern end of the main crest of the Mosquito Range, is an eroded anticlinal fold, from whose crest the overlying Paleozoic strata have been almost entirely removed, leaving the core of Archean exposed. On the very summit of Weston's Peak a small patch of Cambrian quartzites is left, a remnant of the crest of this fold, and at its western base the same beds are found in a vertical position adjoining the fault, while on the more gentle slopes of the eastern spurs are found the regular succession of easterly-dipping Paleozoic beds belonging to the eastern member of the anticline. The ridge sinks to the southward, and over its southern end the arch of Paleozoic beds is still left entire, but the anticlinal fold also sinks to the southward and entirely disappears beyond the limits of the map.

The same general structure continues northward as far as Empire Hill, but a short distance from the southern edge of the map a second anticlinal fold, that of Sheep Ridge, comes in at the extremity of the eastern slope of the range, while from its steep western slope erosion has removed all trace of the synclinal fold seen on Weston's pass, leaving only the easterly-dipping Paleozoic beds belonging to the monocline on the west of the fault, and the Archean on its east side; the crest of the range is formed of easterly-dipping Paleozoic beds, or, where these have been eroded away, by Archean schists and granite. This double anticlinal structure is best shown in Section G (Atlas Sheet IX), which is drawn at right angles to the strike, and in which the supposed form of the eroded synclinal is shown by dotted lines. The line of this section also crosses two secondary anticlinals or minor waves in the strata, which are the almost invariable accompaniments of the larger folds.

In this southern area the older eruptive rocks are but little developed, their only representative being a thin but persistent sheet of White Porphyry above the Blue limestone. This increases in thickness from about fifty feet at Weston's pass to over a thousand feet at its supposed source in White Ridge, on the north side of Horseshoe gulch.

In the middle region of the area mapped, through an east and west zone which includes the principal mines of Leadville and vicinity, the development of bodies of earlier eruptive rocks is so great that the structure of the sedimentary beds is obscured and not always easy to trace. On the eastern slopes the double anticlinal structure continues as far north as Mosquito Peak, at the head of Mosquito gulch. The great Sheep Mountain fold, with the London fault cutting through its steeper western side, gradually converges toward the crest of the range. Views of the sections of this fault-fold afforded by the cañons of Horseshoe and Big Sacramento gulches are seen in Plates XV, XVI, and XVIII. East of this fold the strata slope gently eastward, with a slight secondary fold traceable along the extreme foot-hills. Between the Sheep Mountain fold and the crest of the range the strata of the gradually narrowing syncline are cut across by the two great eruptive bodies of White Porphyry and of Sacramento Porphyry, in White Ridge and Gemini Peaks, respectively, which are accompanied by a slight displacement. The nearly horizontal Paleozoic beds forming the crest and eastern member of the main anticline extend somewhat to the west of the topographical summit of the range, but the western member of the anticline and the succeeding syncline (if it extended so far north) are either removed by erosion or buried beneath sheets of porphyry.

On the western slopes in this zone the sedimentary strata, now greatly augmented in thickness by interstratified sheets of porphyry and extending nearly to the valley of the Arkansas, are flexed into a number of minor folds and broken by many shorter faults, most of which pass at either end into anticlinal or synclinal folds. This is the area which is included in the detail map of Leadville and vicinity and which is described at length in Chapter V. It is traversed by seventeen larger and smaller faults and has many anticlinals and synclinals, in which the prevailing dip of the beds is to the eastward and the throw of the faults is mainly an uplift to the east.

The area west of the Mosquito fault and north of the Leadville region is mainly occupied by beds of the middle member of the Carboniferous and by porphyry sheets, flexed into gentle folds of varying directions, but apparently not broken by faults. This region is already at some distance from the ancient shore line, which is marked by the outcrops of Cambrian and Silurian beds. These bend to the westward around the head of Tennessee Park, and reach well up on the north slopes of the Sawatch in the Eagle River region; but, while the sedimentary beds bend thus in general strike to the westward, the Mosquito fault and the crest of the range which has been uplifted by its movement continue on unchanged in their trend.

North of Mosquito Peak is a large area in the higher part of the range, including the splendid amphitheaters in which the Platte and Arkansas Rivers rise, where the overlying Paleozoic beds have been entirely removed and only Archean exposures, traversed by dikes of earlier eruptive rocks, now remain.

East of this area the flanks of Loveland hill and the massive of Mounts Bross and Lincoln are occupied by easterly dipping Paleozoic beds, which evidently are the eastern member of a broad anticlinal fold; but of the actual structure of the beds which once arched over the Archean area there is nothing left to tell. It is probable that there were folds here similar and more or less parallel to the Sheep Mountain fold, as has been indicated in a general way by the dotted lines in the sections which cross this region. A partial proof of this is afforded by a deep synclinal adjoining Mosquito fault on the west, somewhat similar to that on Weston's pass, which is found at the base of Bartlett Mountain, at the northern edge of the map; its axis has more westerly direction than the plane of the fault. In this northern area there is also a great development of earlier eruptive rocks as contrasted with the southern half of the region, though they have less relative importance than in the middle zone, which includes the immediate vicinity of Leadville. The greater proportion of these bodies are in the form of intrusive sheets, interstratified with Paleozoic beds; but the dike form is also found, more especially in the Archean exposures in the amphitheaters along either side of the crest of the range. These dikes are sometimes observed cutting up through the Archean into the overlying sedimentary beds and then spreading out in sheets between the strata.

Displacement.—The movement of displacement of the faults throughout this area has been, with a few unimportant exceptions, an upthrow to the east. The maximum movement of any one fault is that of the Mosquito fault, at the northern edge of the map, which is about five thousand feet. In general the movement of the individual faults decreases to the southward until they gradually pass into folds and it becomes nil. The aggregate amount of displacement, however, summed up along east and west sections, increases toward the middle of the region, where the development of sheets of eruptive rocks is greatest, and decreases as these become less important; thus, as above mentioned, the displacement at the northern edge of the map is about five thousand feet. In the middle region, where the faults are numerous, the aggregate displacement is 8,000 to 10,000 feet, and across Sheep Mountain and Weston Peak it has decreased to 3,500 feet, becoming nothing at all just beyond the southern limits of the map.

Volcanic rocks.—Thus far only the earlier eruptive rocks have been mentioned, for the reason that they alone were involved in the folding and faulting. Later eruptions of Tertiary volcanic rocks have taken place since the folding, and probably after erosion had done the greater part of its work in the removal of Paleozoic sediments. These eruptions within the area of the map consisted of rhyolitic lavas, of which the two most prominent outpourings were at the extremities of this area, the one forming the mass of Chalk Mountain north of the east fork of the Arkansas and some smaller bodies to the east of Frémont's pass, the other that of Black Hill, on the extreme southeastern edge of the area in South Park. Besides these there are small bodies in the granite and in the Cambrian quartzite at the west foot of Empire Hill. A few miles south of the southern limit of the map is an important volcanic eruption of andesitic lava, cutting across both the Archean and the Paleozoic beds, which forms the high mass of Buffalo Peaks. These later eruptions, however, so far as can be determined, had no influence upon the ore deposits of the region.

General erosion.—It is now impossible to determine how much of the erosion that has removed the crests of these folds and denuded such large masses of Archean rocks was accomplished earlier than the Glacial period, but it is evident that the carving and shaping out of the valleys which score the flanks of the range has been mainly accomplished since that time. It is, moreover, not absolutely certain that this area was entirely covered by later beds than the Triassic, since the only proofs that Jurassic and Cretaceous strata also extended over it conformably are founded on the fact that no unconformability between Jura and Trias has yet been observed here. On the other hand, no opportunity was offered for a detailed study of the relations of these two formations. That the beds of the Trias formed part of the conformable series and were deposited along the shores of the Sawatch island is definitely proved, although they are no longer found within the area of the map, by the fact that just beyond its limits to the north and east, in the Ten-Mile and Mount Silverheels districts, respectively, they form a continuous and conformable series with the Carboniferous beds, are folded and faulted with them, and carry the same intrusive sheets of eruptive rocks.

Arkansas Valley erosion.—The manner and date of formation of the main Arkansas Valley is a matter of interesting speculation. It is evident, as has already been said, that it did not exist before the dynamic movements which uplifted the Mosquito Range, and yet it must have already been a deep valley at the commencement of the Glacial period, since a large lake was formed in it during the first melting of the ice of that period, in whose bottom at least three hundred feet of sediments were deposited. Although no beds of undoubted Tertiary age have yet been recognized in it which would afford a definite date to reckon from, it is probable from structural evidence that a line of depression was formed by the elevation of the Mosquito Range and the accompanying faulting, which corresponded approximately with the present general direction of the valley. A new drainage system having thus been formed, the erosive agencies which have carried away so many thousand feet of rocks from the range itself gradually deepened and enlarged this new depression, until it has now assumed those majestic proportions that make it a topographical feature of scarcely inferior importance to the great parks themselves, which date back to pre-Cambrian time.

Glacial erosion.—The detrital materials brought down from the adjoining mountains and deposited along the Arkansas Valley during the Glacial period show that the general form of the latter had already been determined before that time. These deposits, though of similar origin and lithologcal character, belong to two distinctly marked epochs. Those of the former constitute the so-called Lake beds, formed of detrital and mainly morainal material, brought down from the mountains by the freshets which occurred during the melting of the ice at the close of the first cold epoch of the Glacial period, and which formed stratified deposits at the bottom of the great lake at the head of the Arkansas Valley, which will be called the Arkansas Lake. These beds, which reached a thickness of at least three hundred feet, are now found on either side of the alluvial bottom of the present stream, forming the base of the mesa-like terminations of the mountain slopes and in some cases extending to an elevation of 1,000 feet above the present valley bottom, a height to which the angle of the deposition of the beds could hardly have carried them and which gives evidence that the elevation of the range has continued in a modified degree since Glacial times. After the draining of this lake, in some manner not now to be traced, a second epoch of glacier formation set in, during which the new glaciers occupied the same positions as the older ones and continued the work of grinding and valley carving. They extended out over the Lake beds deposited during the warmer period, as proved by the present position of the lateral moraines of Iowa and Evans gulches. An immense amount of detrital material must have been accumulated on the slopes of the range by this second system of glaciers, and during the floods and freshets that must have accompanied their melting and recession this material was partially rearranged and spread out over the lower part of the Leadville region, both above the already existing Lake beds and in some cases over rock surfaces not previously covered by these deposits. This rearranged moraine material has received the local name of "Wash." From the present regular and even surface of the lower spurs, where the Wash lies conformably over the Lake beds, it is evident that the former, like the latter, must have been deposited in quiet waters, like those of a lake rather than of a mountain torrent, for which reason it seems probable that a second Lake Arkansas was formed at the very close of the Glacial period, perhaps by the damming up of the valley by a terminal moraine, which in its turn finally broke its barriers and was drained of its waters, leaving a basin-shaped valley in whose original bottom, as represented by the mesa-like spurs, the lower part of the present stream beds have been cut out.

Stream erosion.—The valleys of the minor streams which head in the amphitheaters at the summit of the range were shaped out and took their general direction during the Glacial period. It is evident that their upper portions, at the heads of these amphitheaters, have been but little changed by later erosion, since glacial striæ are still found in some cases on their present bottoms.

The amount of erosion produced by rain and running water increases in direct ratio with the distance from the crest of the range. In the valleys of some of the larger streams running down from its summit this erosion has cut to a depth of 500 feet below the valley bottom left when the glaciers receded, and many minor valleys, like California gulch, which do not head at the actual summit, have been entirely carved out by these agencies since the close of the Glacial period.

Valleys.—The valleys of the minor streams, or gulches as they are generally called, may be divided in the vicinity of Leadville into three classes, according to age and manner of formation. They may be distinguished as (1) glacial valleys, (2) valleys of erosion, and (3) surface valleys.

The first and oldest, which owe their main outline to the carving of glaciers, have in cross section a U-shape and head in glacial amphitheaters, from which they pursue a relatively straight course down the mountain slope. Their original form is more or less modified by subsequent erosion. To this class belong the larger valleys, often forming cañons on the east side of the range, and the east fork of the Arkansas and Evans, Iowa, and Empire gulches on the west side.

The valleys of the second class, which have been cut out of solid rock exclusively by the action of running water, have a V-shaped outline in cross section and a winding course, their direction being dependent on the unequal resistance offered by the peculiar position or texture of the rocks out of which they are carved. They also want the amphitheater-shaped head which characterizes the first class. They are more recent than the glacial valleys and have sometimes been cut out of their bottoms. The most striking example of this kind of valley is California gulch.

The third class, which are of the most recent formation, are likewise valleys of erosion; but they have been cut, not out of solid rock, but out of recent surface accumulations like the Lake beds, which have not yet become solid rock. They are relatively broad and shallow and are often dry for a great part of the year. They are like the shallow ravines and river valleys of the Great Plains and of the Nevada valleys, and like them probably mainly carved by sudden freshets. Little Evans, Georgia, and Thompson's gulches are valleys of this class. On the map of Leadville and vicinity it will be seen that the geological outlines cross these valleys without the re-entering angle which they have on the lines of the other valleys.

Little Evans Valley drains the amphitheater on the south face of Pros pect Mountain, being separated from Big Evans Valley only by a moraine ridge formed by the glacier of the second epoch. It is thus proved that the amphitheaters were carved out by the earlier set of glaciers, since the glacier from the Prospect Mountain amphitheater was originally a branch of the main glacier from the Evans amphitheater, and it was the moraine of the second Evans glacier which, being placed across the mouth of the Prospect Mountain amphitheater, necessitated its seeking a new outlet for its waters. That at one time ice must have filled the amphitheaters to their brim, and been in places over 2,000 feet thick, is proved by their configuration and by the position of erratic blocks.

In the region shown on the accompanying maps, the two main glaciers of the second epoch were the Evans and the Iowa. The latter had three heads, but its lower portion, as shown by the lateral moraines which remain on the sides of the present gulch, was straight and narrow. The later Evans glacier, however, spread out as it descended, having left a prominent moraine ridge along the north bank of the present stream at the foot of Prospect Mountain, while on the south side a somewhat disconnected moraine ridge follows approximately the course of Stray Horse gulch, the moraine material remaining being 250 feet or more thick in the Rothschild and Denver City shafts. The steep north face of Breece Hill below the present grade formed its southern wall, and below this it probably covered more or less completely all the region north of Stray Horse gulch, so that to its action is probably due the exposure of the valuable ore deposits of Fryer Hill, and also the removal of a great portion of them.

CHAPTER III.

ROCK FORMATIONS.

SEDIMENTARY.

ARCHEAN.

The Archean rocks as developed in this district belong apparently to the very oldest of the crystalline sedimentary rocks, and on this ground may be considered as corresponding with the eastern Laurentian. As yet no systematic study of the Archean formations in the Rocky Mountain region has been made in accordance with which the different developments of Archean rocks may be classified as regards their age and correspondence with the different divisions made by eastern geologists. In the reports of the Survey of the Fortieth Parallel recognition was taken of the fact that at least two distinct developments of crystalline sedimentary rocks are found in the Rocky Mountain region.

Of these, the one, consisting essentially of granites, mica and hornblende gneisses, and amphibolites, being evidently the older, was considered to correspond with the Laurentian series; certain accessory occurrences of norite and beds of ilmenite and magnetic iron further allied it to this formation.

The second class, which was supposed to correspond to the Huronian, was found in rather limited development at Red Creek, near the Uinta Mountains, and along the Wasatch Range, and consisted of mica schists and quartzites, the former passing into paragonite schists similar to those of the St Gothard, with chloritic and hornblendic rocks, in general of a less perfectly crystalline structure than the former. The Archean rocks of the Black Hills, which consist of a great variety of slates, phyllites, quartzites, and amphibolitic schists of singular composition, are also closely allied by their mineralogical character to this latter group.

To the former of these classes belong the mass of the Archean rocks so largely developed throughout the whole Colorado Range of the Rocky Mountains, of which excellent sections are afforded by all the streams which flow out upon the Great Plains. Here in a very general way they seem to consist principally of gneisses resting on a central core of red, friable, coarse-grained granite.

Although no opportunity has been had of making a study of the other Archean bodies of the Rocky Mountains, it would seem, from what has been seen in traveling across them, that the Archean of the Mosquito Range is distinguished from that of the Colorado Range by a greater prevalence of granite over schists, and in a very general way that the more schistoid rocks of the Mosquito Range are resting upon the almost entirely granitic mass of the Sawatch, which should therefore be considered the older.

As shown in the section afforded by the cañons of the Mosquito Range, and hence in comparative nearness to the overlying sedimentary rocks, the Archean formation consists essentially of granite, gneiss, and amphibolite. The granites are in many cases undoubtedly metamorphic and form bedded masses. In other cases there seems little doubt that they are eruptive, but probably of Archean age, since they have not been found to intrude, into or contain fragments of the Paleozoic rocks. In the majority of cases the structural evidence was not decisive either way, but the texture of the granite was decidedly that which is found characteristic of the metaphorphic types.

GRANITE.

The granites are prevailingly very coarse-grained, especially those in which evidences of bedding are found. If the classification given by Rosenbusch[1] be here adopted the greater part will belong to his class of granite in the narrower sense of the word, or granite proper, consisting, namely, of quartz, two feldspars, biotite, and muscovite. These granites always contain muscovite and variable biotite, but rarely if ever hornblende; where

[1] Mik. Physiog. der mass. Gesteine. H. Rosenbusch. Stuttgart, 1877, p. 18.

biotite is absent it is due to a later alteration of the rock. In color they are gray or very frequently of a reddish tinge. The red color is sometimes very marked, and certain varieties are fully as fine in color as the famous Aberdeen granites. As an exceptional color is also found a reddish-yellow, due apparently to hydrated oxides of iron.

Those which it has been thought might be of eruptive origin are generally fine-grained, of gray color, and contain an abundance of biotite, whereas those which are distinctly metamorphic are generally coarse-grained, often red in color, and have a porphyritic structure owing to the prevalence of large twin crystals of orthoclase. Surfaces of the latter type often show such parallelism and rectangularity in the disposition of the long narrow prisms of orthoclase as to present a superficial resemblance to the so-called graphic granites. These coarse-grained metamorphic granites, especially when found in the immediate vicinity of the overlying sedimentaries, have sometimes a foliated structure approaching that of gneiss, but the direct passage of granite beds into gneisses was not observed. As typical granites of the former or eruptive class, may be mentioned that found in the Platte Valley, north of Mount Lincoln; in Democrat Mountain, at the head of Buckskin gulch; and along the western slope of the main crest, opposite the head of Mosquito gulch.

Of the second class typical forms are found at Bartlett Mountain and along the Arkansas Valley, which are distinguished from the former by the development of orthoclase in tabular twins, following the Carlsbad law, porphyritically distributed throughout the rock. That found at Leadville, generally in large erratic bowlders, and which has been considerably used as foundation stone, is a remarkably beautiful rock, the orthoclase having a delicate flesh-red tinge, while the groundmass, if such it may be termed, is a bright, clear-gray mass, rich in dark mica.

The finer-grained granites of a deep blood-red color were observed on the ridge between Empire and Weston gulches, and also in the valley of Eagle River, opposite Tennessee pass. Yellow granite was found also in the last-mentioned locality and on the summit of Weston's pass.

In addition to the above are masses of secondary origin, which occur in the form of huge white veins of extremely irregular outline, to which, in accordance with the custom now prevalent among German geologists, the term pegmatite has been given. These pegmatites consist of large intergrown crystals of white orthoclase, microcline, and quartz, with irregular masses of muscovite, and are evidently of later formation, probably the filling in, by secretion from the surrounding rocks, of fissures and irregular openings formed in the mass by contraction or dynamic movement.

Microscopic constitution.—Besides the normal components, which are easily detected macroscopically—viz, quartz, orthoclase and plagioclase feldspars, potash and magnesia micas—the only constituent of importance revealed by the microscope is microcline, which occurs in all rocks examined except those of the type from Democrat Mountain. This is often quite abundant, and seems to have been the last feldspar formed, which may be the reason for its superior freshness and freedom from particles of limonite and hematite, the abundance of which in the other feldspars causes their reddish color. The quartz grains are often full of fluid inclusions and hair-like needles. A few of the fluid inclusions were observed to be double, the inner substance being probably carbonic acid.

GNEISS.

The gneisses, which are next in importance to the granites, are more generally micaceous than those of the Archean along the Fortieth Parallel, among which the distinctly hornblende gneisses were the more prevalent. They are much contorted and seldom exhibit very distinct bedding over large areas. In structure they present a great variety of forms, prevailingly the typical gneiss structure with fine, even grain and constant composition in the different layers, aside from the flat lenses of quartz or feldspar which are inserted between them. At other times a banded appearance is produced by the alternation of layers in which biotite or hornblende prevail over quartz and feldspar. A porphyroidal structure is very marked in a variety from the South Platte amphitheater, caused by the development of large white orthoclase crystals, usually Carlsbad twins, reaching two to three inches in length, in a matrix of ordinary gneiss. The tendency to a granitic structure is locally noticeable, especially in the Twelve-Mile amphitheater. In composition the gneisses are prevailingly micaceous, hornblende being seldom present in large quantity, except in those rocks which are classed distinctly as amphibolites. Biotite is in some cases the sole mica, but frequently muscovite is associated with it in subordinate quantity. A careful search with the lens is often necessary to determine the presence of plagioclase. The feldspars are generally white, but in the Mosquito, Horseshoe, and Twelve-Mile amphitheaters a pink or reddish color predominates. In these cases the pegmatite which forms veins in the schists is also pinkish.

Microscopic constitution.—A microscopical examination reveals the presence of microcline in small quantities, while ordinary plagioclase is very abundant, as is also muscovite frequently intergrown with the feldspars Apatite and ilmenite are the most common accessory minerals, the latter giving rise to titanite in the form originally called titanomorphite by von Lasaulx.[1] Isolated rounded grains, which are nearly or quite colorless and but very faintly dichroic, are doubtless referable in part to titanite and in part to pyroxene of a variety near sahlite. The dark portion of a banded gneiss from the Arkansas amphitheater consists principally of quartz, three feldspars, biotite, and hornblende. The last two minerals are often intergrown in a peculiar manner, the biotite leaves being parallel to the orthopinacoid of the hornblende. Ilmenite is abundant and passes by alteration into "leucoxene," which appears dull white by reflected light. This again passes into a granular mineral resembling titanite, although not very strongly dichroic. Blood-red films of hematite are discovered in the leaves of biotite.

In the porphyritic gneiss of the Platte amphitheater microcline is an important element. One large grain of it contains inclusions of quartz and mica in considerable quantity. Muscovite, which is not prominent macroscopically, is abundant in delicate plates intergrown with the feldspars, either parallel to the common crystal faces or without regularity. This muscovite seems to be original and not a decomposition product. An intergrowth of biotite and muscovite, whereby a crystal of the former is surrounded by a zone of the latter having the same orientation, was also observed. Quartz grains contain biotite crystals, needles of rutile (?), and double fluid inclusions with carbonic acid The pink feldspar in gneiss

[1] A. von Lasaulx, Neues Jahrbuch für Min., etc., 1879, p. 568.

from the Twelve-Mile amphitheater presents a confused intergrowth of different feldspars, a part being undoubtedly microcline.

AMPHIBOLITE.

The amphibolites are the next in importance to the gneisses among the crystalline schists, and occur interstratified with them in layers of varying thickness, and sometimes in large lenticular bodies. Under the name amphibolite are here understood rocks of comparatively coarse grain, with less marked schistose structure than is common in hornblende schists proper, and also differing from these in that other minerals, particularly feldspar and quartz, occupy prominent positions beside the hornblende. They are of frequent occurrence throughout the Archean formation of this district and have a comparatively uniform structure, although sometimes showing a mottled appearance, from the concentration of hornblende in patches. Biotite and magnetite are often quite prominent in them. Pyrite is frequently visible macroscopically.

Microscopic constitution.—The microscope shows that orthoclase and plagioclase are present in about equal quantities, but that microcline, which was found in many gneisses, does not appear in the associated amphibolites. Hornblende occurs in stout, irregular individuals, and often contains inclusions of a clear, colorless mineral in minute rounded particles, which are probably quartz, although too small for certain determination. Amphibolite from Weston's pass contains hornblende which is so full of black ore-grains as to be opaque in certain cases. A fine striation parallel to the plane $P\bar{\infty}$ [1] was observed on the same hornblende. Apatite in its usual form is common to all. Titanite, as formed through the alteration of a titanium mineral, probably nigrine or rutile containing titanic iron,[2] is present in two cases in most typical form. The rutile has a dull-reddish hue by reflected light and is surrounded by titanite in clear oval grains. Two occurrences, viz, from Buckskin gulch and from Twelve-Mile amphitheater, show the mode of formation of titanite with exceptional clearness.

[1] C. W. Cross, Studien über bretonische Gesteine; Min. und petro. Mitth. von G. Tschermak. Neue Folge, III., p. 386.

[2] Rammelsberg, Mineralchemie, IIer Theil, 2te Auflage, p. 169.

These two rocks, gneiss and amphibolite, constitute the main mass of the Archean schists, mica schists, phyllite, and other thinly bedded rocks not occurring in any well defined bodies. Peculiar schistose forms do appear in the gneissic series, but are subordinate in every respect, with only local extension, and of abnormal constitution. In the contorted state of the strata, the tracing out of the relations of these bodies to the gneiss, while extremely interesting, would have taken much more time than could have been devoted to this subject. A few examples will show the interesting nature of these masses.

On the north face of Mount Lincoln occurs a contorted schist of dark color, in which the naked eye can determine biotite and small flakes of glistening muscovite. The microscope shows that the two micas form nearly the whole rock, the compact appearance being due to extremely minute flakes of biotite, often so small as to require a power of 800 diameters to distinguish them clearly. Between these two elements, in varying quantity, is a mass appearing between crossed nicols like the decomposition product of orthoclase in many of the older rocks, where muscovite in tiny flakes has been the chief mineral formed; this substance is here very uniform in composition, giving the brilliant polarization colors of such an aggregate, and, as no feldspathic substances can be detected, it remains uncertain whether this muscovite comes from orthoclase or is original, corresponding to the minute leaflets of biotite. No hornblende is visible. Tourmaline in bundles and brushes is the next most abundant element, being brown in ordinary light, with a tinge of red or blue; a few small grains of quartz, and specks of ilmenite altering into "leucoxene," are the only remaining minerals.

RELATIVE AGE.

The Archean rocks just described are all without question older than any of the Paleozoic series, which rest unconformably upon them; but of the relative age of these different components of the ancient crystalline series it is in the nature of things difficult to form any very decided judgment. Even had time permitted a careful and detailed study of any of the remarkable exposures in the great glacial amphitheaters which have been carved out of them, it is doubtful whether their original relations could have been clearly made out, since they have been subjected not only to the dynamic movements which brought about the present elevation of the range, but, no doubt, to many previous movements of which no record now remains. As a consequence they are found to be contorted, fissured and reconsolidated, and fissured again, and this action seems to have been more intense the further one goes from the original surface, or rather from that which was the surface at the commencement of Paleozoic deposition. In general, it may be said that the pegmatites are the latest formations in the Archean proper, leaving out of consideration, of course, the later eruptives (porphyries, porphyrites, and diorites) and that gneiss must certainly have formed part of the original undisturbed mass, while of the granites proper some were earlier and some later, but all previous to the pegmatite.

On the accompanying plate (Plate IV) are reproduced a few hasty field-sketches of occurrences in which the different varieties of rock are found so intimately interlaced as to afford some idea of their relations and of the difficulty of tracing a sequence in their formation.

In Fig. 1, it is seen (1) that across the original gneiss a small feldspar vein has been formed, probably the filling of a small fissure or crack resulting from dynamic movement; (2) that the fine-grained and probably eruptive granite has been intruded in tongue-like masses into the gneiss after the formation of this first vein; (3) that after consolidation the mass has again been shattered, a great fissure formed and filled by a coarser-grained granite, which surrounded fragments of gneiss and earlier granite alike; this fissuring was accompanied by a certain amount of faulting; (4) a second opening on the wall of this fissure has been made and filled with pegmatite.

In Fig. 3, again, fragments of gneiss are found in a mass of fine-grained granite, in such position as to show that the latter must undoubtedly have been a more or less fluid mass, which traversed the gneiss and caught up included fragments of it in its passage.

In Fig. 2, on the other hand, this granite is seen to have been subjected to at least two movements; as a result of the first, narrow feldspar veins have been formed across its mass, and again, by the second, these, together with the inclosing granite, have been successively opened along the same fissure to admit the formation in fissures thus made of pegmatite

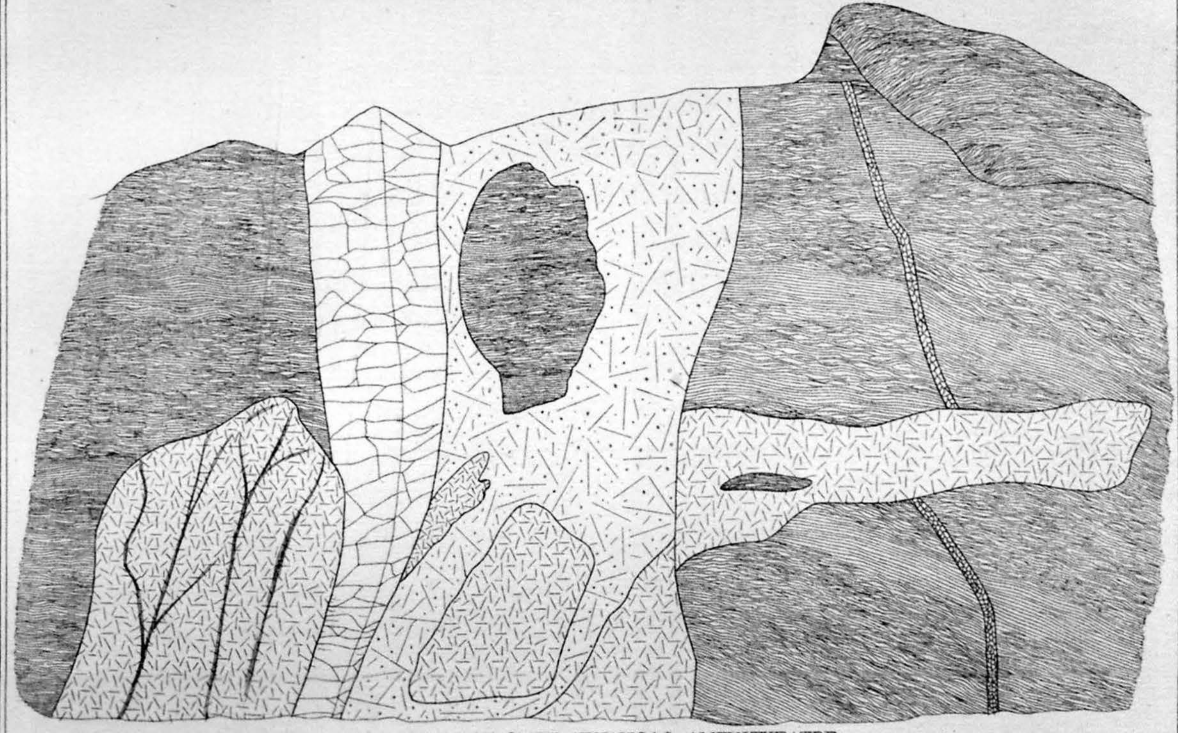
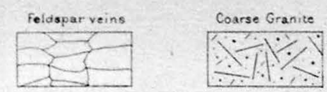


FIG. I. FACE OF CLIFF. ARKANSAS AMPHITHEATRE.



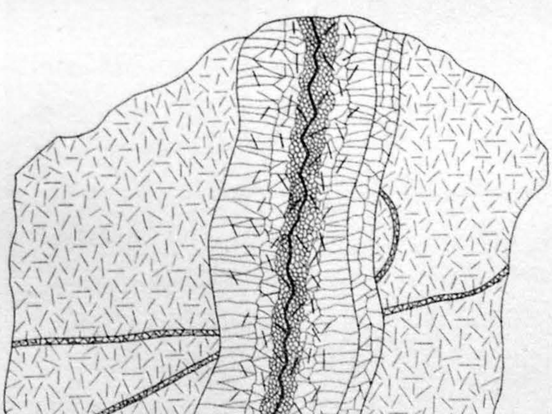


FIG. II BOULDER. BUCKSKIN AMPHITHEATRE.

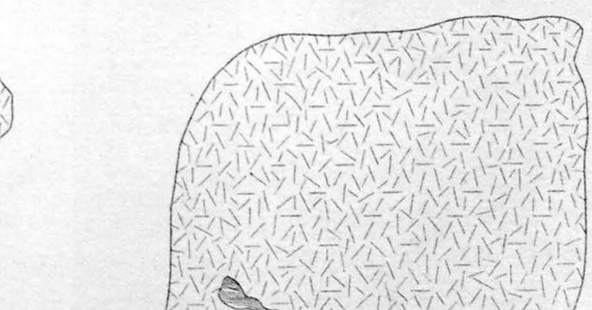


FIG. III BOULDER. MOSQUITO GULCH.

Julius Bien & Co. lith.

S. F. Emmons, Geologist-in-Charge.

ARCHAEAN PHENOMENA.

veins. The curving form of the smaller feldspar veins would also suggest an intermediate compression, during which the granite became sufficiently viscous to admit of some movement within its mass without producing fracture, for it is fair to assume that these veins are the filling of a crack along a fracture-plane, and therefore originally more or less straight.

PALEOZOIC.

The sedimentary deposits later than the Archean which are found in this region belong, with the exception of certain very recent beds, to the Paleozoic system. In the multitudinous sections afforded by the exposures along the cliffs of amphitheaters and the walls of cañons remarkable uniformity in the physical characteristics of these beds is observed. Practically the same bed, a fine-grained conglomerate, is, with a single exception, found in contact with the underlying Archean wherever the contact is exposed and no non-conformity of stratification or other evidence of a physical break exists.

In determining the geological age of the different strata included in these series two difficulties are met at the outset: first, the rarity of fossil remains in the beds, due probably to their relatively metamorphosed and altered condition; second, the absence of any systematic description of the Paleozoic horizons of the Rocky Mountain region, to be found in the published works of other geologists. The voluminous reports of the Hayden Survey contain, it is true, many local sections of sedimentary rocks and frequent surmises as to their age, but as yet, unfortunately, a systematic summary which shall correlate the material thus gathered by many different individuals into a harmonious whole, and sift out that which is to be considered fact from that which is only surmise, is wanting.

It has long been the opinion of the writer, and one which is confirmed by later geological investigations, that it is impracticable to determine by similarity of molluscan fauna alone the correspondence of beds and formations in regions so widely separated as are the Rocky Mountains, where as yet meager data have been gathered, and the Eastern States, where paleontological horizons are firmly established. In Paleozoic times these regions were practically two distinct continents, and the conditions of life must have varied considerably. Until, therefore, the sequence of development and of extinction of molluscan life in the former region shall have been thoroughly investigated by detailed paleontological determinations, founded upon accurate and systematic stratigraphical studies, the assignment of geological horizons must be somewhat provisory and considerable importance must be given to the conditions of deposition which prevailed during the Paleozoic era.

Geologists have observed, both in the East and in the Rocky Mountain region, a certain general sequence in the character of the sediments deposited in the oceans of former geological periods. This sequence has received from Dr. J. S. Newberry the name of "circles of deposition," and in a memoir on this subject he has endeavored to prove that in the Appalachian system each great geological period consisted of two extremes, during which the oceanic conditions were such that calcareous sediments were deposited, separated by an intermediate period, during which silicious sediment prevailed. The former, in a general way, are supposed to have occurred in deep seas and under conditions of comparative quiet, while coarser silicious sediments were formed either in shallow waters or during periods when this coarse material would be carried further out towards the middle of the ocean.

As regards the assumption that limestone may be considered an evidence of deep-sea deposition, it seems that this evidence can be considered only as relative. The limestone depositions in the region under consideration, for instance, were formed in an inclosed arm of the sea, not more than 40 miles in width, and which can therefore have had no very great depth. Mr. John Murray, geologist of the Challenger expedition, informed the writer that the result of their investigations had been to prove that no limestone could be formed in the greatest depths of the ocean, and that the area of sedimentation is confined to a comparatively shallow and limited belt along the shores of the present continents. While it is probable, therefore, that none of the deposits of the Rocky Mountain region were formed in seas at all comparable in depth to what are classed as deep seas by ocean explorers, the alternations of prevailing silicious and calcareous material in the sediments doubtless represent significant changes in the oceanic or climatic conditions which prevailed to a greater or less extent over the whole region. It is, therefore, instructive to observe the parallelism of these conditions in the Paleozoic section of the Wasatch Range, as determined by the geologists of the Fortieth Parallel and which was considered by them as the key-section of the Rocky Mountain region, and that of the Mosquito Range.

In the former the Paleozoic series has a thickness of about thirty thousand feet and is characterized by two great silicious series, the Cambrian at its base and the Weber Quartzites in the middle of the Carboniferous. The former had a thickness of about twelve thousand feet and was followed by 1,000 feet of Silurian limestone, which was again succeeded by quartzites and sandstones of equal thickness; this was followed by a great limestone formation of a maximum thickness of 7,000 feet, in the lower portion of which were found Devonian and Waverly forms, the main body of the limestone being, however, characterized by fossils of Carboniferous age. The coarse sandstones of the Weber series, which were deposited over this limestone, had a thickness in the Wasatch of about six thousand feet, and were succeeded at the close of the Carboniferous by alternating silicious, calcareous, and argillaceous beds. Followed eastward along the forty-first parallel, the whole Paleozoic series thins out rapidly, and in the Laramie hills, on the meridian of the Colorado or Front Range, seems to be represented by a thickness of only 1,500 feet of rocks, though the exposures are not sufficiently good to render it certain that the entire series is here exposed.

In the Mosquito Range the Paleozoic series has a maximum thickness of less than five thousand feet. The Cambrian is represented by quartzites, passing gradually upwards into calcareous shales, with limestones of probable Silurian age above, the aggregate thickness of the two being about four hundred feet. Above these limestones, and separated from them by a thin bed of quartzite, is the Blue, or ore-bearing, limestone, about two hundred feet in thickness, in which only Carboniferous forms have yet been found. This is succeeded by a relatively large development of silicious material, consisting mainly of coarse sandstones and conglomerates, corresponding lithologically to the Weber series, which passes upward into beds containing a greater or less development of limestone, with sandstones and shales, and which has been provisorily designated the Upper Coal Measures.

Of the existence of the Devonian, which is recognized in the Wasatch section, and which was also found by Mr. Walcott in the Kanab, in the Colorado Plateau country, no direct evidence was found in the Mosquito region. On the one hand there is a gap of two hundred feet or more of beds from which no fossils were obtained, between the horizons in which Carboniferous and Silurian forms, respectively, were recognized. On the other hand, at one point evidence of non-conformity by erosion was observed between the Blue Limestone or base of the Carboniferous and the Parting Quartzite or top of the Silurian. Had this evidence of erosion been generally observed throughout the region, it would have afforded sufficiently conclusive proof that, owing to a perhaps local elevation, no sediments had been deposited here during the Devonian period. As it is, the question must remain for the present undecided, though the probabilities are in favor of the latter solution.

As to the existence or non-existence of the Devonian on the eastern slopes of the Rocky Mountains in general, the evidence is equally unsatisfactory. Waverly forms, which are associated with it in the Wasatch, have been found in the limestones of Lake Valley, in New Mexico. It is indicated on the Hayden maps as occurring on the south slopes of the San Juan Mountains, and Dr. Endlich's description of the formations in the neighborhood of the Animas River would seem to indicate the existence of a considerable thickness of beds below the Carboniferous which are not like the Silurian or Cambrian formations of Colorado in general. Unfortunately the fossil (*Rhynconella Endlichi*[1]) upon which he mainly founded his determination of the existence of Devonian beds in the region, has, upon recent, more careful study by Prof. R. P. Whitfield, been decided to be a Carboniferous and not a Devonian type.

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[1] Geological and Geographical Survey of the Territories, 1874, p. 213.

In the following tables are given the average Paleozoic section in the Mosquito Range, in the Kanab from Mr. C. D. Walcott,[1] and in the Wasatch from the Fortieth Parallel Reports:

Mosquito section; 4,600 feet; possible unconformity by erosion.

Carboniferous 3,700 feet to 4,200 feet.	Upper Coal Measures.	1,000 to 1,500	Blue and drab limestones and dolomites, with red sandstones and shales. Mud shales at top.
	Weber Grits	2,500	Coarse white sandstones, passing into conglomerates, and silicious and highly micaceous shales, with occasional beds of black argillite and blue dolomitic limestone.
	Weber Shales		Calcareous and carbonaceous shales, with quartzite.
	Blue Limestone	200	Compact, heavy-bedded, dark-blue dolomitic limestone. Silicious concretions at top, in form of black chert.
Silurian 200 feet.	Parting Quartzite	40	White quartzite.
	White Limestone	160	Light-gray silicious dolomitic limestone, with white chert concretions.
Cambrian 200 feet.	Lower Quartzite	150 to 200	White quartzite, passing into calcareous and argillaceous shales above.

Kanab (Colorado River) section; 5,000 feet; unconformities by erosion.

Permian 855 feet.	Upper Permian	710	Gypsiferous and arenaceous shales and marls, with impure shaly limestone at base.
	Lower Permian	145	Same as above, with more massive limestone.
Carboniferous 3,260 feet.	Upper Aubrey	835	Massy cherty limestone, with gypsiferous arenaceous bed, passing down into calciferous sandrock.
	Lower Aubrey	1,455	Friable, reddish sandstone, passing down into more massive and compact sandstone below. A few fillets of impure limestone intercalated.
	Red Wall Limestone	970	Arenaceous and cherty limestone 235 feet, with massive limestone beneath. Cherty layers coincident with bedding near base.
Devonian 100 feet.	Devonian	100	Sandstone and impure limestone.
Cambrian 785 feet.	Tonto Group	235	Massive mottled limestone, with 50 feet sandstone at base.
		550+	Thin-bedded, mottled limestone in massive layers. Green arenaceous and micaceous shales 100 feet at the base.

Note.—Planes of unconformity by erosion denoted by double dividing lines.

[1] American Journal of Science, September, 1880, p. 222.

Wasatch section; 30,000 feet; conformable.

Permian .... 650 feet.	Permian	650	Clays, marls, and limestones, shallow.
Carboniferous .. 14,350 feet.	Upper Coal Measure limestone.	2,350	Blue and drab limestones, passing into sandstones.
	Weber Quartzite	6,000	Compact sandstone and quartzite, often reddish; intercalations of limestone, argillites, and conglomerate.
Waverly......	Wasatch Limestone	7,000	Heavy-bedded blue and gray limestone, with silicious admixture, especially near the top
Devonian .... 2,000 feet.	....		
	Ogden Quartzite......	1,000	Pure quartzite, with conglomerate.
Silurian .... 1,000 feet.	Ute Limestone........	1,000	Compact or shaly silicious limestone.
Cambrian......... 12,000 feet.	Cambrian	12,000	Silicious schists and quartzite.

CAMBRIAN.

Lower Quartzite.—The beds assigned provisorily to this horizon, which are indicated on the map in a dark-purple color (*b*), are prevailingly of quartzite. To them, therefore, the local name of Lower Quartzite has been given. Their average thickness is about one hundred and fifty feet to two hundred feet, of which the lower one hundred feet are composed of finely and rather thinly bedded white saccharoidal quartzites, while the upper fifty feet are shaly in character and more or less argillaceous and calcareous, passing by almost imperceptible transition into the silicious limestone of the Silurian formation above.

At the very base of the series, at the contact with the underlying Archean, wherever this could be observed, is found a persistent bed of fine-grained conglomerate, from a few inches to a foot in thickness, made up of rounded and finely polished grains of bluish translucent quartz, generally not larger than a pea in size. Above this is a white quartzite of remarkably uniform and persistent character, always very readily distinguishable as a white band in the numerous sections offered by the cañon walls of the range. Its thickness, when measured on the west side of the range, or near the Sawatch island, is, as mentioned above, 100 feet of purely silicious beds. On the east side of the range the thickness seems somewhat to diminish, and in places was found to be only 40 feet.

In Buckskin cañon a thin bed of silicious limestone was found included in the quartzite. The rock of this bed is remarkable as containing relatively a smaller proportion of carbonate of magnesia than any other limestone of the range, the specimen analyzed having—

Carbonate of lime	25.43
Carbonate of magnesia	4.03

The whole series may often be observed to be divided into two equal parts, the lower half consisting of very pure white quartzite, while the upper half weathers brown and is more or less stained by iron oxide and other impurities.

While the lower series is very persistent in its character, the upper portion or transition series, which has a maximum thickness of 100 feet, is extremely variable, and, though readily recognized in all cliff sections, often seems to be wanting in those afforded by the numerous drill-holes in the neighborhood of Leadville.

Owing to their similar lithological character and to the general absence of fossil evidence, it is difficult to establish a hard and fast line between this and the succeeding formation above. In practice the line has been drawn at the top of the shaly beds and the commencement of the beds of more massive limestone. The transition beds consist essentially of alternating bands of calcareous quartzite and shales. The name Sandy Limestones is often applied to them for the reason that on weathered surfaces of the cliff faces they appear like sandstones, the carbonate of lime having been entirely washed out and only the fine quartz grains left on the thin surface crust.

One especially persistent bed of sandy limestone, generally about a foot in thickness, is often very useful in determining the horizon, on account of the striking appearance of its weathered surface. It is a silicious dolomite, generally of whitish color on fresh fracture, containing spots of dark brick-red resembling casts of fossils; for which reason the name Red-cast beds has been given to it. Fig. 1, Plate V, the reproduction of a photograph of a weathered specimen, shows its characteristic appearance.

Certain of the shaly beds are found to contain a considerable development of pyroxene and amphibole, which often give a decided green color to the rock. The microscope shows besides an admixture of fine ore particles, and in some cases there is so large a concentration of pyrites as to constitute veritable ore bodies.

One of the most interesting features of this series is the local development of serpentine, resulting evidently from the metamorphism of pyroxene and amphibole. It has been found in small quantities at various points, but is developed on a very considerable scale in the Red Amphitheater in Buckskin gulch, where it forms a remarkably beautiful verd-antique and a peculiar massive yellow rock, resembling bees-wax not only in color but also in texture.

Fossils.—The only fossil remains found in this series occur in a bed of greenish chloritic shales on the east flank of Quandary Peak, about a mile above the Monte Cristo mine. They belong to the genus *Dicellocephalus*, and resemble closely *Dicellocephalus Minnesotensis* of the Potsdam formation.

Owing to the thick covering of forest immediately east of the point where these fossils were found, it was impossible to fix with absolute certainty the exact horizon of the bed in which they occur. They are immediately above a heavy white quartzite, and beneath a bed of white marbleized limestone, which is in turn overlaid by the quartzite which carries the Monte Cristo ore deposit. From analogy with other sections, however, it seems safe to assume that it occurs above the main body of quartzite and near the base of the transition series.

SILURIAN.

The beds assigned to this horizon consist of light-colored, more or less silicious, dolomitic limestone, capped by beds of quartzite of varying thickness which mark the dividing line between it and the overlying formation. On the general map of the Mosquito Range the entire series is included in one color-block (*c*). On the more detailed maps two divisions are made, to which the local terms White Limestone (*c*) and Parting Quartzite (*d*) have been given.

White Limestone.—The beds to which this local name has been given, from their prevailing light color as distinguished from the dark blue-gray or even black limestone above, consist in the main of light drab dolomites, and contain, besides the normal proportions of carbonates of lime and magnesia, from 10 per cent. upwards of silica. They are generally rather thinly bedded, of compact rather than crystalline structure, and frequently have a conchoidal fracture, approaching a lithographic stone in texture.

Red Cast Beds.(Cambrian)

Contorted Limestone,(Upper Coal Measure.)

But rarely do the beds have the whiteness of marble, and in such cases it is evidently due to local metamorphism.

The characteristic feature of this limestone is the occurrence at certain horizons of concretions of white, semi-transparent chalcedony or chert. This occurrence is often useful in the mines of Leadville for distinguishing beds of this horizon from locally bleached limestones of the Carboniferous. Chert also occurs in the latter beds, but is always of dark, nearly black color, and the microscope shows in them a very finely granular structure, while those of the Silurian have frequently a radiate structure in the nature of spherulites. In neither was it possible to detect any trace of the minute organisms found in similar concretions in many other limestones.

The average thickness of the White Limestone is from 120 to 160 feet. A small percentage of chlorine can be detected in these, as in all the other limestones from this region which were chemically examined.

Parting Quartzite.—Above the White Limestone occurs a bed of remarkable persistence, but of rather variable thickness, to which the above local name has been given, and which, on somewhat negative evidence, is regarded as constituting the upper limit of the Silurian formation in this region. In the cliff sections it has an average thickness of 40 feet, in one case attaining a maximum of 70 feet. It does not differ lithologically from the numerous white quartzites found at other horizons, but it is of geological importance as determining the dividing line between the Silurian and Carboniferous groups. In the cliff sections a brecciated structure is often observed in the limestone immediately overlying it, and in one case, on the east fork of the Arkansas, evidence of non-conformity by erosion was observed, which renders it possible that the Upper Silurian and Devonian formations may be entirely wanting in this region.

Fossils.—Paleontological evidence as to the age of the above formation is extremely meager. No form was actually found in place. Casts of a *Rhynconella*, between *R. neglecta* and *R. Indianensis* of the Niagara epoch, were found in a prospect shaft in California gulch, not far from the White Limestone quarry, in such a position that they must have been derived from the beds of this horizon at least fifty feet above the base of the formation. Besides this, other specimens were brought in, obtained from talus slopes at the foot of the cliffs in Dyer Amphitheater and on West Sheridan, whose matrix of light drab-colored limestone renders it reasonably certain that they were derived from some of the beds of this horizon. The following forms are recognized: *Leptena melita* and an *Orthisina* like *O. Pepinensis*, which correspond to forms found in the Calciferous; and the syphon of an *Endoceras*, which belongs to the Trenton epoch.

Corresponding beds in Colorado Range.— In order to obtain, for purposes of comparison, a section of the Paleozoic beds lying directly on the Archean along the Colorado Range uplift, a visit was made by Mr. Whitman Cross to the exposures in Williams cañon, near Manitou, and in Manitou Park. Although only fifty to seventy-five miles distant from the Mosquito Range exposures, the beds were found to vary so much in lithological composition that it was impossible to obtain an exact correspondence of horizons. The purely silicious beds at the base are much thinner than in the Mosquito Range, the greatest thickness found being 50 feet. They are succeeded by calcareous sandstones and shales of variegated colors, red prevailing, which pass up into white or drab limestones, sometimes containing chert secretions and alternating with shaly beds, with an aggregate thickness of about two hundred feet. These beds may be considered as the equivalents of the Lower Quartzite and White Limestone of the Mosquito Range. Owing to extensive denudation it was impossible in the time allotted to trace a continuous series into well-defined Carboniferous horizons.

From the east bank of Trout Creek (Bergens Creek on the Hayden map), in Manitou Park, two miles below the hotel, Mr. Cross obtained fossils which have been identified by Mr. C. D. Walcott as follows:

From reddish-brown sandstone 45 feet above the Archean.

Lingulepis, sp.? An elongate form allied to *L. pinnæformis* of the Potsdam sandstone of Wisconsin.

From red calcareous sandstones, alternating with white limestone, one hundred and five to one hundred and twenty-two feet above the Archean.

Glytocistites (?). Single plates.
Lingula, sp. undet.; probably new.
Orthis desmopleura, Meek.
Metoptoma, new sp.
Cyrtolites.
Orthoceras, sp. undet.; probably new.
Bathyurus simillimus, Walcott (?).

This fauna is essentially the same as that of the upper third of the Pogonip Lime stone of Nevada.

The paleontological information, therefore, is so far a confirmation of the suggestion offered above from lithological composition, viz, that the Cambrian beds are here not more than fifty to a hundred feet thick (a notable decrease from the estimated 12,000 feet in the Wasatch, or from the more definitely-determined thickness given by Mr. A. Hague for Eureka, Nevada, of 7,700 feet), and that the limestone beds above are Silurian.

CARBONIFEROUS.

The beds of this period are, as in other parts of the Rocky Mountain region, more fully developed and more abundant in fossil remains than those of the other Paleozoic horizons. The Carboniferous period here, as in the Wasatch, consisted of two limestone-making epochs, separated by a long period of silicious deposits, with the difference that in the shallow seas, in which the Carboniferous of the Mosquito Range was formed, detrital and silicious deposits predominated over calcareous deposits. The series, therefore, lends itself to a triple subdivision into lower, middle, and upper Carboniferous, which are here assigned to it mainly on lithological grounds, since our knowledge of the Carboniferous fauna of the Rocky Mountain region is not yet sufficiently complete to enable us to establish satisfactory paleontological subdivisions, and many forms considered characteristic of the Coal Measures of the East range from the bottom to the very top of the series.

Blue or ore-bearing Limestone.—The beds included under this local name, which are designated on the map by a deep-blue color (*e*), and which, from the fact that they form the ore-bearing rocks par excellence of the region, it is most important to be able to trace accurately, are fortunately marked by persistent and characteristic features. They have an average thickness of about 200 feet. In color they are of a deep grayish-blue, often nearly black in the upper portion of the series, while some of the lower beds are lighter in color, approaching a drab, and, where locally bleached, difficult to distinguish lithologically from the underlying White Limestone. The upper bed is well marked by characteristic concretions of black chert, frequently hollow in the center and often containing within their mass distinct casts of fossils. Owing to their superior resistance to atmospheric agencies, they are often weathered out and left in nodular masses of irregular shape upon the surface. The forms which they assume are sometimes so fantastic as to suggest to the untechnical that they are the fossil remains of some gigantic animal. Their forms, however, are always rounded, and are more commonly that of a sphere or some solid of revolution. In many cases, that they are the filling in of a pre-existing cavity in the limestone is evident from the fact that they are hollow in the center and contain crystals of pyrite or other minerals lining the cavity.

The series is generally heavily bedded, and the rock is almost always granular, and in the upper part often coarsely crystalline. A characteristic feature, especially of the upper portion of the formation, is a ribbed structure produced by irregular lines and spots of white crystalline material. In some cases the ribbing is so fine and regular as to produce an appearance resembling that of the *Eozoön.*

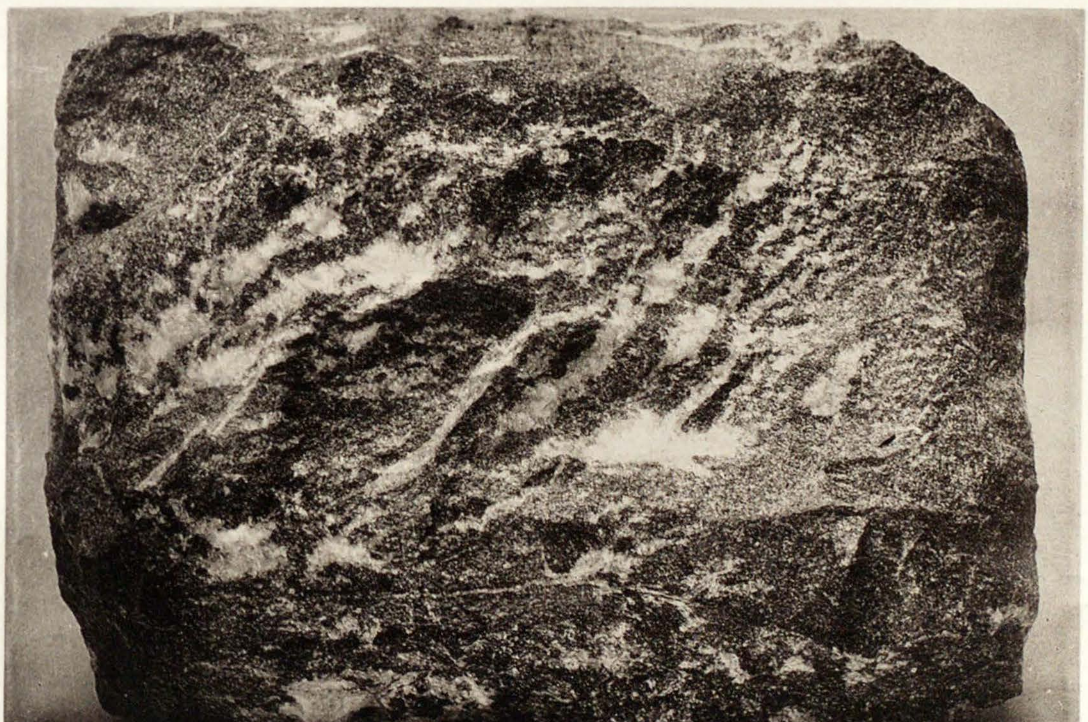
This typical appearance of the rock is shown in Plate VI, on which are represented two specimens from the Blue Limestone of Iron hill, taken a short distance below the ore body on the Silver Wave claim, which were also subjected to microscopical examination. The upper figure in the plate is a photograph of a specimen polished on one side to show the fine ribbing which is peculiar to this limestone. The lower figure shows a specimen roughly shaped by the hammer, in which the ribbings or veins of white crystalline spar are coarser and more irregular. These white crystalline veins may be supposed to be produced by the dissolving out of a portion of the limestone and its redeposition in a crystallized form. As bearing on the question of the relative solubility in natural waters of carbonates of lime and magnesia, a partial analysis of the white spar was made, and it was found to have the same proportions of the two salts as the dark granular rock.

Composition.—The composition of the rock, which is remarkably uniform, is that of a normal dolomite, the average of six lime and magnesia determinations from different localities giving—

Carbonate of lime	54.695
Carbonate of magnesia	43.197

the proportion in normal dolomite being—

Carbonate of lime	54.30
Carbonate of magnesia	45.70



Blue Limestones

Heliotype Printing Co. 211 Tremont St. Boston.

The following complete analyses of typical specimens, taken from localities at considerable distances from each other in the vicinity of Leadville, are further proofs of the uniformity of composition. I, II, and III are from the upper of the Blue Limestone, IV from near its base, and V from the upper part of the White Limestone.

	I.	II.	III.	IV.	V.
Locality	Silver Wave mine.	Dugan quarry.	Glass-Pendery mine.	Montgomery quarry.	Carbonate hill quarry.
Chemist	(Hillebrand.)	(Guyard.)	(Guyard.)	(Guyard.)	(Hillebrand.)
Lime	30.79	30.43	29.97	27.26	26.60
Magnesia	21.14	20.78	21.52	20.05	17.41
Carbonic acid	46.84	46.93	47.39	43.79	40.01
Protoxide of iron	0.24	0.38	0.13	0.57	0.83
Peroxide of iron	0.21	0.11	0.22	0.10	1.51
Protoxide of manganese	Trace	0.05	0.20	0.06	....
Alumina	0.27	0.17	0.04	0.11	1.66
Silica	0.21	0.70	0.27	7.76	11.84
Chlorine	0.10	0.143	0.041	0.062	0.05
Potash	0.03	0.046	0.013	0.017	0.017
Soda	0.062	0.094	0.016	0.037	0.029
Sulphuric acid	Trace	....	....	Trace	....
Phosphoric acid	Trace	0.12	0.03	0 07	Trace
Sulphide of iron	Trace	Trace	....	Trace	....
Organic matter	0.03	0.025	0.015	0.07	....
Water	0.22	0.04	0.07	0.05	0.48
Total	100.142	100.018	99.925	100.006	100.436

The coloring matter is in part evidently organic, but in part, as suggested by Mr. Guyard, may be due to the presence of salts of iron. He says that he finds an appreciable amount of sulphide of this metal which will produce a black color. A remarkable feature in this analysis, as well as in that of the White Limestone, is the presence of appreciable quantities of alkaline chlorides. Microscopical examination under very high power (1,136 diameters) shows that the dusty appearance is due to minute specks in the grains composing the rock, which are fluid inclusions, in some of which the rapid movement of a bubble is visible. As will be shown later, it seems fair to assume that the included liquid consists of alkaline chloride. The microscope also shows that the rock is very finely granular, the size of the grains varying from .05 to .10 of a millimeter in diameter. No twin crystals of calcite are observed, and very little quartz or ore particles could be detected.

The characteristics which may serve in the field to distinguish the rock of the Blue from that of the White Limestone are as follows:

1. Color, which is darker.

2. Composition, the former being almost free from silica, the latter containing 10 per cent. and upwards.

3. Texture, the former being generally crystalline, while the latter is more compact.

4. Chert secretions, which in the former are always black and in the latter nearly white.

5. Structure, the Blue Limestone being generally more heavily bedded than the White.

Fossils.—The only fossils obtained from this horizon were found in the extreme upper part of the formation, either in the limestone itself or in chert nodules, which are found scattered over its weathered surface. The following forms were obtained from five different localities:

Euomphalus, closely resembling *E. Spergenensis*, Hall, from Warsaw limestones of Spergen hill.
Spiriferina, which is probably new, though somewhat resembling *S. Kentuckensis*.
Athyris subtilita.
Pleurophorus oblongus.
Productus costatus.
Spirifera (Martinia) lineata.
Spirifera Rockymontana.
Streptorhynchus crassus (crenistria).
Cyathophylloid corals, resembling *Zaphrentis*, or *Cyathaxonia cynodon*.

While most of these forms are common to the Coal Measures of the East, the first-mentioned is there found in the Lower Carboniferous. For this reason and because this form and the *Spiriferina* do not occur in any of the higher beds, it seems justifiable to assume that this horizon represents the Lower Carboniferous of this district.

The upper limit of this formation has been fixed at the top of the massive Blue Limestone, which is generally marked by the frequency of chert concretions, and in the mining districts has been followed by preference by the ore-bearing solutions. Locally, however, limestone formation seems to have continued somewhat intermittingly for some distance above this horizon.

Weber Shales.—On the general map of the Mosquito Range, owing to its small scale, it was considered advisable to make no subdivisions of the Weber Grits formation, and the whole is therefore included under one color (*g*). On the more detailed maps, however, a subdivision of the Weber Grits, designated the Weber Shales, has been distinguished by a distinct color (*f*). The beds included under this name are extremely variable in lithological character and in thickness. They constitute a transition series between the massive limestones below and the characteristic coarse sandstones of the Weber Grits above. They consist of argillaceous and calcareous shales alternating with quartzitic sandstones. The former are generally carbonaceous, and in their extreme type pass into an impure anthracite. The calcareous shales, on the other hand, are locally developed into a considerable thickness of impure limestone, which is very rich in fossil remains. Owing to its variable character and to the fact that the dividing plane between this and the preceding is frequently occupied by beds of porphyry, it is difficult to assign a definite thickness to the formation. It may, however, be assumed as varying from 150 to 300 feet.

In Leadville itself a thin bed of quartzite is often found immediately above the Blue Limestone, and on Iron hill is a greenish argillaceous shale, called the *Lingula* shale, from the abundant casts of this fossil which it contains. The coal development attains a thickness in one case of seven feet, but is extremely impure and gives little promise of any economical value.

Fossils.—The most common form is *Lingula mytiloides*, Meek, which is supposed to correspond to *L. ovalis*, Sowerby. Besides these were obtained from several different localities the following:

Phillipsia, sp.? (*P. major?*)
Productus cora.
Productus semireticulatus.
Productus pertenuis.
Productus muricatus.
Productus Nebrascensis.
Spirifera cameratus.
Aviculopecten rectilaterarius.
Orthis carbonarius.
Streptorhynchus crassus (*crenistria*).
Chonetes granulifera.
Discina nitida.
Macrocheilus ventricosus.
Archæocidaris.
Eoccidaris Halliana.
Fenestella perelegans.
Rhombopora lepidodendroides.
Myalina perattenuata.
Polyphemopsis, (like *P. chrysalis*).
Pinna, sp.?
Polypora, sp. undet.
Palæschara, sp. undet.

Weber Grits.—This formation, which, as its name implies, consists mainly of coarse sandstones passing into conglomerates, has an estimated aggregate thickness of 2,500 feet, although neither its upper nor its lower limits can in the nature of things be very sharply defined.

The typical rock, which often forms massive beds of considerable thickness and constitutes a prominent feature in the sections afforded by cañons, is a coarse white sandstone passing into a conglomerate, made up of well-rounded grains and pebbles, mainly of white and sometimes of pinkish quartz. In the coarser conglomerates feldspar can often be distinguished in fragments, and this mineral is often disseminated in fine grains throughout the sandstone, but fragments of recognizable Archean schists are not often seen. It would seem, therefore, that these beds are mainly formed by the abrasion of the coarser granites of the Archean. The sandstones often contain a considerable admixture of brilliant white mica, and in some cases, besides the mica, so large a quantity of carbonaceous material as to become quite black. This carbonaceous material, which is insoluble in ether, alcohol, or sulphide of carbon, is probably either graphite or anthracite.

Next to the sandstones and conglomerates, the most important constituents of the formation are quartzose shales and mica schists, generally coarse-grained and of a greenish hue. Their lamination is very regular and often parallel to the bedding-planes, so that they often weather out in slabs or flags of considerable size. The mica, which, as in the sandstones, is mostly potash mica or muscovite, seems to form but a subordinate part of the rock mass, but is generally very prominent in large brilliant flakes on the surfaces of the laminæ. Microscopical examination shows that in the sandstones and schists feldspar is always present with the quartz, and in some cases the three varieties, orthoclase, plagioclase, and microcline, can be distinguished. It also shows that the muscovite is, in part at least, derived from the decomposition of the feldspars; at the same time the uniform occurrence of large brilliant flakes along the bedding-planes of the shaly material suggests the possibility that these may have been directly derived from débris of the Archean and have been deposited in this position by the action of water.

At irregular intervals throughout the formation are found beds of fine black mud-shales or carbonaceous argillites, generally very thin and sometimes calcareous, passing into impure limestones.

About the middle of the formation is a tolerably persistent development of limestone of the usual blue-gray color and dolomitic in composition. Its thickness, however, varies very much according to locality. It was best observed in Big Sacramento gulch, a short distance above the London fault, where are two beds of limestone with associated shales, about fifty feet apart and each about ten feet in thickness.

Fossils.—From the limestones in Big Sacramento gulch were obtained the following forms:

Spiriferina Kentuckensis.
Athyris subtilita.
Productus costatus.
Productus muricatus.
Aviculopecten interlineatus.
Meekella striæcostata.

From micaceous schists in the upper part of the formation between Lamb and Sheep Mountains were obtained abundant casts of *Equisetaceæ.*

Upper Coal Measures (h).—Less favorable opportunities were offered for studying this group than for either of the preceding, since its beds were found only at the extreme limits of the map and in regions where continuous outcrops are rare. It consists of alternating calcareous and silicious beds, the latter not being distinguishable from those of the Weber Grits at the base, but passing upward into reddish sandstones, which in their turn are sometimes difficult to distinguish from the overlying red sandstones of the Trias. Its lower limit is drawn at the base of the first important limestone bed above the Weber Grits. This limestone, locally called the Robinson Limestone from the fact that it forms the ore-bearing horizon of an important mine of that name in the Ten-Mile district, is remarkable for being the first true limestone observed among the calcareous beds of the region. All below this horizon are practically dolomites of varying purity. As developed in this mine, it is of drab color, conchoidal fracture, and of peculiarly compact texture, resembling a lithographic stone. Its purity and textural characteristics are apparently not persistent outside of the Ten-Mile district. In the upper horizons of this district are found mud-shales, resembling in lithological character the Permo-Carboniferous of the Wasatch. Their fossil remains are found, however, to be distinctly Coal Measure forms.

The upper sandstones of this group are distinguished from the overlying Triassic rocks by a deeper color, approaching a Venetian red, whereas in the latter the color is rather of a light brick red.

Plate V (p. 60) shows a remarkably contorted specimen of impure limestone of this horizon from the outcrops on Empire hill, where abundant fossils were found.

FOSSILS.—Fossil remains were found in various beds of this formation in the Ten-Mile district; in a peculiar black limestone of the Hoosier ridge, to the northeast of Mount Silverheels; and on Empire hill, on the west side of the range, adjoining Weston fault.

From ten different localities in these regions the following forms were obtained:

Productus costatus.
Productus Nebrascensis.
Productus Prattenana.
Productus cora.
Spirifera Rockymontana.
Spirifera (Martinia) lineata.
Spirifera camerata.
Athyris subtilita.
Streptorhynchus crassus.
Chonetes Glabra.
Bellerophon crassus.
Bellerophon percarinatus.
Bellerophon (sp. ?).
Microdon tenuistriatum (very small).
Microdon obsoletum.
Pleurophorus occidentalis.
Pleurotomaria (like *P. Greyvillensis*).
Naticopsis (like *N. Altonensis*).
Macrocheilus (*primigenius* ?).
Nucula (*ventricosa* ?).
Nucula (like *N. Beyriche*).
Microdoma (nearly *M. conica*).
Euomphalus (sp. ?).
Archæocidaris (sp. ?).
Astartella (sp. ?).
Loxomena (sp. ?).
Fenestella (sp. ?).
Murchisonia (sp. ?).
Synocladia (sp. ?).
Nautilus (sp. ?).
Entolium (sp. ?).
Amplexus (sp. ?)

MESOZOIC.

As Mesozoic beds do not occur within the area of the map, no attempt was made to study them systematically or to obtain a measurement of their thickness, which would have taken a great deal of time and probably been impracticable without a more detailed map than could be had. Their aggregate thickness has therefore been assumed to be not less than 6,000 feet, a safe estimate judging from the thicknesses given by the geologists of the Hayden Survey for various parts of Colorado.

The red sandstones of Mount Silverheels, above the beds assumed to be Upper Coal Measures in this report, are noticeable for their coarse grain and for the abundant pebbles of Archean rocks which they contain. In some intercalated shaly beds just east of Fairplay, Professor Lakes found plant remains and fossil insects. The former were determined by Professor Lesquereux to be undoubtedly Permian and the latter by Mr. A. Hyatt to be as certainly of Triassic age. In such conflict of evidence it seems safer to trust to that of animal life, since it is already well established that in America plants came into existence in Cretaceous time which in Europe have always been considered to have made their first appearance during the Tertiary.

QUATERNARY.

The Quaternary formations which have been designated by special colors on the maps and sections are the Glacial or Lake beds, and the Post-Glacial or recent detrital formations. As already shown, there is evidence of the existence, during the intermediate flood period of the Glacial epoch, of a large fresh-water lake at the head of the Arkansas Valley, in whose bed was deposited a considerable thickness of coarse and rudely-stratified beds of detrital material from the adjoining mountains.

Glacial or Lake beds (q).—Owing to the limited opportunities afforded for observing these beds in place, it was impossible to obtain a complete section of them or an accurate estimate of their aggregate thickness. The maximum thickness observed is about 300 feet; their material is generally coarse, and, as might be expected, very much coarser along what is known to have been the shore line of the lake. The finest of the beds consist of a calcareous marl, whose development seems to have been extremely local. The prevailing beds are a loose friable sandstone, resembling granite decomposed in place, consisting largely of grains of quartz and feldspar, and often somewhat iron-stained. These beds frequently alternate with those of coarser material, which form a rude conglomerate. The coarser beds contain both angular fragments and bowlders of the rocks which make up the range, and lithologically can hardly be distinguished from the Wash of the succeeding formation; but, where any considerable thickness of the beds is cut through, the stratification lines are easily recognizable and serve to distinguish this formation from the latter.

Along the immediate shore-line—as, for instance, under the Wash of Fryer and Carbonate hills—the upper portion of the Lake beds consists frequently of large angular fragments, a number of which are derived from the actual outcrops of ore bodies.

Recent or Post-Glacial (r).—Theoretically this rubric includes all the beds of the Post-Glacial Quaternary formations, of which there have been recognized in the region under survey several subdivisions, namely: the glacial moraines, a sort of bowlder clay or rearranged moraine material which is prevalent in the immediate vicinity of Leadville, where it received the local name of "Wash;" a sort of terrace formation found in the larger valleys; and the actual alluvial stream bottoms.

The time allotted to the work did not admit of a sufficiently complete study of these different subdivisions to justify their distinction by separate colors on the map. In practice, therefore, on the surface maps only the alluvial bottoms and the broader accumulations of the terrace gravel in the larger valleys and plains, which are sufficient to completely obscure the subjacent geology, have been indicated. In the cross-sections of the special map of Leadville, however, where the explorations of shafts have given unusually complete data, the Wash is also included under this rubric. On the surface maps of Leadville and of the various groups of mines both these formations have been left out, as they would have hidden an important part of the geological outlines of the actual rock surface; they have, however, been indicated to scale in the cross-sections.

DISTRIBUTION OF SEDIMENTARY FORMATIONS.

The superficial distribution of the various sedimentary formations, or the relative area covered by their outcrops, being a function of or dependent upon erosion, is intimately connected with the existing topographical structure of the region. Were erosion the only factor to be considered, the Archean rocks would be found exposed continuously on the west side of a line approximately representing the old shore-line and in the deeper drainage valleys and anticlinal axes of the eastern side. The displacements of the numerous faults which run through the region have, however, considerably modified this normal distribution. In point of fact, the central portion in the latitude of Leadville is mainly covered by the outcrops of Paleozoic sedimentary beds and of intruded masses of porphyry, the Archean exposures being confined to deep glacial amphitheaters near the crest of the range, and to minor masses which represent the eroded crests of anticlinal folds.

In the northern portion of the area Archean rocks are exposed along the main crest of the range and in the deep cañon valleys and glacial amphitheaters of the streams which flow into the Platte, Paleozoic beds being found only on the eastward sloping flanks of the included spurs. On the western side of the range, owing to the displacement of the great Mosquito fault, the area adjoining the valley of the east fork of the Arkansas is covered by beds of the Weber Grits formation, while a bordering fringe of outcrops of Lower Quartzite and White and Blue Limestone beds is found on the northern and eastern rim of Tennessee Park.

In the southern half of the map the western limit of Paleozoic beds is a line running southeasterly from the forks of the Arkansas to the crest of the range at Weston's pass, and southward beyond the limits of the map along the crest, approximately in a north and south line. West of this line are found only the granites and schists of the Archean, and irregular dikes and intrusive masses of porphyry. In the area included between this line and the crest of the range are triangular zones of easterly dipping sedimentary beds, in some cases forming a continuous series from the Cambrian to the Upper Coal Measures, cut off abruptly by fault-lines and succeeded again on the east by Archean exposures. On the east of the crest the Paleozoic beds slope regularly back beneath the floor of the South Park, the Archean rocks being found only in the deeper hollows at the heads of the streams Beyond the limits of the map the outcrops of the more resisting beds of Mesozoic age form parallel ridges, running across South Park from north to south. The Quaternary Lake beds are found only along the lower ends of the spurs extending out into the Arkansas Valley from Leadville south to the limits of the map.

ERUPTIVE OR IGNEOUS.

The eruptive rocks of this region, besides the granites, which were erupted during Archean time, are of Mesozoic or Secondary and of Tertiary age. The most important of these, both in magnitude of development and in their relations to the ore deposits of the region, are the Secondary eruptives; the time of their eruption cannot, as explained in the preceding chapter, be exactly fixed, but was probably toward the close of the Mesozoic. The Tertiary eruptives, on the other hand, are of comparatively limited development and have had no appreciable influence on the deposition of ore; their age is determined as such, not by any direct crossing of Tertiary beds, of which no instances were found in the region, but from their lithological character, their analogy to eruptive rocks of known Tertiary age outside of this area, and from the fact that they are later than the Secondary eruptives.

SECONDARY ERUPTIVES.

The earlier eruptive rocks occur mainly in the form of intrusive sheets, often of great magnitude, which, having been forced up from below through some more or less vertical vent or channel, have spread themselves out between the strata, generally following a definite horizon, but at times crossing the stratification. They also occur in the form of dikes, this form being most common in the underlying Archean rocks. There is no evidence that any of them were poured out upon the surface like the lavas of the present day, but they must have cooled and consolidated under a great weight of superincumbent strata, to which is doubtless in great measure due their unusually crystalline character.

They are with unimportant exceptions porphyritic in structure; that is, they contain larger crystalline elements in a groundmass or matrix of finer grain, as distinguished on the one hand from the granitic structure, in which all the elements are crystalline and of comparatively uniform size, and from Tertiary eruptives on the other, in which, while the structure may be porphyritic, the larger crystals have a somewhat different development and the groundmass is made up in great part of non-crystalline material.

These distinctions are those that were in force before the introduction of the use of the microscope in lithological study. The more intimate knowledge of rock structure obtained by the microscopical study of rocks has brought about many changes in preconceived ideas, which are increasing every year, so that it seems merely a question of time as to when a new system of classification may be required. Already the distinctions noted above are true only of the most typical varieties of each, while between these are transition members which often must be placed in the one category or the other by some other distinguishing characteristic, such as time of eruption, internal structure, etc. In the present work it has been judged best to preserve the prevailing usage of designating the Secondary porphyritic rocks in which the prevailing feldspar is orthoclastic as *porphyries*, and those in which plagioclastic feldspars decidedly predominate as *porphyrites*. When the porphyrite is entirely granitic or evenly granular it becomes a diorite.

On the general map of the Mosquito Range only two colors are given to the porphyries, founded on two general divisions which have a geographical as well as a structural value. In the first of these is included the White Porphyry and its closely allied form, the Mount Zion Porphyry, which are the older and more nearly granular rocks, and which occur, with unimportant exceptions, only south of the north line of the Leadville map; the second includes all other varieties of the Secondary porphyritic rocks of the region, which are generally younger and less uniformly crystalline, and which do not occur south of the south line of the Leadville map.

On the detailed map of Leadville and vicinity the principal varieties of porphyry are each designated by a special color, the division "Other porphyries" including those which could not, with absolute accuracy, be brought into either of the other divisions.

[1] In the time that has elapsed since field work was completed and the maps colored, opportunity has been had for studying more comprehensively the various Secondary eruptives in the course of work carried on in neighboring districts, and it has been found that some of the varieties designated on the following pages as porphyry, viz, the Sacramento, Silverheels, and Green porphyries, should probably be classed as porphyrites. The reasons for this, as well as the detailed description of all the rocks from a microscopical point of view, deduced from their study under the microscope by Mr. Cross, will be found in Appendix A.

MOUNT ZION PORPHYRY.

This porphyry, when fresh and unaltered, is a gray rock resembling fine-grained granite, and is made up mainly of quartz, feldspar, and mica; orthoclase being the predominant feldspar and biotite the original mica; plagioclase feldspar is decidedly subordinate, and biotite but sparingly developed. It is rarely found in an unaltered condition, however, and in the various stages of alteration it passes through a rock in which the partly decomposed biotite produces a slightly spotted appearance into a white rock glistening with fine lustrous particles of muscovite which can hardly be distinguished from the White Porphyry. The muscovite results mainly from the decomposition of the feldspar and also from that of the biotite. Larger individuals of quartz and feldspar, as porphyritic ingredients, can frequently be distinguished by the naked eye. Beside the above minerals the microscope also detects zircon, magnetite, and apatite as accessory constituents of the rock; it shows, too, that the texture of the rock is quite granular throughout, with no amorphous material.

Occurrence.—This rock is of comparatively limited development, being found thus far only on Mount Zion and on Prospect Mountain. It is generally in a less altered and therefore more typical condition on Mount Zion, for which reason it has received that name; but the most entirely unaltered specimens were obtained from some deep shafts on Prospect Mountain. On the south slopes of Prospect Mountain it is generally very much decomposed and apparently grades off into White Porphyry, so that it is difficult to draw a sharp dividing line between the two rocks. No rock that could be definitely classed with this variety has been found south of Evans gulch, and the body in the bed of the gulch above the mouth of South Evans has been assigned to it somewhat doubtfully.

WHITE PORPHYRY.

The White or Leadville Porphyry is a generally white or granular, compact, homogeneous-looking rock, composed of quartz, feldspar, and muscovite. The quartz and feldspar are so intimately mixed together that they can only occasionally be distinguished by the naked eye, the former in small, double-pointed, hexagonal pyramids, the latter in small, white, rectangular crystals. The muscovite as an original constituent occurs in sparingly distributed, dark, hexagonal plates, which were at first supposed to be biotite; their true character was learned only when a specimen was found containing enough of the crystals to be subjected to optical and chemical tests. (See Appendix B, Table I, Analysis II.) A characteristic appearance of the rock is the frequent occurrence of pearly-white leaflets of muscovite, often in star-like aggregations, resulting from the decomposition of the feldspars. Orthoclase is the predominant feldspar. No biotite has ever been detected in the White Porphyry; but, as the rock is always in a more or less advanced stage of decomposition and as biotite occurs in the Mount Zion Porphyry, which seems to pass into it, it may have been an original constituent, though it is rather remarkable that no traces of it exist even in the small dikes where the rock still retains a distinct porphyritic structure and has a fresh conchoidal fracture. By means of the microscope are found zircon as a common and magnetite and apatite as rarer constituents of this rock. No glassy matter is found, either in groundmass or in inclusions. Chemical analysis shows an appreciable amount of BaO and PbO, substances common in the ores, in its composition.

Among the miners it is known also as "block porphyry," on account of its tendency to split up into angular blocks, which are often stained interiorly in concentric rings by iron oxide; and also as "forest rock," from the frequent deposition of dendritic markings of oxide of manganese on the cleavage surfaces.

Occurrence.—The principal development of the White Porphyry is confined to a zone about the width of the Leadville map, and running from the western boundary of that map south of east, instead of due east as the map itself does. In other words, its lines have the prevailing northwest and southeast trend of other larger features of the region. Within this zone it is developed on an enormous scale, and occurs mainly as an intrusive sheet directly overlying the Blue Limestone and in contact with the principal ore deposits. It is not, however, entirely confined to this horizon, but is also found at both lower and higher horizons and can sometimes be observed crossing a stratum, generally at a low angle, from one horizon to another, thus splitting the sedimentary bed into two wedge-shaped portions. This occurrence is most noticeable in the area of the Leadville map along an imaginary northwest and southeast line, on one side of which it is found both above and below the Blue Limestone, while on the other it occurs only above it.

The main sheet has an average thickness of several hundred feet and varies in its extreme dimensions from 20 feet along the northeast edge of the zone to 1,500 feet at White Ridge, on the east side of the range, the point of its maximum development and supposed to be the locality of its principal vent.

Although all these masses must have been originally forced up from below through the Archean, it is remarkable that no section has yet been found which would show the actual passage from the Archean dike to the interbedded sheet. The nearest approach to this has been at the head of Iowa gulch, on Empire hill, and in a bore-hole in South Evans gulch, where White Porphyry has been found in the Archean in probable dike form, and on White Ridge and Lamb Mountain, in Horse Shoe gulch, where it is seen cutting up nearly vertically across Carboniferous strata.

South of the zone above mentioned, White Porphyry is found as a remarkably persistent sheet at the Blue Limestone horizon gradually thinning out and extending to the southward as far as Weston's pass. North of the zone it is found only in small sheets at Little Zion, Mosquito Peak, and London hill, and in several small dikes in the Mount Lincoln massive, its place being occupied by other varieties of porphyry.

LINCOLN PORPHYRY.

The other forms of porphyry found (and which on the Mosquito map have been designated by one general color), though presenting a number of varieties in the field, have essentially the same general composition, both mineralogical and chemical. They consist mainly of quartz, two feldspars, and biotite, hornblende occurring as an essential ingredient only in one variety. The crystalline ingredients are easily distinguishable by the eye, and there is therefore no danger of confounding them in the field with White Porphyry, except in the conditions of extreme decomposition in which they may be found near the ore bodies. This crystalline structure, on the other hand, is often so far developed that they are not readily distinguished by the untechnical eye from granites; as such, indeed, they are frequently classed by the miners. A careful examination, however, readily reveals their structural difference, which is that in them the larger crystals are inclosed in a finer-grained groundmass, whereas between the crystals of granite there is no such intervening and apparently structureless material.

The principal subdivision of this group has been called Lincoln Porphyry, from the fact that it is typically developed in the mountain mass around Mount Lincoln. Its most striking characteristic is the frequent occurrence of large crystals of pinkish orthoclase, from one inch upwards in size, with a peculiar luster like that of sanidine. Plagioclase is generally in small, white, opaque crystals. Quartz occurs in double-pointed hexagonal pyramids, which have a rounded outline on fracture surfaces and often a slightly roseate tint. Mica is found in small hexagonal plates, generally decomposed and of greenish color. The microscope discloses, in addition to the above minerals, allanite, zircon, magnetite, titanite, and apatite. No microfelsitic or glassy matter is found in any rock of this type and no glass inclusions occur in the Mount Lincoln rock. Orthoclase feldspar predominates in the groundmass and in the rock as a whole, while among the porphyritic crystals of rocks, in which the characteristic large orthoclase are wanting, plagioclase is in relatively larger proportion. Owing to the size of the crystals, large masses of the rock have at a little distance a decidedly granitic appearance. On weathered surfaces, especially in the dry region of the mountain peaks, it is of light-gray color, somewhat bleached, and often slightly stained by hydrous oxide of iron. In mine workings, on the other hand, when freshly broken it has a decidedly greenish tint, from the change of biotite into chlorite.

Occurrence.—The main development of the typical Lincoln Porphyry is in the neighborhood of Mount Lincoln, where it occupies the same position with regard to the ore deposits of that region that the White Porphyry does about Leadville. It forms the immediate summit of Mount Lincoln, where it is apparently the remains of a laccolitic body or head of a channel of eruption. It occurs as an interbedded sheet in the Cambrian and forms several large bodies, apparently interbedded sheets, in the Weber Grits which form the wooded ridges on either side of the Platte Valley in that region. It also occurs in the form of narrow dikes, cutting through the Archean. On the west side of the range it forms many large bodies in the Weber Grits, the most important of which is the laccolite body of Buckeye Peak. These bodies in the northwestern part of the region pass into the closely allied variety called Eagle River Porphyry, with which they doubtless connect, and which will be described in detail in a forthcoming report on the Ten-Mile district.

GRAY PORPHYRY.

This rock, which occurs only in the immediate vicinity of Leadville, is in its typical form apparently a decomposed Lincoln or Eagle River Porphyry. It has the same mineral composition and frequently the large orthoclase crystals that the former has, and can be traced as a continuous sheet through transition forms into the typical variety of the latter. It is almost invariably decomposed, and on or near the surface is generally a greenish-gray rock, showing numerous crystals in a prominent earthy-looking ground-mass; in the mines it is usually found bleached and often reduced to a white pasty mass in which the outlines of former crystalline constituents are but faintly traceable. It is of importance in connection with the ore deposits, as where it has crossed the Blue Limestone it has often played the same rôle with regard to them as the White Porphyry.

As distinguished from the Lincoln Porphyry the microscope detects traces of former hornblende in the rock and finds glass inclusions in the quartz and numerous fluid inclusions in the feldspar.

Occurrence.—The main sheet of Gray Porphyry, the only body which is distinguished by a distinct color on the Leadville map, occurs above the main sheet of White Porphyry in the northern half of the area shown on that map, and extends beyond it to Mount Zion. Other bodies which belong without question to this variety, as well as those which are more doubtful, have, for reasons to be given below, been included under the color of "Other porphyries" on this map. The most important of these is a sheet occurring in the Blue Limestone, cutting transversely upwards from its base to the overlying White Porphyry. Among those which are doubtful are the Printer Boy and Josephine Porphyries, which occur the one on Printer Boy, the other on Long and Derry hill. Among rocks so thoroughly decomposed as are those in the immediate vicinity of the ore bodies it is often impossible to assign an occurrence with absolute certainty to a distinct type; the miner can, however, in most cases distinguish these porphyries from the White Porphyry by the outlines of former crystals which the slight stain of iron oxide caused by their decomposition leaves.

SACRAMENTO PORPHYRY.

This rock in the hand specimen has the same general appearance as the variety of Lincoln Porphyry which has no large crystals. It is a dark-gray, granular, rather even-grained rock, in which the groundmass is decidedly subordinate, and contains quartz, two feldspars, biotite, and hornblende. It is distinguished from the former rock by carrying a much larger proportion of plagioclase feldspar, and hornblende as well as biotite. The microscope discloses the usual accessory minerals, with allanite and pyrite, and shows that the groundmass is holocrystalline and contains no glassy material. In the large masses of the higher mountain region it is usually a fresh-looking rock, but in mine workings and under a covering of soil and gravel capable of holding water it is usually much decomposed and bleached to a light-green, almost homogeneous-looking rock, with much epidote. The processes of decomposition in this rock, which are exceptionally interesting, are explained at length in Appendix A.

Occurrence.—The main laccolitic body of Sacramento Porphyry is found under Gemini Peaks, between the heads of Big and Little Sacramento gulches. A fine cliff section of the body is also found on the face of Mount Evans towards Evans Amphitheater. It reaches a thickness of over a thousand feet in this region. Its main sheet occurs above the White Porphyry, or, when this is wanting, with an interposition of Weber Shales between it and the Blue Limestone. East of the London fault it rests directly on the Blue Limestone, and in the neighborhood of the Sacramento mine it plays the same rôle with regard to the ore deposits that the White and Lincoln porphyries do at other points. It also forms sheets higher up in the Weber Grits and less frequently in the lower Paleozoic strata In a broad, general way it may be said that on the eastern slope of the range Lincoln Porphyry extends from the northern edge of the map to Mosquito gulch, Sacramento Porphyry from Mosquito gulch to the ridge south of Little Sacramento gulch, and White Porphyry from there south to the limits of the map. The only point observed which showed evidence of a feeding channel from below was at the head of Little Sacramento gulch.

PYRITIFEROUS PORPHYRY.

This rock, though an extremely important element in the geology of the immediate vicinity of Leadville, does not occur outside that region and, like most of the eruptive rocks in the vicinity of the great ore concentrations, is in such a universally decomposed condition that its original constituents cannot be definitely determined. It is generally of a white color, with grayish-green or pinkish tints, comparatively fine grained, and with no traces of large crystals. In it can be distinguished small grains of white feldspar, quartz, biotite which is generally altered to a chloritic substance, and pyrite. The last ingredient, from which it derives its name, is found abundantly scattered through the rock in crystals, often so fine as to be undistinguishable by the naked eye. They occur at times within the crystals of quartz and biotite, and are hence supposed to be an original constituent of the rock. They are frequently concentrated along cleavage planes, sometimes associated with finely disseminated crystals of galena. Pyritiferous Porphyry is readily distinguished from the White Porphyry by its crystalline constituents. It differs from the Sacramento and Gray Porphyries by a relatively small amount of plagioclase feldspar and from the former by the absence of hornblende. Its most strikingly distinctive feature is the amount of pyrites which it contains, which is estimated to constitute, on the average, 4 per cent. of its mass. The only further constituents disclosed by the microscope are minute crystals of zircon. Fluid but no glass inclusions are found.

Occurrence.—The Pyritiferous Porphyry, as stated above, is confined to the area of the Leadville map, and is at present principally developed on Breece hill and the slopes of Ball Mountain. Its original extent previous to erosion was probably much greater than at present. It is a stratigraphical replacer of the Gray Porphyry on the north and of the Sacramento Porphyry on the east, occurring mainly above the Blue Limestone, but with either White Porphyry or Weber Shales interposed between it and that horizon. In California gulch it is also found at lower horizons, but apparently cutting across them upwards.

MOSQUITO PORPHYRY.

This porphyry, a light-gray, fine-grained rock occurring exclusively in the form of dikes, is formed of quartz, two feldspars, and biotite. The quartz is very prominent, in clear, irregular grains; orthoclase feldspar is predominant over plagioclase; biotite occurs in small leaves and is not abundant. The occurrence of macroscopical apatite in glistening hexagonal prisms is a noticeable feature of the rock. The microscope discloses a remarkable association of small ore grains (ilmenite, pyrite, specular hematite, and magnetite), together with zircon.

Occurrence.—The type rock was only observed in dikes in the Archean, viz, in the North Mosquito Amphitheater, on the north face of Mount Lincoln, and in Cameron Amphitheater where it extends from the Archean up into the Paleozoic.

GREEN PORPHYRY.

This is a fine-grained, almost compact rock, of light-green color, resulting from the chloritic decomposition of its original constituents, which renders their identification difficult. Quartz, two feldspars, biotite, and hornblende have been identified; but the relative proportions of orthoclase and plagioclase are not readily apparent. Muscovite and calcite are decomposition products of the feldspars. The groundmass is often so subordinate that the rock seems macrocrystalline.

Occurrence.—It is found as interstratified sheets on lower Loveland hill near the Fanny Barrett claim and in Cambrian quartzite on the north side of Mosquito gulch; also, as a dike running north across the Paleozoic beds from the lower edge of Bross Amphitheater.

SILVERHEELS PORPHYRY.

This rock forms important intrusive sheets on the mountain mass of Silverheels outside of the limits of the Mosquito map; it has not been so carefully studied as the other varieties. It is an extremely fine-grained, greenish-gray rock, which in the hand specimen is characterized by fine needles of what is apparently decomposed hornblende. It carries quartz in small amount, two feldspars whose relative proportions are not readily apparent, with hornblende and biotite. These constituents are so very small as not to be readily distinguished. The microscope discloses the usual accessory minerals, including allanite and pyrite. The groundmass is holocrystalline and contains no glass. A porphyritic rock found on a southern spur of Mount Silverheels, at the forks of Crooked Creek, although of much coarser grain and more distinctly porphyritic habit, has essentially the same elements as the Silverheels Porphyry.

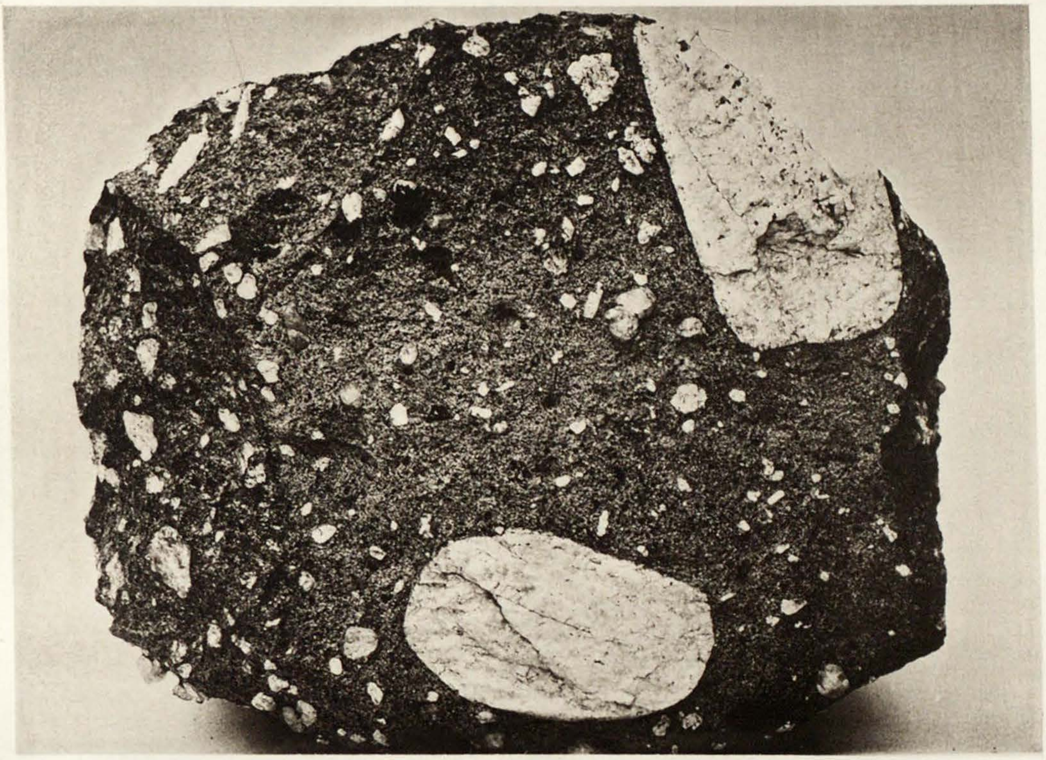
DIORITE.

Only three occurrences of granular plagioclastic rocks were found in the region, each of which was in the form of a dike cutting through the Archean in Buckskin gulch. The rock of each of these occurrences represents a distinct variety of the type.

Hornblende diorite.—The normal diorite, which forms a broad dike crossing the head of the gulch, is a fine-grained, gray rock, in which the prominent constituents are plagioclase feldspar and hornblende, while a little quartz, brown biotite, yellow titanite, and dark ore grains can be detected by the naked eye. The microscope discloses also zircon and apatite, with chlorite and epidote as alteration products of the hornblende and biotite, and muscovite formed from orthoclase. A similar rock is found in French gulch, on the west side of the range.

Quartz-mica diorite.—This rock occurs on the south side of Buckskin gulch, opposite the Red Amphitheater. It is a dark, even-grained rock, in which quartz and feldspar are more prominent than the small irregular leaves of biotite; hornblende is wanting. The microscope shows zircon, magnetite, apatite, biotite, plagioclase, orthoclase, and quartz as original constituents.

Augitic diorite.—This rock, which is darker and finer grained than either of the preceding, occurs in the Red Amphitheater, cutting up through the Archean into the base of the Cambrian. In the hand specimen only hornblende, biotite, plagioclase, and a little quartz can be distinguished, but the



Hornblende Porphyrites

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microscope detects also augite, orthoclase, zircon, titanite, magnetite, hematite, and apatite.

PORPHYRITE.

As compared with the quartz-porphyries, the type rocks of this class are distinguished at first glance by a great predominance of basic silicates (hornblende or biotite), by a comparative rareness of quartz, and by their rather younger field habit, as shown by the marked conchoidal fracture and generally fresher appearance. For the latter reason it was at first thought in the field that they might possibly be of Tertiary age, but the fact that they are folded and faulted with the inclosing Paleozoic rocks, as well as their internal structure, proves them to be, like the quartz porphyries, of Secondary age. In their manner of occurrence they are also distinct from the latter rocks, in that they do not form large bodies, neither dikes nor intrusive sheets being as a rule over twenty feet in thickness. The former often occur in the form of interrupted dikes; the latter, on the other hand, while occasionally crossing from bed to bed, have a most remarkable extent in one general horizon as compared with the thickness of the sheet. Although subordinate in amount to the quartz porphyries, these rocks occur with so many variations of internal structure and composition that they afford a complete series, including almost all the possible varieties of the type, and a complete description and classification made by Mr. Cross from a lithological point of view will be found in Appendix A. Only the general features of the rocks will therefore be given here.

The typical rock, both in composition and manner of occurrence, may be taken as that which occurs interbedded in the Paleozoic beds along the cliff sections on either side of Mosquito gulch. A photograph of a hand specimen of this rock is reproduced in Plate VII, Fig. 2, which gives some idea of its general appearance; it is a rather dark greenish-gray rock, with dark weathered surface and clean conchoidal fracture. The most prominent macroscopical constituents are well defined prisms of dark hornblende and small, white, opaque crystals of plagioclase. The microscope detects some biotite both among the porphyritic constituents and in the groundmass, and both orthoclase and quartz in the groundmass No glass and but few fluid inclusions are found.

Occurrence.—The manner of occurrence of this rock in the region above mentioned is quite remarkable. It has been traced in practical continuity over an area of some four square miles, and probably has a much wider extent. It is regularly interbedded and rarely over twenty feet in thickness. It is easily traceable from a distance on the cliff walls, as a dark band between the lighter-colored sedimentary strata, and, while it apparently follows rigorously the same horizon, it is found, on close examination, to cross from bed to bed at different points, so that its range in this area is actually from the upper part of the Cambrian to the top of the Silurian. The manner in which it crosses the beds is shown in Plates XIII and XIV. It also occurs at various other points in narrow dikes in the Archean.

This rock forms Type V of Division B of Mr. Cross's classification, this division being that in which the hornblende and biotite are found both in the groundmass and as porphyritic constituents. His Division A includes rocks in which these basic minerals are entirely wanting in the groundmass, and which, in consequence, are of much lighter color than either of the other divisions. The rocks of his Division C, on the other hand, in which the hornblende and biotite are found only in the groundmass, are generally of darker color, and the arrangement of these minerals around the larger porphyritic crystals often shows a fluidal structure.

Included fragments of pebbles of Archean rocks are more frequent in these than in any other eruptive rocks of the region, and in Plate VII, Fig. 1, is shown a specimen of a rock of Division A, from a remarkable dike in the Arkansas Amphitheater, in which the included fragments are large rounded crystals of orthoclase, whose presence in such form it has not yet been possible to account for.

TERTIARY ERUPTIVES.

The Tertiary eruptives found in this region consist of rhyolites and one occurrence of quartziferous trachyte within the limits of the Mosquito map, and of an interesting occurrence of andesite just south of those limits. The quartziferous trachyte being a small body, and of no great importance as bearing on the subject-matter of this report, has not been designated by a special color, but is included on the map under the rhyolite color. The eruption of these rocks had apparently no influence on the ore deposition of the region, since that, as well as can be determined, was pre-Tertiary, and no ore bodies have been found in connection with these rocks. Their interest is therefore chiefly lithological.

RHYOLITE.

The most important body, both in mass and in lithological interest, is that of Chalk Mountain, on the northern edge of the map, which, as the name of the mountain indicates, is prominent on account of its dazzling white color. It is a very crystalline rock, in which the groundmass is so subordinate as to appear in the hand specimen entirely wanting; it corresponds, therefore, to the generally accepted definition of Nevadite. Its prominent constituents are sanidine, generally in large crystals and having a peculiar satiny luster, and smoky quartz. The microscope also detects some plagioclase, a little biotite, with magnetite, apatite, and zircon in relatively small proportion as compared with the quartz porphyries. The quartzes contain fluid inclusions. A careful study of this rock by Mr. Cross has developed the fact that the peculiar luster of these feldspars is due to an actual parting, analogous to cleavage, which has already been determined as that which gives the blue color observed in the feldspar of many rocks, notably labradorite and some rhyolites. He also found crystals of topaz in some of the druses of this rock, the first instance, so far as known, in which this mineral has been found in Tertiary rocks. On Plate VIII is the reproduction of a photograph of a hand specimen of this rock, in which the smoky quartz grains appear black; above this are two microsections which show the similar granular structure of this rock and of White Porphyry.[1]

The next important body of rhyolite is that at the west base of Bartlett Mountain, at the head of McNulty gulch, a tributary of the Ten-Mile Creek; it here cuts across porphyrite and quartz porphyry. This rock, though generally light colored, is not as white as the Chalk Mountain rock, nor is it so decidedly of the Nevadite type, the groundmass being often quite prominent. It contains glassy feldspars, quartz, and biotite. In darker

[1] In some of the plates, by an error in proof-reading, the title White Porphyry, which belongs to the left-hand section, has been placed below the right-hand section and vice versa. The reader will bear in mind that the section containing the large crystal is Nevadite.

portions of the rock biotite is quite abundant and some hornblende appears. The microscope shows glass, but no fluid, inclusions in both quartz and feldspar. The groundmass is cryptocrystalline. In general habit it is more like the recent volcanics than the Chalk Mountain rock, and yet, in some parts, it is with difficulty distinguished from a quartz porphyry.

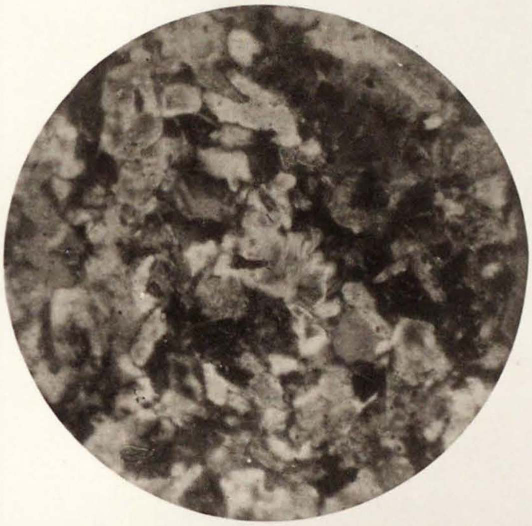
A third important body of rhyolite is that which forms Black hill, at the southeast extremity of the map. This is a light, often rather pinkish colored rock, of fresh habit and conchoidal fracture. It carries macroscopically two feldspars, smoky quartz, and some biotite. The microscope shows the groundmass to be granular, and that fluid inclusions occur in both quartz and feldspar and glass inclusions in the quartz. From the hand specimen alone the rock would be difficult to distinguish from an earlier quartz porphyry, but the manner of its occurrence and its relations to the surrounding rocks leave little doubt that it must be of Tertiary age.

On the west slope of Empire hill a fine-grained, nearly white rock occurs below the White Limestone, which is distinctly orthoclastic and contains quartz and biotite. The fact that the quartz contains glass and no fluid inclusions points to a Tertiary age, but the occurrence has not been very carefully studied. A similar rock with larger crystals was found in a brecciated material from the Eureka shaft, in Stray-Horse gulch, which it has not yet been possible to account for.

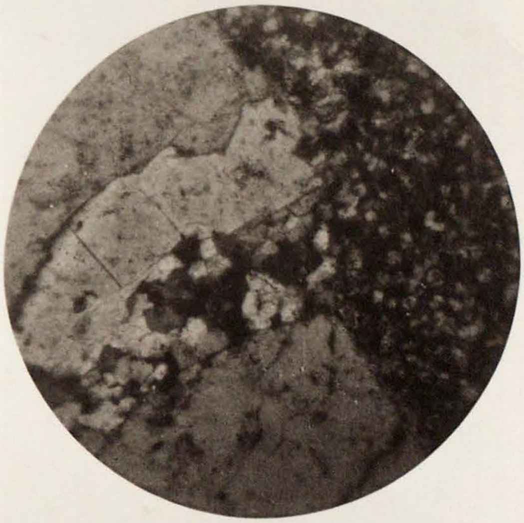
Trachyte.—At the head of Union gulch are small irregular bodies, in granite and White Limestone, of fine-grained, dark-gray rock, full of brown biotite, with small glassy feldspars and some rounded yellowish quartz grains. The microscope shows hornblende and about equal portions of orthoclase and plagioclase. The groundmass is microfelsitic and has a fluidal structure. The quartz grains seem rounded and worn, and are confined to macroscopic individuals, for which reason they are regarded as accidental rather than normal constituents, and as the rock contains only 61.22 per cent. silica it is considered a trachyte rather than a rhyolite.

ANDESITE.

The Buffalo Peaks form a double-pointed mountain mass, rising about a thousand feet above the main crest of the Mosquito Range, some ten miles



Nevadite



White Porphyry

Nevadite,
from Chalk Mt.

Heliotype Printing Co. 211 Tremont St. Boston

south of Weston's Pass. They consist of a normal hornblende-andesite, which is the cap rock, with a black vitreous rock which was at first considered an augite-andesite, and a great development of tufaceous and breccia beds. A careful study of the darker rocks led Mr. Cross to the conclusion that their characteristic mineral was hypersthene, and to the establishment of hypersthene-andesite as a normal pyroxenic variety of this class. These rocks are described briefly in Appendix A, and more fully in No. 1 of the Bulletins of the United States Geological Survey.

CHAPTER IV.

DESCRIPTIVE GEOLOGY OF THE MOSQUITO RANGE.

Introductory.—The following pages present a detailed description of the area included in the Mosquito map, summarized from field notes made during the summer of 1880. They contain the facts upon which have been founded the general conclusions drawn elsewhere with regard to the geology of this region, and therefore include many details that may not interest the general reader, but which will be of use to those who wish to use the maps on the ground or who desire to investigate critically the correctness of the generalizations. In preparing them it has been the aim of the writer to condense the description as far as could be done without omitting any essential observations. Circumstances made the time of field work extremely limited, and the detail in which it was possible to examine different parts of the region was necessarily unequal. The prime object of the work was to gather all information which might have bearing upon the origin and manner of formation of the ore deposits of the Leadville region. In the prosecution of this object much information of interest in other directions has been collected, and many lines of investigation have suggested themselves which it would have been a pleasure to pursue further had time permitted. That such material be found incomplete is to be attributed, therefore, to a want of opportunity rather than of scientific zeal.

In the following description the region has been treated in the general topographical order in which it was examined; that is, following the eastern slopes of the range from the northern edge of the map southward to Weston's pass, and then along the west side in the inverse direction. Both geological and topographical structures lend themselves to this method of treatment, and permit four general divisions of the area: 1. The *northeastern*, including the Mount Lincoln massive, which, as shown in Plate IX, stands out quite by itself. 2. The *middle-eastern* region, or from Buckskin to Horseshoe gulch, inclusive. 3. The *southern*, including both sides of the range south of the line of Horseshoe and Empire gulches. 4. The *northwestern* division, including the area on the west side of the range north of the line of the Leadville map; the middle area, which comes within the limits of this map, being described in a separate chapter. Each of these four divisions presents a general type of geological structure peculiar to itself.

The numbers after rock descriptions are the catalogue numbers of the specimens in the Leadville collection of the United States Geological Survey.

Surface features.— The whole region treated of in this report may be divided as regards its general superficial characteristics into three belts or zones: (1) The bare summits and high ridges above timber-line; (2) the belt of forest growth covering the mountain slopes below timber-line; (3) the open grass-grown and treeless valleys.

The elevation of timber-line can only be given in a most general way as the average height at which tree-growth stops on the spurs where surface conditions are favorable. The bare glacial amphitheaters in the interior of the range and the almost perpendicular walls of the cañons present conditions unfavorable to tree-growth even at points below the timber-line, in spite of which the line is often well marked. Below an average elevation of 11,700 feet the flanks of the mountains are covered with coniferous trees of the more hardy Alpine varieties, such as the Douglas fir and Engelman spruce, which in favorable situations often form a dense forest by no means easy to traverse, owing to the abundance of dead and fallen trunks, relics of former forest fires. The lower limit of tree growth is even more sharply defined; not, however, by its elevation above sea-level, but by the change of surface slope to the low angle which characterizes the valleys. Whether it be the bottom of a little mountain stream, a hundred feet wide, or the broad expanse of the South Park, almost as many miles in extent, the downward spread of forest growth is arrested with equal suddenness, provided only there be a sufficient thickness of loose detrital material, whether gravel or alluvial soil, accumulated over the hard rock surface. Along the alluvial bottoms of the streams, it is true, there is often a fringe of willow, alder, or cottonwood; but the sturdy pine, although delighting to face the mountain blasts on bare inaccessible precipices, seems afraid to trust himself where he cannot thrust his roots down to a base of firm rock, or around bowlders large enough to act as a counterpoise to the shaft he exposes to the force of the wind.

The high mountain region, the forest region, and the valley region represent fairly three degrees of comparative difficulty in reading the geological story. In the former, except where covered by talus slopes at the foot of great cliffs, the rock surfaces are all laid bare and the geological structure is an open book, only needing an understanding and careful observer to be read correctly. In the forest region there is more or less accumulation of soil and decaying vegetable matter, and rock outcrops are often rare and widely spaced. The record has many gaps which time and care are not always sufficient to fill without resorting to hypothesis or analogy. In the larger valleys, however, whose surfaces are covered to unknown depths by gravel and soil, no outcrops are visible, and induction or analogy are the geologist's only resources for determining the structure of the underlying rock formations.

Glacial formations.—In the Arkansas Valley, as already noted, there is distinct evidence of the existence of a glacial lake, and the Arkansas Lake beds, composed of stratified sands, marls, and conglomerates, have been actually exposed in a thickness of several hundred feet. In the South Park, on the other hand, no such stratified deposits have been observed, nor is the topography such as to suggest the possibility of a local lake of any great extent having been formed there during the Glacial period. While the existence of such a lake in the South Park is therefore considered improbable, the fact that the exigencies of this work admitted the examination of only a small portion of its surface, immediately adjoining the Mosquito Range, does not justify a positive statement to this effect.

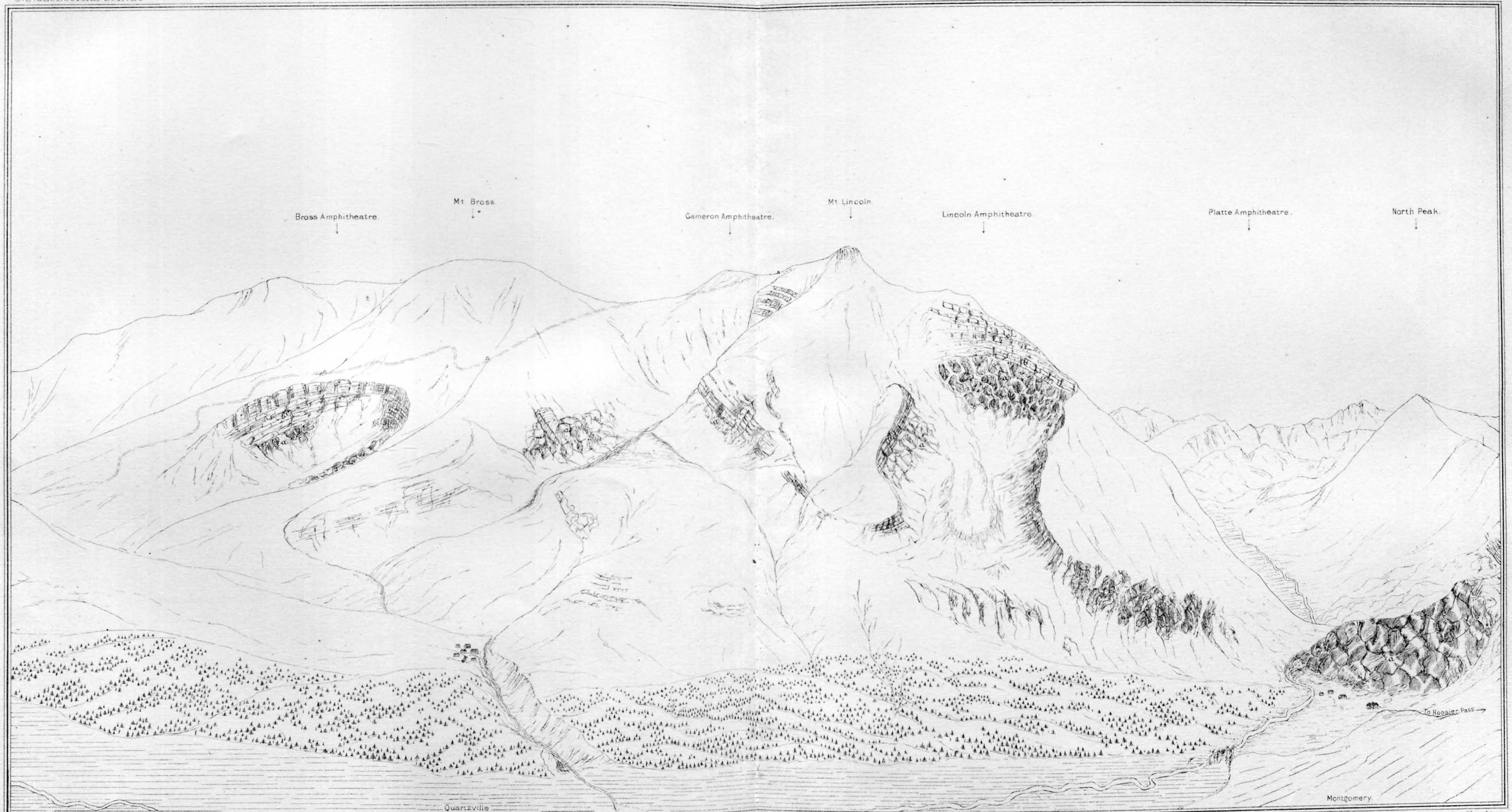
Post-Glacial formations.—The Post-Glacial deposits of unstratified gravels are equally prominent, however, on both sides of the range. They result in great part from the redistribution of glacial moraines by the floods which accompanied the melting of the ice at the close of the Glacial period. In the Arkansas Valley they were spread out over the already existing Lake beds, and reach a relatively high level on the mountain spurs. In the western portion of the South Park they form the flood-plain of the larger valleys, which they filled up to a very considerable depth, as has been shown by excavations made at Alma and Fairplay in washing them for gold. Depths of 60 to 100 feet have here been proved of coarse gravel conglomerate, entirely without stratification. These points are comparatively high up and near the source of supply, and it may be assumed that finer material of the same origin extends to equal if not to greater depths well out on the bottom lands of the park. Within these flood-plains the streams run in alluvial bottoms which widen as one descends and often open out into broad meadows, partially drained lake basins, where some natural obstacle has caused a partial damming up of the earlier streams. Of actual moraines no inconsiderable remnants still remain. They can be most clearly seen along the steep sides of the cañon gorges through which the mountain streams debouch into the more open valleys, where they often form gravel ridges several hundred feet in height; and on the lower spurs beyond these cañons their existence under the forest growth may often be surmised by their characteristic topography of irregular ridges inclosing rounded hollows without exterior drainage, as well as proved by shafts and tunnels made by the misapplied energies of prospectors.

Archean exposures.—To the lithologist no more favorable opportunity could be had for an exhaustive study of the older crystalline rocks which form the backbone of the Rocky Mountain system than that afforded by the exposures in the deep gorges and glacial amphitheaters of the interior of this range. The scope of this work did not admit, however, of any such exhaustive study, which would have required much more time than could have been devoted to the whole region. The utmost that could be done was to grasp the more salient characteristics of the series and to outline on the map such of the more important eruptive masses which intersect them as fell under observation, without pretending to present them in any determined degree of completeness. The special study of the Archean rocks in the field was assigned to Assistant Whitman Cross, to whom also was allotted the duty of examining them microscopically, and the greater part of the observations here recorded are derived from his notes. Granites and gneisses with accessory occurrences of amphibolite constitute, as already stated in Chapter III, the main components of the Archean in Mosquito Range. As seen from one of the commanding peaks of the range the most striking features of the rocks are the great irregular vein-like masses of white pegmatite, which form an infinitely intricate network on a background of darker gneiss. When examined more closely, however, the definite outline of these pegmatite bodies is no longer so apparent, and they are found to be intergrown in the surrounding rocks in a most intricate manner. It is only in the smaller veins, such as are shown in Plate IV, that their outlines can be definitely traced. Structure lines, as defined by relics of former stratification, are so seldom to be distinctly traced that no attempt has been made to co-ordinate the few facts observed into any general structural system.

Of eruptive rocks in the form of dikes and intrusive masses of irregular shape an almost infinite variety, both in form and composition, is found. The dikes are generally narrow, being rarely over 50 feet in width, and of limited continuous length. Those shown on the map are only the more prominent of those actually observed, and it must be borne in mind that a great portion probably did not come under observation at all.

NORTHEASTERN DIVISION.

Platte amphitheater.—Like the Arkansas River, whose amphitheater adjoins this on the west, separated only by a single narrow, knife-like ridge, the Platte at its source flows first north and then bends round upon itself to take its main course in a diametrically opposite direction. A reason for this by no means uncommon occurrence in the glaciated regions of the Rocky Mountains may be found in the fact that on the northern sides of the higher peaks are the greatest and most permanent accumulations of névé ice, to whose erosive action, not yet thoroughly studied, are doubtless



Julius Bien & Co. lith.

S. F. Emmons, Geologist-in-Charge.

Mt. LINCOLN MASSIVE FROM SILVERHEELS.

due the semicircular form and remarkable verticality of the upper walls of glacial amphitheaters or cirques.

The main area of the Platte amphitheater lies directly west of Mount Lincoln, but a smaller northwest branch extends back of North Peak, holding on its basin-shaped floor, which is about six hundred feet higher than the other, several pretty glacial lakes with characteristically emerald-tinted waters. The glacier formed by the confluence of the two immense névé masses that once filled these amphitheaters, which must have been about two thousand feet thick, flowed directly east, carving out a straight U-shaped valley in the crystalline rocks, whose general form remains essentially unchanged to the present day.

On the upturned sedimentary beds which rest upon the Archean, however, later erosion has acted more rapidly and irregularly, and at the little town of Montgomery the valley suddenly widens out into a broad, grassy bottom-land, with forest-covered hills sloping away more gently on either side. Immediately above Montgomery, as shown in Plate IX,[1] the present stream bends a little southward around a boss of Archean, composed chiefly of gneiss and amphibolite, penetrated by a fine-grained white granite, in which reticulated veins of white pegmatite stand out prominently. In the bottom of the valley, above this boss for a mile or more, extend glacier-worn hillocks (roches moutonnées) of typical form, evenly rounded and scored by very distinctly-marked grooves and striæ on the upper side, but breaking off unevenly on the lower side toward the stream. On either side of the gorge, above the talus slopes of broken rock masses at their foot, steep walls of Archean rocks rise about two thousand feet, with a thin capping of nearly horizontal Paleozoic strata at the very summit. The structure planes of the Archean, which are unusually distinct in the Platte gorge, stand nearly vertical, with a strike south-southeast.

The eastern portion of the Archean mass seems mainly composed of gneiss and crystalline schists, granite occurring only in subordinate masses. The granite near Montgomery is of the gray, fine-grained type, suggestive

[1] In this and the succeeding diagrammatic sketches, which are intended mainly to illustrate the geology of the various exposures shown, the letters on the outcrops are the same that are used on the geological maps to designate the different rock formations, i. e., *a* = Archean, *b* = Cambrian, *c* = Silurian, etc.

rather of an eruptive origin, and contains relatively more mica and quartz than that found in Buckskin gulch. The gneiss is of the normal gray type, generally rich in quartz and biotite. Its feldspar occurs often in large Carlsbad twins. The microscope detects plagioclase, microcline, and muscovite; also, abundant fluid inclusions in the quartz, sometimes double and with salt cubes and moving bubbles. A schist found locally on the northern face of Mount Lincoln is of dark-green color and contains only biotite, muscovite, and tourmaline, with a little feldspar, which is scarcely visible, even under the microscope, and then appears in a stage of alteration into muscovite. The white pegmatite masses are specially prominent, as already mentioned, on the faces of the spurs on either side of the gorge at Montgomery. Their color is due to the large proportion of white orthoclase feldspar, which in the mass gives its tone to the quartz also, while the mica, generally muscovite, occurs in bunches of subordinate importance, growing between the crystals of the other constituents.

The more prominent eruptive masses observed and which are indicated on the map are:

1. Half a mile above Montgomery a dike of porphyry crosses the valley at right angles and can be traced for a considerable distance up either wall. It is a light-colored, felsitic-looking rock, in which only very small quartz grains and biotite leaves can be detected by the naked eye. It most nearly approaches the Mount Zion, or fresh variety of White Porphyry, and has a holocrystalline structure as seen under the microscope.

2. A mile above Montgomery is a wider dike of light-gray quartz-porphyry, whose distinguishing peculiarity lies in brilliant-green grains of epidote, which are scattered uniformly through the rock and which are, in part certainly, the result of the decomposition of biotite. Its ground-mass is also microcrystalline.

3. A third dike is particularly noticeable for its peculiar form, changing half way up the cliff from a vertical to a horizontal sheet. This change of form is not unusual in dikes which extend up into the Paleozoic or regularly bedded rocks; but this is the only instance in which it has been observed in the Archean. The rock belongs to the Mosquito Porphyry type, and is identical with that found (type No. 2) on the south face of Mount Lin-

coln and at the head of the Cameron amphitheater. It is a light-gray, fine-grained rock, consisting of quartz, feldspar, and biotite crystals in a very scanty groundmass. The groundmass is a fine-grained mosaic of quartz, with some feldspar and muscovite, the latter resulting from decomposition of feldspar and probably in part also from fine biotite leaves, since this alteration is visible in the larger individuals.

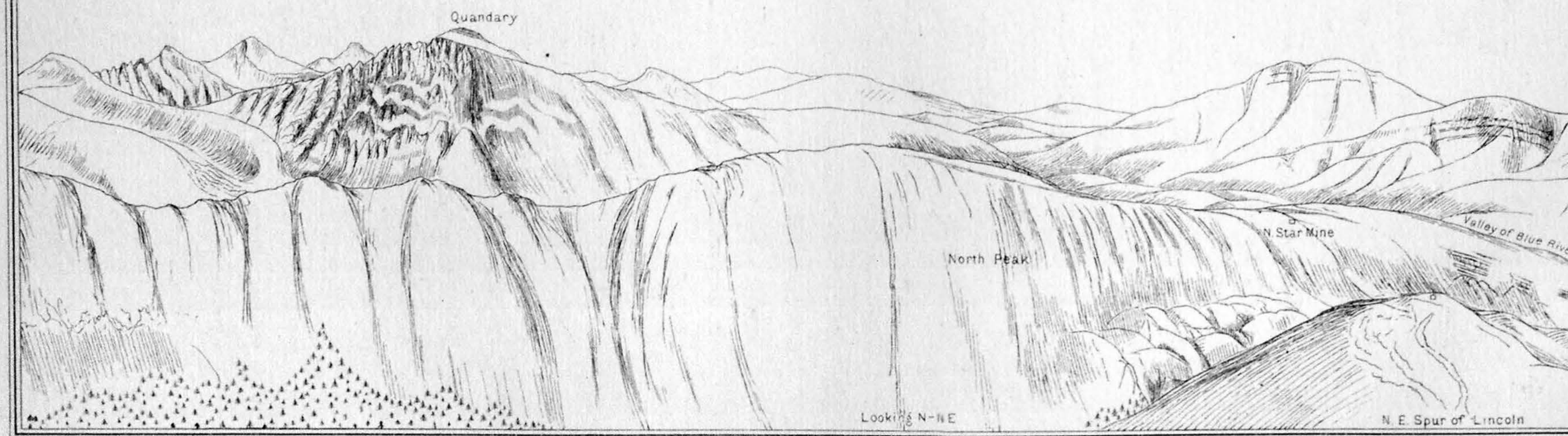
4. Just west of this is a very irregular body of quartz-porphyry, not shown on the map. It occurs at the base of the cliffs and is very variable in form and thickness, branching out irregularly and continually changing its direction. It is a dull-green rock and belongs to the Green Porphyry type. It is rich in feldspar, with a few grains of quartz, and what is probably a decomposition product of hornblende which gives the color to the rock. On the cleavage-planes are coatings of epidote.

5. Still further up the valley, directly under the summit of Mount Lincoln, is a dike of White Porphyry extending high up on the face of the cliff. It resembles closely the typical White or Leadville Porphyry, but is less decomposed. A few small crystals of quartz and feldspar are visible, also frequent light-green specks of partly decomposed biotite. It is almost identical with the similarly situated dike (dike No. 1) in Cameron amphitheater, on the south face of Mount Lincoln, and with fragments found at the head of Buckskin amphitheater, for which this description will also apply. Its outer weathered surface is very white and homogeneous-looking; immediately under this is a dark zone, less than an inch in thickness, which apparently owes its color to the oxidation of some heavy metal originally contained in ore particles or in the biotite. It was impossible to obtain sufficient biotite for a chemical test to prove this assumption, which is founded on indications observed by the microscope. In the Cameron rock small crystals of pyrite could be detected, and in that from Buckskin a little galena also, whose decomposition would more directly account for the dirty-brown color alluded to.

On the raised floor of the northwestern arm of the Platte amphitheater granite predominates among the Archean rocks. It is of the same variety as that found directly west in Bartlett Mountain and Clinton amphitheater, and has large and prominent crystals of feldspar disposed in regular order throughout the mass. The associated gneiss also contains large orthoclase crystals, often two inches in length and usually Carlsbad twins. On the surface of this floor was observed an interrupted dike of hornblende-porphyrite, which is figured on the map; also, small outcrops of other eruptive rocks, notably one of White Porphyry, whose outlines were not determined with sufficient accuracy to be there indicated. On the west wall of this amphitheater appears a dark line, which may probably be part of the same dike of porphyrite as is shown on the map to extend almost continuously along the west wall of the Arkansas amphitheater. Owing to their darker color and peculiar fracture in large masses, which is like that of a basalt or andesite, the porphyrite bodies can readily be distinguished at a considerable distance.

The North Peak ridge, which forms the northern wall of the Platte gorge, being lower than the corresponding spurs to the north and south, respectively, is composed almost entirely of Archean rocks, a proportionately smaller capping of Paleozoic strata being left on its crest. The actual outline of the remnant of Cambrian quartzite remaining on the ridge could only be determined with exactness by the expenditure of more time than it was possible to devote to this point, and the line given on the map is that determined by observation of the apparent stratification lines from Mount Lincoln.

Quandary Peak.—On the Quandary Peak ridge, which lies just north of the limits of the map, it is easily seen from a distance that a remnant of Lower Quartzite is left at the very summit of the peak, as shown in the sketch given in Plate X, which is taken from the summit of Mount Lincoln. The angle of inclination of these beds, which is 15°, is less than that of a portion of the ridge, in consequence of which they have been eroded off the saddle immediately east of the peak, and are found again lower down on the spur. At the timber-line, which reaches only the eastern end of this spur, the dip steepens to 25°. This line of steepened dip can be traced on all the principal eastern spurs of the range and corresponds very nearly with the mouth of the cañon gorges which have been cut in the Archean. It is often accompanied by some apparent dislocation of the strata, the amount of which, owing to discordant dip angles, it was not easy to determine. For pros-



Julius Bien & Co. lith.

S. F. Emmons, Geologist-in-Charge.

MOSQUITO RANGE AND BLUE RIVER VALLEY.

NORTH FROM MT. LINCOLN.

pectors this line seems to have had especial attraction, and not without reason, since along it are the best exposures of the lower Paleozoic rocks, in which on this side of the range there has been a considerable concentration of ore.

The sketch given in Plate X is a view of the region adjoining the upper Blue River Valley, as seen from Mount Lincoln. To the left or west of this valley the hills are almost entirely Archean, with a few later sedimentary beds resting against their eastern spurs. On Quandary Peak alone do they still extend up to the very summit. On the east of the valley are the hills surrounding the town of Breckinridge, made up of Mesozoic beds and numerous porphyry sheets, in which valuable ore deposits have been discovered and from the débris of which rich gold placers have been accumulated in the valleys.

The Quandary Peak ridge is here described, although it does not come within the limits of the map, since it was the only point at which the search for fossils in the Cambrian quartzite was successful. On its eastern end, a short distance above timber-line and perhaps half a mile above the Monte Cristo mine, about fifteen feet of greenish argillaceous slates, belonging to the upper part of this formation, are exposed by a prospector's tunnel which was run in on the north face of the spur. From these shales, after a diligent search, good impressions of the Potsdam species *Dicellocephalus* were obtained. Unfortunately the ground is too much covered by soil and forest to afford a continuous section; but, unless a fault intervenes, this shale bed should be below the quartzite and limestone in which the Monte Cristo deposit occurs, and not many feet from it. Lithologically it resembles the greenish shale beds observed in very many points throughout the region below the calcareous shales and sandy limestones of the upper portion of the Lower Quartzite series, but nowhere were any further traces of these fossils found.

The exposures of the Cambrian or Lower Quartzite formation are nevertheless those of the Paleozoic series which can be most clearly and continuously traced, as they slope up in a **U**-shaped curve on either side of the valleys below the cañon gorges of this portion of the range. In general the outcrops in the valley bottoms and along the lower slopes are concealed by surface accumulations, either talus slopes or alluvial soil. In the relatively wider valley of the Platte, however, about half a mile below the town of Montgomery, a moraine ridge which crosses the valley once dammed up a shallow lake basin, now a bit of meadow-land; the present stream, which drains this basin, exposes as it cuts through this ridge the quartzites and shales of the Lower Quartzite formation and a considerable portion of the overlying White Limestone, striking N. 15° E. and dipping 20° to the east.

Hoosier pass ridge.—On the slopes of the Hoosier pass ridge, just above Montgomery, about one hundred feet of the Lower Quartzite are again exposed in section, with two parallel intrusive sheets of porphyrite, the one 10, the other 40 feet thick; the whole dipping 25° to 30° east, with a strike to the west of north. This rock is the mica variety, having for its chief constituents a white plagioclase feldspar, with a much altered biotite and a few scattering quartz grains, in a dull-green groundmass.

The general line of contact of the Cambrian is traceable along the slope towards the crest of the North Peak ridge, but distinct outcrops are first found again at the saddle between Montgomery and the Blue River, over which a horse-trail leads. This saddle marks the outcrops of the Blue Limestone, which consist of a dark iron-stained dolomite, weathering black and carrying thin seams of barite. On the east of the saddle its limits are somewhat loosely defined by outcrops of blue shales, carrying casts of *Zaphrentis* and corals, which form a little knoll on the ridge, and may be assumed to belong to the shale member of the Weber series. On the west of the saddle, outcrops of the Blue and White Limestones extend to the steeper slopes of the North Peak ridge, where their limits are defined by a bed of green, fine-grained, silicious shale, impregnated with cubes of pyrite which at times forms beds a foot in thickness. Only the Lower Quartzite beds extend west of this on to the higher portion of the ridge. The workings of the now abandoned North Star mine on the first shoulder of the ridge have, as shown by the dump, passed through this quartzite into the schists of the Archean.

On the northeast face of the ridge, overlooking the valley of the west fork of Blue River, is a small amphitheater with a little lake in its basin, which the topography of the map shows but imperfectly. It is entirely in the Archean, with the exception of a thin rim of Cambrian quartzite around its upper walls, and was probably carved out by a tributary of the main Blue River glacier, which descended the gorge from the back of Quandary Peak.

A section was made from this saddle eastward across Hoosier pass to Hoosier Ridge, which connects the Silverheels massive with the group of hills to the north that constitute the eastern boundary of the Blue River Valley. This ridge also forms the divide between the waters of the Blue and Upper Platte Rivers and those of Tarryall Creek.

No satisfactory measurements could be obtained of the thickness of the members of the Carboniferous group above the Blue Limestone, as was hoped: first, because the line followed did not cross the strata at right angles, but at times almost followed the strike; secondly, because of the great number of beds of porphyry included in the section, whose thickness could not be determined; and, thirdly, because of the evidence of a syncline on Hoosier pass itself. Nevertheless, the data obtained are given here somewhat in detail, as it was one of the few opportunities offered during the investigation to follow continuously the ascending series of beds from the Blue Limestone up to the assumed top of the Carboniferous formation.

From the saddle eastward to the grass-covered summit of the pass the outcrops may be assumed to indicate a thickness of about two thousand feet of beds. In this are included those of two prominent sheets of porphyry, which are apparently interbedded. On the first hill east of the saddle is an outcrop of shales, containing indistinct casts of fossils, apparently *Zaphrentis* and corals, which probably form part of the Weber Shales. The other outcrops are of the characteristic gritty rocks of this series (either micaceous, quartzose schists or coarse white sandstone, rich in muscovite and often passing into conglomerate) and one bed of black argillaceous shale, which all show a conformable dip to the east and north. The grass-grown glades which form the summit of the pass leave a gap about half a mile without outcrops. Towards the eastern side, and overlooking the head of Blue River, a prospect shaft on the Ready-Pay claim has cut a body of light-gray limestone, which is probably one of the thin beds of limestone found in the middle of the Weber Grits series. This limestone, as well as an outcrop of coarse white sandstone a little east of the shaft, has a dip of 30° to the westward, with a strike of about N. 25° W. On the slope of the pass towards the Platte Valley the Dead-Broke tunnel discloses what is probably the same bed of limestone, with sandstones dipping in the same direction. A body of light-colored mica-porphyrite is also cut in the end of the tunnel.

The existence of a synclinal fold, as proved by these western dips, is in complete accord with the evidence, obtained farther south along the flanks of the ridge, of a secondary roll or minor fold in the strata parallel to the great fold of the center of the range, and explains the great thickness of exposures of Weber Grits beds. That the fold may have been accompanied by faulting is possible, but, as already stated, no direct evidence of a fault was found. Perhaps, had time permitted, a careful exploration of the ravine at the head of the Blue River and on the west face of Hoosier ridge might have afforded more definite proof. As it is, the geological outlines given on the map are generalized from observations made on the spur connecting it with Hoosier pass. The results of these observations are graphically shown in section A A, Atlas Sheet VIII, for the eastern end of which, beyond the Platte Valley, they furnished the data. The largest body of porphyry there shown, which forms the shoulder of the spur above Hoosier pass to the east, consists of typical Lincoln Porphyry (54). It contains the usual large pinkish crystals of feldspar, which in this rock, however, seem exceptionally susceptible to alteration and, instead of being fresh and rather glassy in appearance, are opaque and often quite kaolinized. The microscope shows rather more plagioclase than in the type rock, which may be accidental. The quartz occurs in small, double-pointed, hexagonal pyramids showing also the development of the prism; and on the crest of the spur, where, owing to the gentle slope and accumulation of soil, decomposition seems to have gone on most freely, the rock surface is covered with a coarse sand made up almost entirely of such quartz crystals, often with well defined angles and facets.

The steep north slope of the spur, facing the basin-shaped head of an eastern tributary of the Platte, shows a cliff wall of this rock with characteristic cross-jointings and vertical cleavage, almost amounting to a columnar structure. The thickness of the body can be hardly less than five hundred feet, as roughly determined from the width of the outcrop on the spur. That it forms so regular a sheet as shown in the section is an assumption based only on analogy from other sheets of porphyry observed in the Silverheels massive It apparently has its greatest thickness at this point, and thins out to the south and east, and in this respect has something of the laccolite form; but there is no evidence of any sudden steepening in the dip of the adjoining strata. On the contrary, the sandstone beds immediately overlying it, as shown in the outcrops on the crest of the ridge, have a regular dip eastward of about 10°. Only a few hundred feet of sandstones and sandy shales separate this from the next succeeding sheet of porphyry, which forms the cap of the first prominent shoulder about twelve hundred feet above the pass. This is a blue-gray rock, weathering yellow, of quite distinct habit, having a conchoidal fracture and a tendency to weather into sherdy fragments. It approaches the normal Silverheels Porphyry, although coarser grained, showing few distinct crystalline ingredients when freshly fractured. On its weathered surface, however, fine needles of hornblende are easily distinguishable.

Beyond another body of sandstone and shales, and a similar though not identical body of porphyry which caps a second shoulder, a body of argillaceous shales of green, red, and purple colors marks what is assumed as the base of the upper division of the Carboniferous group. From these to the main crest of Hoosier ridge are several outcrops of porphyry sheets and intervening gaps of shaly rocks; among which a bed of dark-blue limestone, about a hundred feet in thickness, stands out prominently on account of its black weathered surface, opposite the head of the north fork of Beaver Creek. From this were obtained the following Coal Measure fossils:

Athyris subtilita.
Productus cora.
Pleurotomaria, (*P. Valvatiformis ?*).
Loxomena, (sp. ?).
Bellerophon, (sp. ?).
Fenestella, (sp. ?).
And spines of an *Archæocidaris.*

On the crest of Hoosier ridge are the reddish sandstones which form the passage from the Upper Carboniferous formation into the overlying

Trias, dipping 15° to 20° east and north. Two other beds of limestone at least are found in this formation, on the same line of strike southward along the western face of Silverheels and in the valley of Beaver Creek, and they may occur here in some of the numerous covered gaps in the section.

Silverheels Massive.—In order to complete the somewhat meager data obtained upon the upper member of the Carboniferous group on this side of the range, the observations made in the region west of the Platte Valley will be next recorded, comprising in this the eastern portion of Mount Silverheels and Beaver Ridge, with the included valley of Beaver Creek.

In a general way the eastern half of Mount Silverheels may be said to be Mesozoic, in great part probably Triassic, while its western face belongs to the Upper Coal Measures, and Beaver ridge to the Weber Grits. The included porphyry sheets in the former rocks have a more recent and trachytic appearance, like that found at the forks of Crooked Creek; those in the second group being rather of the Silverheels type, and those in the Weber Grits either identical with or similar to the Lincoln Porphyry. The number of these porphyry sheets is probably very much greater than is shown on the map, which represents a generalized outline of the more important bodies, deduced from observation made along three transverse lines only in the area represented east of the Platte; while in that portion of the mountain which lies east of the boundary of the map the porphyry bodies are, if anything, still more numerous. The swelling out of the strata, produced by the intrusion of such considerable masses of eruptive rock, is readily shown by the variations in the strike and dip. The steep north wall of Silverheels, as seen from the summit of Hoosier pass for instance, shows a fan-like arrangement of the easterly-dipping strata, which open out as it were to the west. In other words, the section shows strata on the west foot of the mountain, towards Beaver Creek Valley, dipping only 10° east; at the summit of the peak the dip has increased to 17°, while at the eastern extremity it is 22°, 25°, and even 35°. The divergence in strike produced by the bowing-out of the strata is less evident on the map, owing to the fact that at the point of greatest divergence the great elevation of Silverheels above the surrounding valleys brings the outcrops, as projected on a map, so much farther west. A rough calculation of the difference in thickness of given east and west sections, taking the one on a line passing through Fairplay, the other through the summit of Silverheels, would give an increase in thickness in the latter case of 3,000 feet, which may be assumed as the aggregate mass of the intruded porphyry bodies at the latter point, since on the line through Fairplay they have very largely disappeared by thinning out.

On a line eastward from Platte Valley to the summit of Silverheels the succession of rocks is as follows: Beaver Ridge, immediately adjoining the Platte Valley, whose steep slopes are covered with a thick forest growth which impedes observation, consists of the coarse grits of the Weber formation, with two principal and probably some minor bodies of Lincoln Porphyry. The valley of Beaver Creek, a straight depression in the line of strike, is apparently cut out of the softer shaly members at the top of this formation. From its bottom up the steep face of Silverheels are many porphyry bodies, whose débris often so obscures the outcrops that no continuous section can be obtained. In this extent five sheets of porphyry and one bed of gray limestone were observed; these alternate with shales and micaceous sandstones, which pass at the summit of the peak into conglomerates. A considerable number of these conglomerates outcrop on the ridge running eastward from the summit, alternating with purple and green shales and with sheets of porphyry, of which no less than eight were counted. The conglomerates contain an unusual number of rounded and sub-angular fragments of the more resisting Archean rocks, together with the rounded pebbles of pinkish milky quartz which are common in all the sandstones of a coarser nature. Beyond them the brick-red sandstones of the Trias become the prevailing rock, their dip steepening on the east slope to 25° and 35°. Along the west face of Silverheels the porphyry beds, which resist better the action of abrasion, can be traced in curving contours along the slopes, capping the more prominent shoulders of the spurs and disappearing from sight in the forests which clothe the lower spurs to the south.

The type of the Silverheels porphyry (89), which is found at the summit, is a fine-grained rock of slightly greenish-gray color, having a conchoidal fracture, a sherdy habit, and a clear ring under the hammer. It is composed of feldspar, hornblende, and biotite, with a little quartz, and contains from 60 to 63 per cent. of silica. To the naked eye no groundmass is visible, although the crystalline ingredients are so minute (being generally less than 1^{mm} in size) that they cannot readily be recognized. A common variety (90) among the lower beds on the west and north is of coarser grain and more decidedly green color, due doubtless to the presence of chlorite.

The most southern of the three transverse lines above mentioned runs eastward from a little south of Alma, crosses several low forest-covered ridges separated by small valleys, and shows only detached outcrops separated by frequent covered gaps. In this section only one body of porphyry and three distinct horizons of dolomitic limestone were found. The beds, moreover, have a strike somewhat east of north and a dip of 25° or more to the eastward, instead of a strike to the west of north and dips of 10° to 15°, which prevail opposite the summit of Silverheels. The low ridge bordering the Platte Valley is covered on the west side nearly to its summit by the lateral moraine of the Platte glacier, which must therefore at one time have filled the valley to a level about 400 feet above its present bottom. Lincoln Porphyry, a continuation of one of the bodies seen in Beaver Ridge to the north, is disclosed by prospect holes. Various deep-red sandstones are crossed, alternating with limestone and shales, but the characteristic brick red of the Trias is first found at Crooked Creek, to the east of Fairplay, in the forks of which is another important sheet of porphyry, probably the porphyritic trachyte of the Hayden map. This is interesting as being different in appearance from any of the other porphyries observed in the region and resembling that found in a railroad cut through a Cretaceous ridge near Como. Nevertheless it does not possess the characteristics of a Tertiary rock, unless a slightly rough feel may be considered such. It is of light-gray color and contains abundant porphyritically disseminated crystals, mostly of white opaque feldspar, in a subordinated groundmass. Two feldspars, hornblende, altered biotite, and quartz in large but infrequent grains form its macroscopical constituents. Microscopically the groundmass is seen to be evenly granular and the rock to be simply a porphyritic or coarser-grained modification of the Silverheels type, with no glass inclusions or other characteristics of Tertiary volcanics

Lincoln Massive.—The Mount Lincoln massive, as is shown on the map and as may be seen in the sketch given in Plate IX (page 95), is divided by a deep glacial gorge, heading at the base of Mount Cameron, into two mountain masses: that of Mount Lincoln on the north and that of Mount Bross on the south. On the east face of either of these mountains are two smaller glacial amphitheaters, to which the names of their respective peaks have been given. The beds of each of these three gorges stand at a much higher level than the adjoining beds of the Platte and Buckskin gulches; and, if the glaciers which once filled them were ever directly connected with the main Platte glacier, later erosion has removed evidences of this fact. At all events, it is apparent that after the Glacial epoch, when the ice was gradually receding, these were separate glaciers or névé fields. This fact is more particularly manifest in the Lincoln amphitheater, in the middle of which stands a moraine ridge, outlined in the sketch above mentioned, which ends abruptly at the lower end of the amphitheater, about 700 feet above the level of Platte Valley. These amphitheaters have more significance geologically than their topographical importance would indicate, inasmuch as erosion, having once cut through the overlying and more resisting mantle of sedimentary beds, has carved deeply into the underlying Archean, leaving characteristic semicircular walls at their heads which afford most useful sections for studying the interior structure of the mountain mass.

Mount Lincoln itself has three spurs stretching out to the eastward: a northeastern, an eastern, and a southeastern. Lincoln amphitheater is included between the two first. The surface of these spurs is covered by beds of the Paleozoic system, dipping eastward at an angle of 10° to 15°. This is the average inclination of the beds over the main portion of the mountain mass; but, as already mentioned in the case of Quandary Peak, the dip becomes steeper on the extreme eastern flanks. In general, however, the slope of the spurs themselves steepens for a short distance more rapidly than the dip, in consequence of which there is a belt of lower beds exposed along the foot of the steeper slopes.

The eastern spur of Lincoln, a narrow straight ridge, being relatively much lower than the northeastern or southeastern spurs, is covered only by beds of the Cambrian formation, the White and Blue Limestones which still cap the other spurs having been removed by erosion. Section B B, Atlas Sheet VIII,[1] passes through this spur and shows its profile and geological structure as well as can be expressed on so small a scale. In addition to the normal eastern dip, the beds have also a decided inclination to the south, so that the spur presents a perpendicular wall on the north towards Lincoln amphitheater, with a shallow ravine on the south separating it from the southeastern spur, the slope of the spur in that direction corresponding nearly with the dip of the beds. This southern dip is the relic of a lateral fold or slight corrugation produced by the forces of contraction acting in a northerly and southerly direction at right angles to the major force. The Lincoln amphitheater is thus shown to have been cut out of the axis of an anticlinal fold, and in the sedimentary beds still remaining on the northeast spur a slight inclination to the northward can still be detected, showing that they formed the northern member of this subordinate fold.

The Cambrian quartzites which form the mass of the spur are of the characteristic white saccharoidal variety, thinly and evenly bedded, and contain a slight development of white limestone, which has been occasionally observed elsewhere in this formation. At the eastern end of the spur is a cliff of quartzite, just above timber-line, below which the beds assume a steeper dip, so that the lower slopes are occupied by outcrops of successively higher horizons. At the foot of this cliff are several prospect holes, following deposits of copper and iron pyrite near or in contact with a body of decomposed quartz-porphyry. A sheet of Lincoln Porphyry, which may be part of the same body, caps the spur above the cliff and is cut through by what seems to be a dike of porphyrite. The porphyrite contains both biotite and hornblende (the latter being, however, largely predominant) and is more decomposed than porphyrite rocks generally, both these minerals

[1] By an error in proof-reading, the line of this section, as given on the map in blue (Atlas Sheet VI), is partially wrong. It should pass from the summit of Mount Cameron to that of Mount Lincoln, and from there down the eastern spur, whereas on the map it passes directly from Mount Cameron to the spur.

being mostly altered to chlorite. Its groundmass is crystalline and contains a considerable development of calcite. Magnetite is also plentiful and has been frequently changed into hydrated oxide of iron. Muscovite is frequently present as an alteration product of plagioclase. The rock as usual contains many fragments of Archean, in this case of muscovite-gneiss. The Lincoln Porphyry is like the normal type, but contains few large feldspar crystals. Besides these is a more compact rock, apparently a contact product, which in general differs from either rock; however, some specimens show its probable connection with the Lincoln Porphyry. Its biotite and hornblende are completely changed into chlorite and epidote. The groundmass is very fine and not resolvable into its elements.

In ascending the regular slope of the ridge westward, as the dip of the formation is slightly steeper than this slope, successively lower beds of quartzite are crossed, and towards its upper end several interbedded sheets of porphyrite. These can be traced along the steep cliff wall overlooking Lincoln amphitheater, and are seen to follow the stratification lines for a considerable distance to the eastward and suddenly bend down into the underlying Archean, thus affording one of the few opportunities of observing the change from a vertical dike into an interbedded mass. Owing to the contrast of the dark color of the porphyrite with the white including quartzite, these bodies can be distinguished from a great distance, and are distinctly visible from the opposite side of the Platte Valley, on the road which leads from Montgomery to the Hoosier pass.

At its upper or western end, opposite the head of Lincoln amphitheater, this eastern spur merges into a basin-shaped valley with débris-covered slopes. On the east face of the northeastern spur, at the head of Lincoln amphitheater, a bare cliff wall affords a section of the lower sedimentary beds and included intrusive sheets, the whole mass much shattered and dislocated. Although time did not admit of the study of these cliff-sections in detail, as was done in the case of others which will be noticed later, the dark color of the intrusive masses and fragments obtained from the débris show that they are largely of porphyrite, and therefore are probably parts of the sheet already noticed on the east spur.

The upper surface of the northeastern and southeastern spurs of Lincoln, respectively, is mainly formed of beds of Blue Limestone, which have been opened by innumerable prospect-holes and several considerable mines on either spur. On the steep cliff faces towards the Platte cañon and the Cameron amphitheater, respectively, the limits of this formation and those which underlie it can be distinctly traced. On the more rounded interior slopes débris of Lincoln Porphyry obscure very largely the actual rock surface. For this reason and also owing to the small scale of the map, the outlines of the formations there indicated are somewhat generalized.

The sharp summit of Lincoln itself is made up of a mass of typical Lincoln Porphyry, projecting boldly above the sedimentary beds and noticeable for its vertical cleavage planes, producing a columnar structure which is best seen on its steep south face. Lincoln Porphyry is also found for a considerable distance down the east spur, and with it are associated shales and grits belonging to the Weber Shale formation. The short, sharp ridge directly west of the summit of Lincoln, and between it and the saddle that separates Mount Lincoln from Mount Cameron, is also composed of a series of beds which evidently belong to this horizon. They dip somewhat sharply to the east and consist of greenish, yellowish, and reddish shales and of micaceous quartzites, with a bed of black shale near the top, comprising in all a thickness of about two hundred and forty feet. Below this is a bed of Lincoln Porphyry, evidently interstratified, while on the saddle itself are outcroppings of Blue Limestone. A deserted mine on this saddle, known as the Present Help, the highest mine probably in the United States, is apparently at or near the contact of the Blue Limestone with the overlying porphyry; its workings had been abandoned and were inaccessible. The intense metamorphism shown in all the sedimentary beds near the summit of Lincoln and the columnar structure of its porphyry render it probable that the mass which forms the peak is directly above the channel through which this rock was erupted. There is evidence also that from this channel a sheet of the same rock was spread out over the surface of the Blue Limestone, which was probably the determining cause of the great concentration of mineral at this horizon.

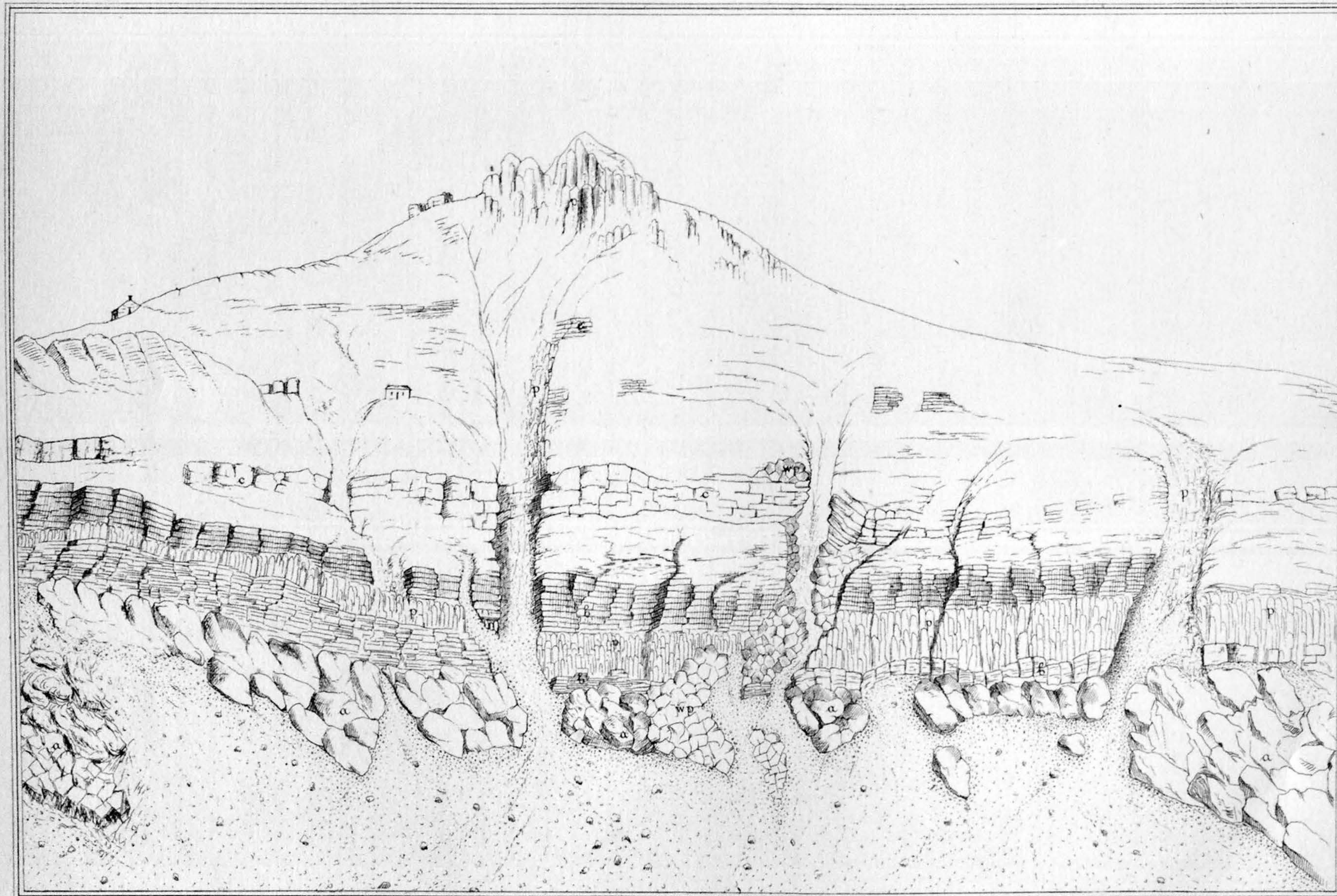
The typical Lincoln Porphyry, as found on the summit of Mount Lincoln itself, is characterized by large orthoclase crystals, which sometimes reach two inches in length, of pinkish color, generally Carlsbad twins, and often so fresh and glassy in appearance as to remind one of the sanidine crystals of more recent rocks. There are five or six large crystals as a rule in an ordinary hand specimen. The smaller feldspars are white, and a large number show distinct striæ. Quartz is very abundant and relatively large, in round grains, often of pinkish hue, and showing more or less plainly the faces of dihexahedral crystals. Biotite in darker or lighter green leaves, according to its condition of decomposition, is quite conspicuous in the rock. A few specks of specular iron are sparingly scattered through the rock. The groundmass is light green or pinkish and is quantitatively quite subordinate to the crystalline element. Under the microscope it is seen to be fully crystalline.

Such is the typical Lincoln Porphyry, which projects in lofty columns from the summit of the mountain in a sharp apex which overtops all the surrounding peaks. Owing to its exposed situation it attracts the storm clouds from all the regions around, and even in midsummer scarcely a day passes without a slight fall of snow or hail on the summit. The very topmost rocks show traces of discharges of the electric fluid in the formation of fulgurite, which encircles the little holes it has bored into the rocks. Around the base of this summit mass of porphyry its contact with the sedimentary rocks is obscured by débris, the few outcrops that are seen being composed of rocks so much altered that their original character cannot be determined.

Cameron amphitheater.—On the steep south face of Lincoln, a sketch of which is shown in Plate XI, a careful study was made of the various eruptive masses. The Lincoln Porphyry of the eastern edge of the summit is of a much darker color than the normal rock and contains few or none of the larger feldspar crystals. It is so much decomposed that only in the center of large blocks is the original grayish color preserved; but the round quartz grains are distinct throughout. The Blue Limestone, which here seems to have a brecciated structure, can be traced as a horizontal line across the face of the cliff, from the Present Help mine on the west to the

Russia mine on the east, immediately below a bed of Lincoln Porphyry. Along the edge of the steep ravine which descends directly from the summit of Lincoln an irregular dike of porphyry crops out here and there, colored brilliant red and yellow on its surface, but so much decomposed that its original structure can no longer be determined. As shown in the sketch, it is only the Silurian (*c*) and Cambrian (*b*) strata which form continuous outcrops across the cliff face, and these are somewhat broken by transverse dikes of eruptive rock. Within the Cambrian quartzite is an intrusive sheet of Lincoln Porphyry, whose darker color contrasts strongly with the bleached weathered surfaces of the summit rock. The base line of the Cambrian, where it rests on the Archean, appears more irregular in the sketch than it is in nature, but it is evident that the Cambrian sea bottom was not so smooth here as it is shown to be in other cliff sections.

In the ravine next east from that already mentioned is a dike of White Porphyry, which can be traced, as shown in the sketch, from the gneiss of the Archean across the Cambrian quartzites into the White Limestone. This is dike No. 1, whose rock has already been described under that which occurs on the north face of Lincoln. Its outline is extremely irregular, and its contact surfaces with sedimentary rocks, which are distinctly visible, show none of the contact phenomena supposed to result from the heat of a fused mass. In its upper portion it is rounded, and curves over one of the heavier beds of White Limestone in an oval mass. On its east side, near its summit, the thinner beds of limestone are bent upwards, as if displaced at the time of its intrusion, and the lower shale beds of the White Limestone belt are more or less serpentinized. It also sends out offshoots a few inches wide through the natural joints of the sedimentary beds. About fifteen to twenty feet above the base of the Lower Quartzite it crosses an interbedded mass of porphyry of a dark-green color, which is here some thirty feet in thickness. This interbedded porphyry is thoroughly decomposed, the only crystals visible being rounded quartz grains, which resemble those of the Lincoln Porphyry. All its cleavage planes are covered by a dark-green coating of chloritic nature, and it is crossed by thin perpendicular fissures, from one to two inches in thickness, containing pyrites and having a bright-yellow weathered surface. A comparatively fresh specimen was obtained



Julius Bien & Co. lith. S.F. Emmons, Geologist-in-Charge.

SUMMIT OF M^{T} LINCOLN
AND NORTH WALL OF CAMERON AMPHITHEATRE [UPPER END]

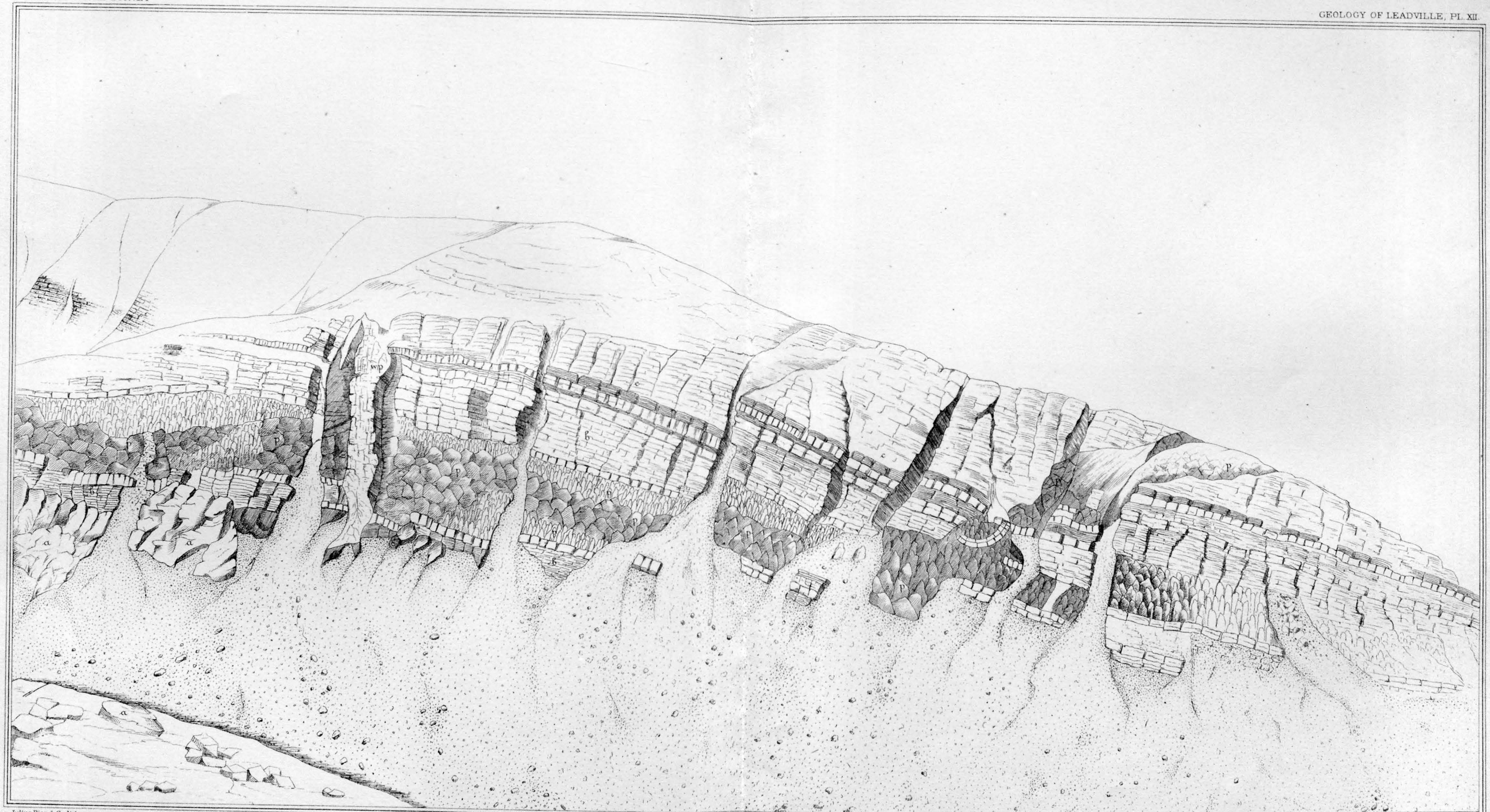
with some difficulty, which shows the characteristic large, pink, orthoclase feldspars of the Lincoln Porphyry. In this the green color is seen to be due to the alteration of biotite into a chloritic substance, which has been deposited on the surface of the smaller feldspars, so that they are scarcely distinguishable by the naked eye. Biotite is also no longer visible except under the microscope. Pyrite can be distinguished throughout the rock by the naked eye.

The Archean rocks (*a*) at the base of this section consist almost entirely of dark-gray gneiss. In this the White Porphyry dike can be traced but a short distance, as it is soon lost under the steep talus slopes at the foot of the cliff.

A few hundred feet east of this dike (to the right in the sketch) a second dike (No 2) can be traced, though less distinctly, from the gneiss entirely across the Cambrian and Silurian formations, apparently terminating at the base of the Blue Limestone. It is much narrower and straighter than dike No. 1, and like that seems to have a northeast and southwest direction. Its rock is a light-colored, fine-grained, highly-crystalline porphyry, belonging to the type designated as Mosquito Porphyry, which has already been described. There is an outcrop of the same rock in the Archean, on the west wall of the Cameron amphitheater directly under Mount Cameron, which may possibly be part of the same body, although the intermediate region is too much obscured by débris to trace any direct connection.

Eastward of this cliff face the northern wall of the Cameron amphitheater is much covered by débris for the distance of nearly a mile, in which extent, although the general dip of the sedimentary beds can be traced, no opportunity was presented for an examination of the intrusive bodies. Near the eastern end of the wall, however, is a second cliff section, which shows in a very instructive manner the position of the intrusive masses and dikes. It is graphically represented in Plate XII, which, like the preceding plate, is copied from sketches made on the spot by Prof. A. Lakes. The section was studied by Mr. Cross, from whose notes the following description is largely taken.

Here, as in the section just described, is an intrusive interbedded mass of porphyry in the Lower Quartzite (*b*), only a few feet above its base, which is also crossed by a nearly vertical dike. This vertical dike, as may be seen on the left half of the sketch, can be traced from the Archean up to the base of the Blue Limestone. It is from fifteen to twenty feet wide at the bottom and branches at the top into five small arms, but does not spread out between the strata. Its rock is a White Porphyry, which differs from any of those observed elsewhere in carrying large orthoclase feldspars, sometimes an inch in length. They are Carlsbad twins, and have a pinkish tinge like those in the Lincoln Porphyry. Small rounded grains of quartz are also abundant, but no trace of hornblende or biotite could be seen, either by the naked eye or with the microscope. Under the microscope the feldspar is seen to be partly plagioclase, and in the quartz are many small fluid inclusions. The interbedded porphyry mass, like that on the south face of Lincoln, is prominent by its dark color; but on examination it is seen to consist of two distinct rocks, one of which seems to have pushed its way through the other after it had been already spread out between the beds. The later rock is a Lincoln Porphyry, whose outlines can be distinguished from a little distance by its peculiarity of weathering, its fragments showing larger surfaces than that of the earlier rock. The earlier rock is of a light-green color, and shows, to the naked eye, scarcely any distinguishable crystals, feldspars being decomposed to a substance very like groundmass. Altered hornblende, a few biotite leaves, and an occasional quartz grain can be distinguished by the lens; also, a few small specks of some metallic combination. Under the microscope the groundmass resolves itself into a fully crystalline admixture of quartz, mica, and feldspar. Calcite is present in filmy particles and occasionally in grains. The larger quartz crystals contain fluid inclusions. The contact specimens of these two porphyries show a blending of the characters of the two in the tendency to the formation of large quartz and pink feldspar crystals in a base more like the older porphyry. As shown in the sketch, the Lincoln Porphyry throughout the greater extent of the section is entirely included within the older mass. Towards the eastern end, however, it forms a distinct bed above the other, and each sends off a branch upward in a northeast direction across the strata, forming nearly parallel dikes which meet at the surface of the ridge. These



Julius Bien & Co. lith.

S.F. Emmons, Geologist-in-Charge.

NORTH WALL OF CAMERON AMPHITHEATRE

LOWER END.

dikes are about fifteen feet in thickness each, while the combined beds have a thickness of from fifty to sixty feet.

This intrusive sheet of Lincoln Porphyry at the Cambrian horizon, which seems continuous along the north wall of the Cameron amphitheater, was traced out to the end of the southeast spur of Lincoln; and what is apparently the same bed was also observed lower down the slopes, in the more steeply-dipping members of the same formation. Outcrops of similarly situated bodies, as shown on the map, are also found on the south wall of the Cameron amphitheater and on either wall of the Bross amphitheater. Time did not permit of tracing any connection between these different outcrops; and it seems doubtful whether any exists, inasmuch as for some unknown reason there seems to have been much less tendency to spread out in extensive sheets at this horizon than at that above the Blue Limestone. Although this latter porphyry bed is only found to a limited extent above the Blue Limestone on Mount Lincoln, there is no doubt that it once covered that bed, forming a sheet comparable in extent to that of the White Porphyry in the Leadville district.

Cameron and Bross.—The summit slopes of Mounts Cameron and Bross, except those on the cliff faces which are too steep to permit the lodgment of débris, are mainly covered by fragments of Lincoln Porphyry. Eruptive rocks under the action of atmospheric degradation split up into fragments whose shape and relatively small weight, as compared with their superficial area, render them more susceptible to being moved by melting snow, so that on mountain sides they generally cover a surface disproportionately large as compared with their actual outcrops. This is eminently the case on Mount Bross, where angular fragments of porphyry often cover the surface to a depth of ten feet or more and the character of the underlying rock can often only be determined by actual excavation.

The porphyry of the summit of Mount Cameron is remarkable for the unusual development of large orthoclase crystals, often more than two inches in length, which weather out from its surface. Associated with the much-weathered fragments of porphyry are various brown quartzitic sandstones, which may represent a bed of the Weber Grits formation not yet eroded off the summit. No sufficient evidence was found, however, to justify its indication on the map.

On Mount Bross the Lincoln Porphyry shows a still lighter color than that on Mount Lincoln, which seems due to the fact that the decomposed mica, instead of remaining as chlorite, has been entirely removed Fragments of shales and quartzitic sandstones of the Weber Grits formation are mingled with the porphyry débris of the upper slopes of Bross, and outcrops of these rocks are found on the ridge connecting it with Cameron, as well as to the south of its summit on the ridge overlooking Buckskin gulch. In the latter instance they stand at a much steeper angle than the lower series of Paleozoic beds, and give evidence of some local movement. In Section L, Atlas Sheet X, is shown the probable form of the Lincoln porphyry body on the summit of Mount Bross, as deduced from observed outcrops. It is very possible that, like that of Mount Lincoln, it stands over a channel of eruption, but the evidence of this was not considered strong enough to justify its being indicated on the plane of the section.

On the north face of Mount Bross, towards Cameron amphitheater, the base line of the Paleozoic formations can be traced with tolerable distinctness. Of dikes crossing the formation, like those on the face of Mount Lincoln opposite, there are doubtless many, but only one was actually traced, which is cut by the western workings of the Moose Mine. In the Archean below this mine is a prominent mass of light-gray granite. The workings are in the Blue Limestone, which is exposed on the east spur of the mountain between the Cameron and Bross amphitheaters, forming the surface of the spur, until cut off by its steeper slope, whose angle is greater than that of the dip of the beds. This bed is completely honeycombed by abandoned mine workings, but the underlying White Limestone here, as in the Leadville district, seems to have yielded little or no ore. At the foot of the spur, erosion has exposed the quartzite beds of the Cambrian, in which is a prominent dike of porphyry running from the edge of Bross amphitheater a little north of east, in the direction of the summit of Mount Silverheels. It was traced as far as the secondary ridge bordering the Platte Valley into the White Limestone, where it was lost in the forest.

The rock (88) of which it is composed differs from any yet described. Its weathered surface is so white that at first glance it might be taken for the White or Leadville Porphyry. On a fresh fracture it has a light-green color and shows few macroscopical crystals. It has certain resemblances to porphyrite and also to the Silverheels Porphyry, but the microscope shows it to be identical with the quartz porphyry found on Loveland Hill and on the north wall of Mosquito Gulch, which has been described under the name of Green Porphyry.

Bross amphitheater, like those of the other two peaks, lies nearly due east of the summit, but, owing to the steeper inclination of the Paleozoic beds which cap its walls, it has not been carved to so great a depth into the underlying Archean schists, whose outcrops are therefore of much less superficial extent. As in the others, the highest beds exposed in the cliff sections on its walls are those of the Blue Limestone. Shales, probably belonging to the Weber Shale formation, are disclosed in prospect holes along the road which curves round its head, and very possibly a considerable portion of the area which has been given the color of porphyry on the map may prove by actual excavation to be underlaid by beds of this formation. The road which leads by the Dolly Varden and Moose mines, along the north face of Mount Bross and the west face of Mount Cameron, to the Present Help mine, on the south face of Mount Lincoln, is indicated on the sketch in Plate IX by a light double line, the location of the respective mines being shown by the house outlines. The Dolly Varden mine, on the spur south of the amphitheater, finds its ore in the Blue Limestone adjoining a dike of White Porphyry 40 feet in thickness, which crosses it at an angle of 60° with the horizon. Below the Dolly Varden mine the spur slopes more steeply than the beds, and at its base the Parting Quartzite of the Silurian is exposed. In the basin-shaped valley called Mineral Park, south of this spur, erosion must have exposed still lower beds than on the spur, and it is possible that the quartzite beds said to be exposed there may belong to the Cambrian.

The ridge running south from Mount Bross, between Mineral Park and Buckskin gulch, is mainly covered by easterly-dipping beds of the Blue

Limestone horizon. There are several bodies of Lincoln Porphyry, besides the main sheet near the summit, which are not shown on the map, as time did not admit a sufficiently detailed study to determine their outlines or whether they were remnants of this sheet or distinct bodies. The upper part of the Blue Limestone on this spur seems to have been particularly rich in black chert concretions, which now lie scattered over the surface of the ground, and from which Prof. Lakes obtained the following fossils:

Spiriferina (sp. like *S. Spergenensis*).
Spirifera Rockymontana.
Productus costatus.
Euomphalus (sp. ?).
Athyris subtilita.
Streptorynchus crassus.
Pleurophorus oblongus.

These were mainly collected in a slight depression of the ridge, where the overlying porphyry had been eroded off, and therefore must have come from the upper part of the horizon.

The lower Paleozoic beds are exposed in section at various points along the steep western wall of this spur, which faces Buckskin gulch. They were examined at two points. At the extreme southern end of the spur, just above the town of Buckskin Joe, where the steeper eastern dip of the formation comes in, several ore bodies have been discovered, and the now abandoned mines (the Excelsior, in White Limestone, and the Criterion, in Lower Quartzite) were once worked. At the Criterion mine a thickness of 150 feet of quartzites was measured between the Archean and the first bed of White Limestone. The ore bodies are accumulated here along vertical planes, running northeast and southwest, which seems to be the direction of a dike of dark-green decomposed porphyrite, whose outcrops are found in the ravine below the mine, near the contact with the Archean. There is evidence also of a slight displacement along a plane running northeast and southwest, whose upthrow is to the west. At the Excelsior mine, which is about a quarter of a mile farther west, near the point of the cliff in the angle of the gulch, the ore bodies follow similar and nearly parallel planes. A section measured on the cliff near the mine gave the following thicknesses, in descending series:

		Feet.	
	Blue Limestone, covering surface of spur	?	
Silurian	Parting Quartzite (exposed in prospect holes)	?	
	White Limestone, partly covered by débris, estimated	200	
Cambrian	Shales and sandy limestones	35	
	Gray quartzite, impregnated with metallic mineral	20	
	Massive white quartzite	6	
	Greenish quartzite, with calcareous layers	8	
	White saccharoidal quartzite	10	
	Greenish-white, compact, thin-bedded limestone	3	
	White saccharoidal quartzite	55	
			137
Archean		?	

The limestone bed in this section is of interest as being the only one examined from this region which was not a dolomite. It contained 25.48 per cent. carbonate of lime, 4.03 carbonate of magnesia, with traces of chlorine, the residue being mainly silica. It has already been noted that the Cambrian beds in their upper part are often more or less calcareous, but generally resemble a sandstone on the surface, whereas this bed has the compact, even texture and clean fracture of a limestone. The strata at this point dip 15° to the east, with a strike a little east of north.

Red amphitheater.—Nearly under the summit of Mount Bross and high up on the east wall of Buckskin gulch is the Red amphitheater, a semicircular recess in the cliff-wall nearly a thousand feet above the bed of the valley. The scale of the map does not permit an adequate expression of the form of this remarkable basin, which is rendered still more prominent by the brilliant red and yellow coloring of its walls. This color comes from a thin coating of ocherous clay, which covers the rock fragments of débris piles, and which contains, besides oxide of iron, traces of arsenic, antimony, and sulphur. The rock fragments thus coated are so much decomposed that it is seldom possible to determine their original character, and it would have taken much more time than was available to thoroughly decipher the geological history of this remarkable locality, which has evidently been the scene of long-continued metamorphic action, probably a sequence of the eruption of the igneous rocks now forming dikes and intrusive sheets in the Archean and overlying Paleozoic beds. The results of the metamorphic action are shown, not only in the decomposition and coloring of the rocks above mentioned, but in the marbleizing of the limestones and the large development of serpentine within these limestones.

The eruptive bodies developed here consist, besides the large body of Lincoln Porphyry near the summit of Mount Bross, first, of a considerable body of augite-bearing diorite (96), which cuts through the Archean from the valley below up into the bed of the amphitheater, and either spreads out along the base of, or extends into, the Cambrian beds under the talus slopes of débris; secondly, of a dike of White Porphyry, crossing Silurian and Carboniferous limestones in a vertical direction; thirdly, of several thin intrusive beds of green and much-altered quartz-porphyry, parallel with the stratification. It is only on the south side of the amphitheater that a continuous cliff-section of the Paleozoic beds is exposed, and here the top of the Blue Limestone and the base of the Cambrian are each covered by surface accumulations. One principal and several smaller faults can be distinguished on the cliffs, in each of which the upthrow is to the west, but the amount of displacement is only slight. The Colorado Springs mine is opened on this cliff, near the base of the Blue Limestone, from which rich ore in small quantities has been obtained. The following section was made, by means of a pocket level, on the cliff just south of the mine and near the dike of White Porphyry above mentioned:

		Feet.	
Lower Carboniferous	Black cherty limestone	50	
	Blue-gray limestone	50	
	Light-blue limestone White marbleized limestone Light drab limestone with serpentine	60	
			160
Silurian	White and greenish quartzite	40	
	White limestone	10	
	Light-bluish limestone	40	
	Green porphyry, 20 feet.		
	White limestone	10	
	Blue-gray crystalline limestone	40	
	Light-colored limestone with serpentine	30	
			170

Cambrian	Dark-green serpentine	10	
	White limpid quartz	15	
	Yellowish-green serpentine	1½	
	Green porphyry, 4 feet.		
	White quartzite	10	
	Green porphyry, 20 feet.		
	White quartzite	10	
	Green porphyry, 5 feet.		
	White quartzite	40	86½
	Intrusive mass, disturbing strata and disappearing under débris		(?)

Neither the top of the Blue Limestone nor the base of the Cambrian is reached in this section, and to the aggregate thickness given an unknown amount, probably in the neighborhood of 200 feet, should be added. At the head of the amphitheater above the Blue Limestone is a very thick body of Lincoln Porphyry, above which, on the summit of the ridge and separated by a low saddle from the main summit of Mount Bross, are intensely altered shales, frequently chloritic, belonging to the Weber Shale formation.

The development of serpentine, which elsewhere seems confined to the "sandy limestones" of the upper part of the Cambrian, here extends, though on a minor scale of development, a short distance into the silicious beds below and up as far as the base of the Blue Limestone. The serpentines obtained from here are remarkably beautiful rocks, grading in color from a homogeneous yellow to a dark green, mixed with gray and having the general effect of a veined verd-antique, although more critical examination shows that the green and gray or yellow are a simple shading off and intergrowth. In some cases thin, vein-like sheets seem to cross the strata, though in general the development of serpentinous material is parallel to the stratification. Under the microscope they are seen to contain a very considerable amount of calcite, an appearance which is confirmed by chemical analysis. The development of serpentine is apparent, in looking at the cliffs from a little distance, as a lenticular-shaped body, giving at first the impression that it causes an actual thickening of the beds; but the measurements given by the above section show that this is not the case, and the chemical examination, which is discussed in Chapter VI, shows that this mineral is the result of a change within the rocks themselves, and, probably in great part, of the alteration of pyroxene and amphibole in the limestones.

Eastern foot-hills.—The higher part of the Lincoln massive thus far described may be considered structurally to form part of the crest of an original great anticlinal fold, inasmuch as the average inclination of the beds is comparatively small. The wooded ridges between the foot of the steeper slope and the Platte Valley, which form a low shoulder to the Lincoln massive, and where steeper dips prevail, would form the actual eastern member of the fold. On the ridge between Quartzville and Montgomery, for instance, the beds dip as steeply as 45°. South of this a wider region is included between the outcrops of Blue Limestone and the Platte Valley, and, were the steep dips continued without interruption, an immense thickness of beds would be represented. There are reversed dips found, however, notably in the ravine below Quartzville and in Buckskin gorge above Alma, which give evidence of the existence of a secondary flexure parallel to the main fold, a sort of minor ripple following at the heels of the great breaker or wave which caused the main uplift of the range, such as is almost invariably found along lines of great plication. Another noticeable feature in the structure is a decided change of strike, which commences opposite the east spur of Mount Bross, or between the Bross and Cameron amphitheaters. North of this line the average strike of the beds is north or a little east of north; south of it the strike bends more and more to the east of north; and on the southeast slopes of Bross the strata have a dip with the slope to the southeast.

The outer wooded ridge above mentioned is composed of coarse sandstones of the Weber Grits formation and of various intrusive bodies of porphyry. Porphyry bodies similarly situated were observed on four distinct section lines followed across this ridge, but the assumption that they form part of a continuous body, as indicated on the map, is here, as in the case of those on the east side of the Platte Valley, not founded on the tracing of a continuous line of outcrops, as in the cañon sections. They generally belong to the Lincoln Porphyry class. That found in the ravine above Dudley in considerable thickness has the round pink quartz grains, but wants the striking large orthoclase crystals of the Lincoln Porphyry. The actual line of contact of Blue Limestone and Weber Grits, occurring generally in the covered gap of the depression between the ridge and the steeper mountain slope, was seldom observed. It was therefore impossible to determine whether the sheet of Lincoln Porphyry, which occurs above it on the higher part of the mountain mass, extended eastward as far as the foot-hills or not. Some outcrops of porphyry were observed which might have belonged to a continuation of this sheet, but no facts of sufficiently definite significance were obtained to justify its indication on the map.

A good section of these outlying ridges is obtained in the narrow winding gorge of lower Buckskin Creek for about a mile above Alma. The beds of the Weber Grits formation exposed along the walls of the valley, which lie within the forest-covered belt, show much more decomposition and disintegration than is found in the same beds above timber line. They consist of coarse micaceous sandstones, with a considerable development of argillaceous shales, also micaceous, and one or two thin beds of gray limestone. Among the shales is conspicuous a black carbonaceous bed, and the limestone is supposed to be that which occurs at about the middle of the formation and which outcrops again in the wooded hills east of the Platte Valley. The sandstone which immediately underlies the town of Alma itself, and which is made up of grains of quartz about the size of duckshot, with considerable muscovite, might be mistaken at a little distance for a decomposed granite. It shows but few bedding planes, and, though in excavations for buildings it stands as a straight wall, when broken down it crumbles at once into coarse sand.

Buckskin amphitheater.—This immense basin at the head of Buckskin gulch bears the same relation to Mount Bross that the Platte amphitheater does to Mount Lincoln, the two separating the Lincoln massive from the main crest of the range, with which it is connected by the dividing ridge running from Mount Cameron to Democrat Mountain.

An excellent exposure of the Archean formation is afforded in its steep walls, which rise 1,500 to 2,000 feet from the bottom of the basin and are capped on the eastern side by a thin covering of Paleozoic beds. The rocks are mainly gneisses and amphibolites, with local developments of granite, through which run irregular vein-like masses of white pegmatite. The latter are particularly prominent on the northeastern walls of Buckskin cañon, a short distance above the town of Buckskin Joe. In the bottom of the upper part of the basin is a small lake, above which a dike of hornblende diorite forty to fifty feet wide runs across the basin in an easterly direction from the base of Democrat Mountain and disappears under the débris slopes on the other side.

At the south base of Democrat Mountain are three small lakes or tarns, on a raised shoulder or knoll of granite, back of which is a small raised basin extending to the base of the mountain. This granite is of the fine, even-grained type without large porphyritic crystals, almost white in color, and contains both biotite and muscovite. It is traversed by many small veins of pegmatite, consisting of orthoclase and quartz and often having a regular banded structure, like that shown in Fig. 2, Plate IV, which is from a sketch of a bowlder standing near the lake.

In this raised basin many eruptive dikes, mainly of porphyrite, were observed, only a few of which it has been possible to delineate on the map. These porphyrites belong to the types carrying either mica or hornblende and mica. They occur frequently in the form of interrupted dikes. That found near the uppermost of the lakes contains both hornblende and mica, with considerable quartz, and is remarkable for the numerous fragments of Archean rocks included in it. One of these fragments was several feet square and penetrated in all directions by veins of porphyrite, in which a distinctly fluidal structure of the elements of the porphyrite about it could be observed.

Near the middle lake is a dike of White Porphyry, a fresh and compact variety of the Leadville rock; fragments of the same rock are abundant in the débris pile at the head of the gulch.

One of the porphyrite dikes, which dips 30° to 40° north, can be traced to the south shoulder of Democrat Mountain, which forms the divide between this and the Platte amphitheater, and apparently connects with the long dike, which can be traced as a thin black line high up along the eastern wall of the latter. A double dike of similar appearance occurs further south on the same divide, near the north base of Mount Buckskin.

On the south wall of this raised basin under Mount Buckskin the white granite disappears and is replaced by gneiss and hornblende schists, which show a remarkably contorted structure. Running nearly parallel to this wall, and forming its face in certain parts, is a dike, thirty to forty feet wide, of mica-diorite. It projects out into the valley in the direction of the Red amphitheater, but could not be traced on the east side.

North Mosquito amphitheater.—The Archean exposures at the head of the north branch of Mosquito gulch may properly be mentioned here. They consist of the same general character of rocks—gneiss, schist, and granite. On its north wall the irregular shading of the dark mass produced by the white pegmatite veins is particularly prominent. The coarse-grained red porphyritic granites are more common lower down the cañon, while towards the crest of the range the fine-grained, eruptive-looking granite is found, and apparently extends through to the west side at the head of Bird's Eye gulch.

In the neighborhood of the little lake in this basin many dikes, often of the interrupted form, were observed, the more important of which have been indicated on the map. East of the lake, in the center of the amphitheater, is a dike of Mosquito porphyry, similar to the dike No. 2 on the south face of Mount Lincoln, though of somewhat lighter color, owing to a difference in the mica, and containing more ore in small specks. The oxidation of this ore gives a brown color to the weathered feldspars, which when fresh have a faint pink color. Under the microscope the groundmass is seen to be fully microcrystalline. The apatites are dusty. The only mica seems to be muscovite, which, judging from the associated yellowish grains and rarer needles, has come from biotite. Part of the ore seems to be magnetite, and part is entirely decomposed. The quartz grains contain fluid inclusions. This porphyry is cut in one place by a mica-porphyrite, which is a light-colored rock, containing numerous feldspars in a dark-gray groundmass, with some hexagonal plates of dark-brown biotite. Quartz, in quite large grains, can be distinguished by close examination. Single grains of pyrite are scattered through the rock. Striations are distinctly visible on many feldspars. Under the microscope plagioclase is seen to largely predominate and the biotite to be quite fresh. The groundmass, which is fully crystalline, is composed of very uniform minute grains of quartz and feldspar, with mica in opaque dots, and intrudes in bays into the quartz grains, which are quite free from inclusions.

To the northeast of the lake a considerable body of quartz-mica porphyrite was observed; but its exact form, whether a large dike or an isolated mass, could not be determined. It closely resembles the rock already described from the knoll south of Democrat Mountain. It is extremely fine-grained, but of very dark color, owing to the large amount of biotite, and contains no hornblende. Many other eruptive dikes were observed on the face of the cliffs, which time did not admit of studying carefully. Prominent among these is a dike or sheet of dark porphyrite, cutting the ridge which divides the upper part of the amphitheater into halves.

MIDDLE-EASTERN DIVISION.

This division includes the eastern slopes up to the crest of the range, from the line of lower Buckskin Valley south to that of Horseshoe or Four-Mile Creek. The region is crossed diagonally by the line of the London fault, which divides it into two parts in such a manner that there is a repetition of the same series of sedimentary beds exposed in the cañon sections on given transverse lines.

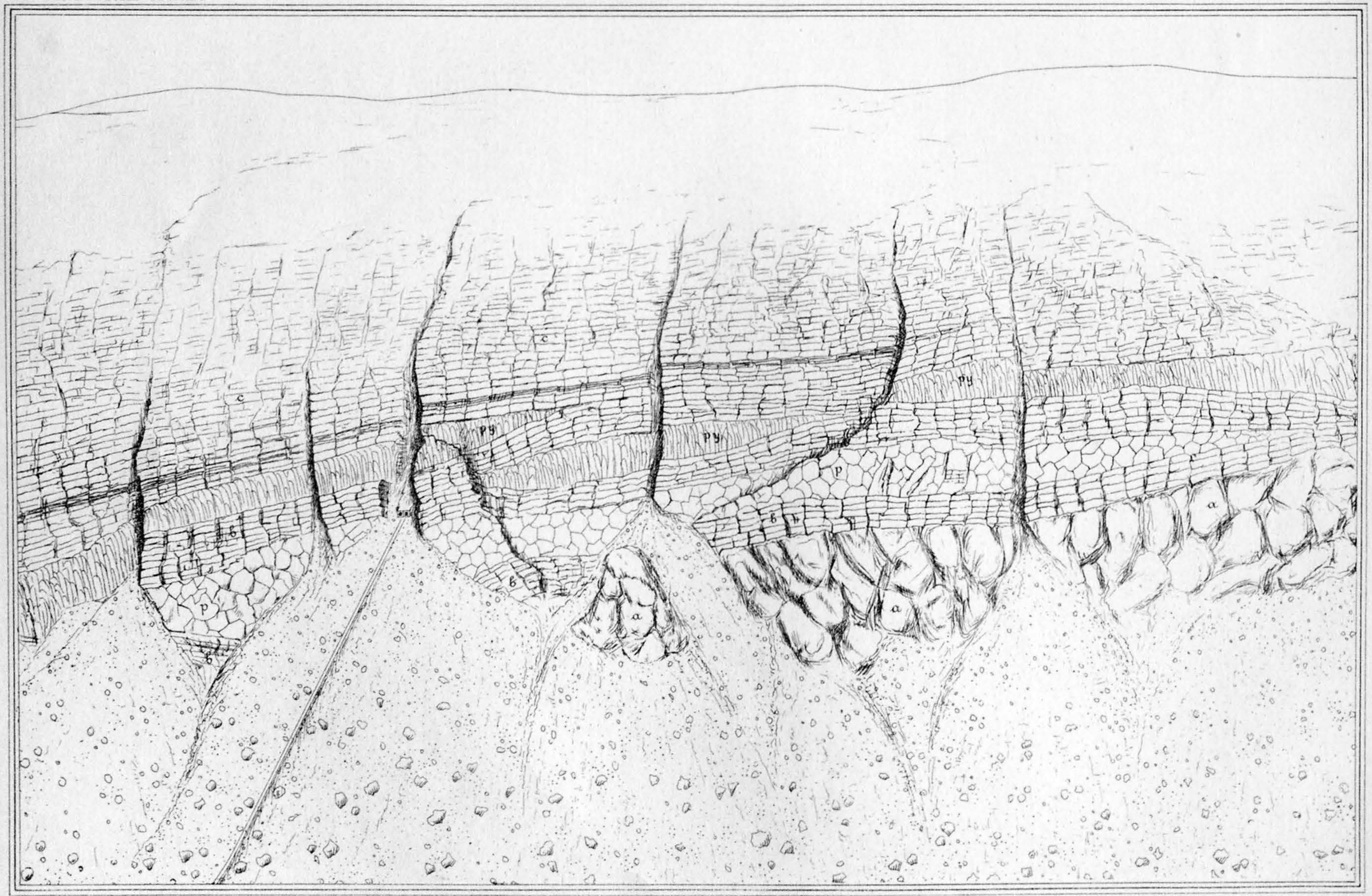
Glacial erosion.—Evidences of glacial erosion are abundant in the valleys of all the streams flowing from the crest of the range, but the data afforded by Buckskin and Mosquito gulches is so definite as to seem worthy of special mention. As the map shows, the two valleys are nearly parallel and similar in general form, in that their main course in the Archean rocks is southeast, the glaciers which originally filled them having been fed by a very broad névé-field, filling two or more less distinct basins at their head, and that in their lower course, where they reach the upturned edges of the Paleozoic strata at the line of their steepening dip, they bend sharply to the east and cross these strata approximately at right angles to their strike. Just above the bend a raised bench or shoulder is found on the south side of either cañon, several hundred feet above its present bottom, which is evidently a portion of a former valley bottom, and marks approximately the level to which the valley was cut out by the glacier which once filled it.

In Buckskin Cañon this bench, which has been cut across by several minor ravines, is not sufficiently regular to be defined by the contours of the map, although it is readily apparent to the eye. That in Mosquito gulch, however, which forms a practically continuous terrace nearly a mile and a half in length on the north face of Pennsylvania Hill, is shown by the topography of the map, and is about seven hundred feet above the bed of the present stream. It has about the same slope in an easterly direction as the present valley, and this slope carried upward corresponds with the present bottom of the South Mosquito amphitheater above the London fault, which is formed by gently-dipping quartzites and schists of the Weber Grits formation whose angle over a considerable area is about the same as that of the bottom of the basin. On the rock surfaces of the flat portion of this basin glacial grooves and striæ are still distinctly to be seen, showing that but little erosion has taken place since the Glacial epoch. On the other hand, in the neighborhood of the fault and in the Archean rocks below it, the present stream-bed deepens very rapidly and the valley becomes a narrow, winding, V-shaped gorge. In the north Mosquito amphitheater, which is entirely in Archean rocks, the upper part of the basin (which, owing to its great elevation and the consequent low temperature that prevails in it, suffers but little abrasion by running water) remains at essentially the same level as the South Mosquito amphitheater, but the V-shaped cutting by present streams extends back much farther than in the latter. The conclusion to be drawn from these facts is that the eroding force of glacier ice is a power so great as to be comparatively independent of the materials on which it acts, while that of running water varies very greatly with the different forms and characters of these materials. Thus the original glacial cutting of lower Mosquito gulch formed a comparatively straight and regular valley, but the present stream-bed near the mouth of the cañon makes a bend to the south, around a boss of more resisting granite on the north side of the valley, and then is deflected to the north by the upturned edges of the Paleozoic strata which cross its course diagonally.

The Mosquito glacier, as might be expected from its course, left its moraine material mainly on the south side of the valley, where it forms several wooded ridges opposite Park City. It was of greater extent than the Buckskin glacier, and probably once reached down to the Platte, the actual bottom of the present cañon being from one hundred to two hundred feet lower than corresponding portions of Buckskin gulch. Both Mosquito and Buckskin gulches open out into alluvial bottoms below the cañon mouth, but the stream in the latter soon runs into a narrow, winding gorge, which extends for a mile above Alma. The connection of the Buckskin glacier with the Platte glacier, if it ever existed, must, therefore, have been above the low ridge through which this gorge is cut.

Buckskin section.—The most complete and instructive sections of the lower Paleozoic beds and their included sheets of eruptive rock are obtained on the walls of the cañons near their mouths, just before the beds dip down more steeply to the east and disappear beneath the softer slopes of the lower rounded hills or are covered by the alluvial deposits of the streams. That on the south side of Buckskin gulch, just about the deserted town of Buckskin Joe, is represented by the diagrammatic sketch given in Plate XIII. The total height of the cliff above the valley bottom is here about one thousand feet.

The Archean exposures (*a*), occupying the lower portion, are largely concealed by huge talus slopes of débris, which in some places extend up so high as to cover the base of the Cambrian, while the Blue Limestone at the top of the cliff is covered by soil. The portion represented in the sketch shows, therefore, only the Cambrian and Silurian beds and the manner of distribution of the intrusive sheets of porphyry and porphyrite. These are here very irregular as compared with sections elsewhere, which is doubtless due to the fact that they are near the northern limit of the bodies, and hence that the intrusive power which forced them between the beds was already diminishing in energy. The upper bed is about fifteen to twenty feet in thickness and consists of dark-green hornblende-porphyrite, of the typical variety already described from Mosquito gulch. As shown in the plate, it varies in thickness and often wedges out, its continuation occurring farther on at a slightly higher or lower horizon. At its contact with the bounding sedimentary rocks it becomes more compact, but the sedimentary beds show no caustic phenomena, though they are sometimes slightly contorted. About thirty feet below this is a second intrusive sheet, also



Julius Bien & Co. lith.

S. F. Emmons, Geologist-in-Charge.

SOUTH SIDE OF BUCKSKIN GULCH

very variable in thickness, of gray quartz-porphyry, like the Lincoln, but without its large feldspars and with its basic silicates generally much altered. Between this and the Archean are forty to fifty feet of white saccharoidal quartzite, with a thin bed of fine-grained conglomerate at the base, wherever the base can be distinguished. The Archean here consists of a dark mica-gneiss, approaching a mica-schist in structure.

The dark, more or less perpendicular lines on the sketch represent shallow ravines on the face of the cliff, which are generally fracture planes across the beds, accompanied by a certain amount of dislocation. The principal ravine is that to which the double line over the débris pile (which represents a raised tramway for carrying down ore) leads, and in which are the now deserted workings of the Northern Light mine. This fault had a movement of about fifteen or twenty feet, and the ore seems to have been found in the crevice of the fault. These small faults were probably produced by the general dynamic movement in which the rocks were folded, and it will be noticed in the sketch that the intrusive sheets are faulted in the same degree as the inclosing sedimentary beds. About half a mile west of the point represented on the sketch is a prominent fault on the cliff, with an upthrow to the west of about one hundred feet. The direction of this fault, as of the minor fracture planes in the sketch, is between north and northeast, which corresponds with those observed near the Criterion mine, on the opposite wall of the gulch.

East of the Northern Light mine the beds slope rapidly down in a graceful curve to the bed of the gulch, in which only the outcrops of the harder and more silicious beds project above the gravel. The former mining town of Buckskin Joe, the oldest settlement in this region (now, like its companions, Quartzville and Montgomery, consisting mainly of deserted cabins and mill foundations), is situated on the outcrops of the base of the White Limestone. On the south side of the creek, a little above the town, is the once famous Phillips mine, an open trench, some twenty feet wide and in places as many deep, cut in an immense concentration of iron pyrites along a bedding plane of the Cambrian quartzite. In one place a decomposed quartz-porphyry is found on the hanging wall, which apparently cuts across the formation, as it is also found in the creek bed near the bridge at a somewhat higher horizon than the ore body. This porphyry resembles the rock of the lower intrusive sheet shown in the sketch, and may form part of it, though it was not possible to trace the connection between the two.

Loveland Hill.—Loveland Hill affords an excellent illustration of the often-observed fact that the deeper transverse valleys often follow the line of a minor or lateral anticlinal fold, while the intermediate hills or more elevated region, which has been relatively less eroded, is the locus of a minor synclinal fold.

On the broad, flat back of this hill or spur, whose slope corresponds very nearly with the easterly dip of the sedimentary beds, is a shallow ravine draining into Mosquito gulch, towards which there is a very perceptible dip of the beds from either side; in other words, the strata dip eastward, and at the same time dip north and south towards the bottom of this valley. The larger part of the surface of the hill is covered by beds of Blue Limestone. The White Limestone comes to the surface at its upper end, and on the sharp ridge which separates the north Mosquito amphitheater from Buckskin gulch are the remains of the lowest quartzite beds of the Cambrian. The Blue Limestone has been extensively prospected for ore, and a number of irregular deposits have been discovered, generally occupying gash veins, or cross joints and fault planes in the limestone. Numerous irregular bodies of porphyry are also found. Time did not admit, however, of a complete study of these beds nor of the ore deposits. The principal facts ascertained will be found in the description of mines in Part II, Chapter V.

The synclinal ravine already mentioned divides the hill somewhat unequally into a northern and a southern portion. The former forms a continuous ridge, which extends down to the junction of Mosquito Creek with the Platte River below Alma. East of the mouths of the cañons this ridge is comparatively low and covered with forests and soil. It is made up of beds of the Weber Grits formation, in which there is evidence of a secondary roll, as shown in Section C, Atlas Sheet VIII. Along the steeper slopes of the spur between Buckskin Joe and Park City are outcrops of a body of quartz-porphyry of the Lincoln type, which apparently forms a sheet above the Blue Limestone. These outcrops are not very continuous, but it seems probable that they are the remains of a sheet that once covered Loveland Hill in an analogous manner to the porphyry sheets on Mounts Bross and Lincoln.

By the erosion of the synclinal ravine above Park City the White Limestone is exposed in its bed with some irregular bodies of porphyry, and the southern half of Loveland Hill, south of this ravine, ends to the eastward in a cliff, at the base of which are exposed quartzites, apparently of the Cambrian formation, in which several ore bodies have been found. From the base of this cliff the formations sweep in a curve across Mosquito gulch and up the north face of Pennsylvania Hill. The Cambrian and Silurian outcrops can be traced in the bed of the gulch, dipping eastward at angles of 20° to 25°, but the Blue Limestone outcrops are concealed by gravel and alluvial deposits in the widening valley below.

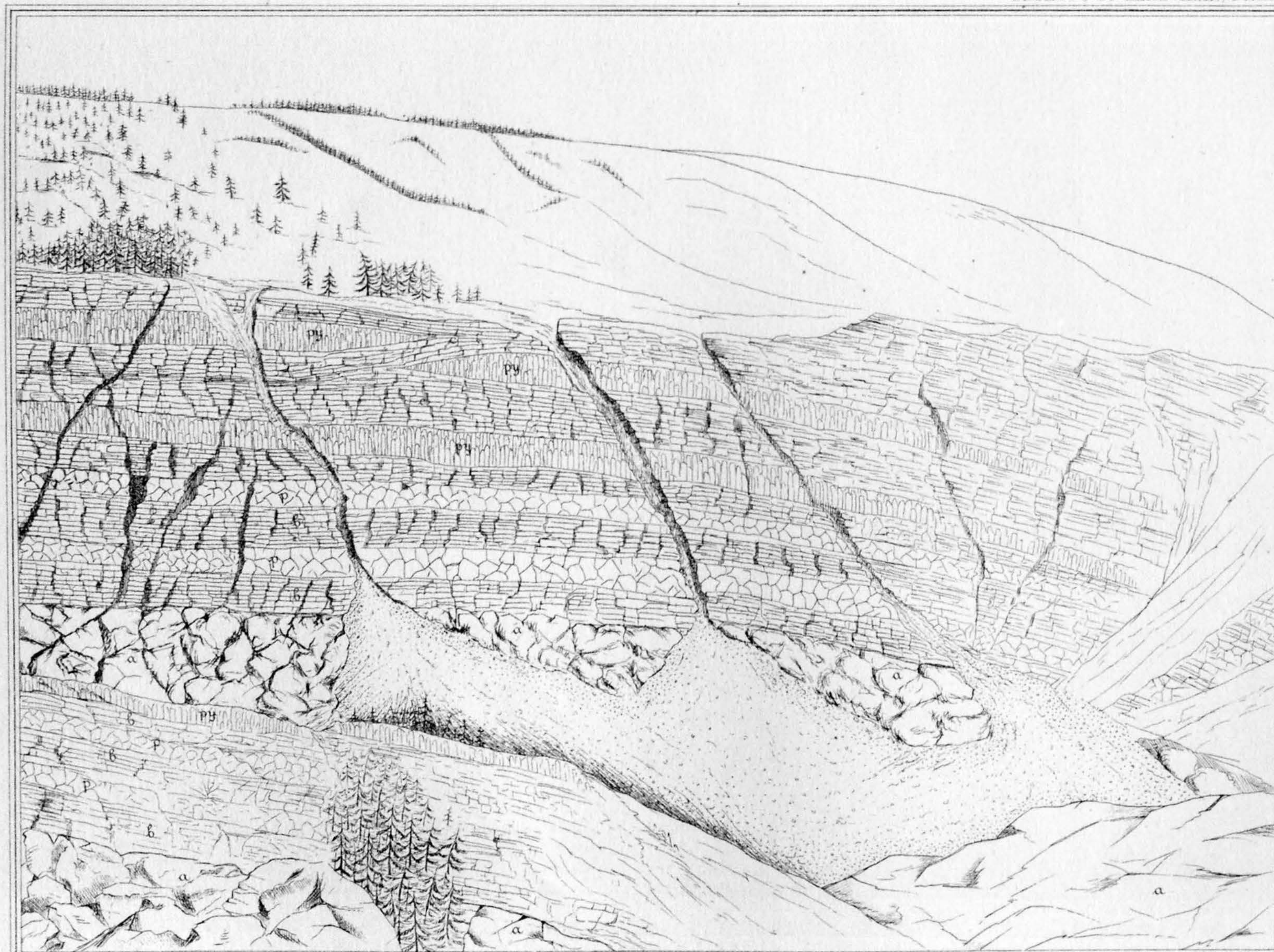
North Mosquito section.—The cliffs on the south face of Loveland Hill afford a section of the lower Paleozoic, with their included intrusive sheets, similar to but even more perfect than that on its northern face toward Buckskin gulch. Thin sheets of interbedded porphyry and porphyrite can be traced along them for nearly two miles in practical continuity. The fault which was observed on either side of Buckskin gulch is not found on this cliff wall, but near the mouth of the cañon is a more remarkable fault, whose direction is at right angles to the one above mentioned. Seen from the other side of the cañon, the strata seem to slope rapidly eastward until they abut against the western side of a little knoll of granite, which projects out into the valley at this point and deflects the stream to the southward. When one actually climbs the cliff, however, it is found that there is a reduplication of the lower part of the beds; that a faulting has sheared or split off a portion of the strata on a southeast line, nearly parallel with the face of the cliff; and that the piece thus separated has apparently fallen down at its eastern end to the base of the cliffs, while at its western end it still maintains its connection with the regular line of outcrops. In Plate XIV is given a diagrammatic sketch of a portion of this cliff toward the eastern end, where the steeper dips come in. In the foreground may be seen the faulted-down beds referred to above, which form a low ridge or shoulder, standing out a little distance from the face of the cliff. Above and back of this ridge the main cliff rises nearly perpendicularly, showing the regular series of Cambrian and Silurian beds above the Archean, the softer covered slopes on the top of the ridge being underlaid by the Blue Limestone. The section from the commencement of actual cliff slope downwards is as follows:

		Feet.	
Silurian	White Limestone, not measured.		
	Porphyrite, 25 feet.		
Cambrian	Quartzite and shales	50	
	Porphyry, 20 feet.		
	Quartzite	50	
	Quartz porphyry, 10 feet.		
	Quartzite	25	
	Altered quartz-porphyry, 15 feet.		
	Quartzite with fine conglomerate at base	15	
		—	140
Archean	Gneiss		

The upper intrusive bed is the normal hornblende-porphyrite, found also on the opposite side of Mosquito gulch, and already described in the Buckskin section. This bed, as will be observed in the sketch, is at the base of the White Limestone on the right, and above this horizon in the White Limestone on the left. It does not, however, break the continuity of the sedimentary beds in the plane of this section as it passes from one horizon to another, but it wedges out at one horizon and comes in again a little further on, also in a wedge-shaped body, at a slightly higher horizon. The rock of the second intrusive bed has also the external characters of a porphyrite, and has been indicated as such in the sketch; but microscopical examination shows it to belong to the Green Porphyry type. The third bed is a true quartz-porphyry, resembling the Lincoln Porphyry, but without its large feldspars, and corresponds to the sheet in the Cambrian on the Buckskin section. The lowest sheet is also a quartz-porphyry, but so much altered that not much can be said as to its probable type.

On the faulted-down ridge at the foot of the cliff the Green Porphyry forms the top rock, and the main bed of quartz-porphyry below can be readily traced; but the lower one is less distinct.

The chimney-like ravines which furrow the face of the cliff probably follow, as on the Buckskin section, fracture or fault planes. In the one which was examined, the left hand of the three from which the débris piles descend in the sketch, there is a discrepancy of about six feet in the beds on either side.



Julius Bien & Co. lith.

S. F. Emmons, Geologist-in-Charge.

CLIFFS ON NORTH SIDE OF MUSQUITO GULCH

SHOWING FAULT AND INTRUSIVE MASSES OF PORPHYRY

It is to be remarked that, as the scale of the map and sections was too small to show all the intrusive sheets mentioned above, they have there been generalized into two bodies, one of porphyry and one of porphyrite.

South Mosquito section.—On the south wall of Mosquito gulch, opposite the cliff described above, a similar and equally instructive cliff section is found, in which however there is no great fault; only the slight dislocations marked by shallow ravines, common to all the cliff sections. The beds on this cliff were examined in some detail and careful measurements were taken, as it was considered to be a type section. The series from the top of the cliff downwards is:

		Feet.	
Lower Carboniferous	Coarse granular gray limestone } with black chert		
	Blue lighter-colored limestone. } seams	60	
	Light-bluish limestone, weathering yellow	30	
	Blue limestone, generally thin-bedded	40	
		——	130
Silurian	White Parting Quartzite, heavy-bedded, coarse at top	40	
	Porphyrite, 2 feet, thickening to 20 feet farther west.		
	Limestones, light blue at top, gray semi-crystalline below; more silicious and shaly towards base	100	
	Very thin blue clay-shales, with shaly quartzite	10	
	White quartzite, more or less calcareous	30	
		——	180
Cambrian	Shales, argillaceous and silicious, containing red-cast beds	12	
	Thin-bedded quartzite, with shale beds few inches thick	14	
	White saccharoidal quartzite	18	
	Porphyrite, 6 feet (thickens to the eastward).		
	White saccharoidal quartzite, in beds from 4 inches to 4 feet	30	
	Quartz porphyry, 30 feet.		
	White saccharoidal quartzite, massive above, thin-bedded toward base; often discolored red and brown on surface	35	
	Quartz-porphyry, altered, 7 feet.		
	Quartzite, iron-stained	1	
	Quartz-porphyry, altered, 8 feet.		
	White quartzite, conglomerate at base	40	
		——	150
Archean	Gneiss, rich in mica		
	Granite, with red tabular feldspars		

In the above section the top of the Blue Limestone was possibly not reached, as it forms the surface of the hill, and may have been partially removed by erosion. The thickness given of 130 feet is much less than is found in the vicinity of Leadville. It is readily seen from the varying character of the beds at the base of the Silurian and at the top of the Cambrian that, in the absence of paleontological evidence, it is difficult to draw a definite line between the formations. These beds were deposited at a time when the general character of the sediments was changing from silicious to calcareous, and the rapidity with which the change progressed naturally varied much within comparatively short distances. The Red-cast bed, of which a specimen from this section is figured in Plate V, is the only one whose character is found to be persistent over the whole area, and this has, therefore, been adopted provisorily as the top of the Cambrian. The average strike of the beds is north and south, and the dip varies from a very low angle to 25° east.

The rock of each of the porphyrite beds is of the typical hornblende variety figured on Plate VII, Fig. 2. As in other sections, while the porphyrite is continuous on a large scale throughout certain horizons, in detail it is found to be very variable in form, now ending on one bedding plane in a tongue, around which broken masses of the sedimentary beds are distributed like material pushed before the end of a lava flow, and then continued a few feet farther on another bedding plane. Again it appears in small transverse dikes, probably offshoots from the interbedded sheets. Of these the most prominent is at the horizon of the Red-cast beds, standing vertically, with an east and west strike, and 10 feet thick. There are two main sheets of porphyrite. The upper one is only two feet thick in the line of section, and occurs between the Parting Quartzite and White Limestone. As it rises with the slope of the beds to the westward it gradually thickens, becoming 17 to 20 feet thick at the point where it reaches the top of the cliff, and here occurring between the Blue Limestone and Parting Quartzite. The second sheet occurs in the upper part of the Cambrian, being only six feet on the line of section, but thickening to the eastward.

The rock of the porphyry sheets is so much decomposed that it cannot be definitely decided whether it is more closely allied to the Lincoln or to the Sacramento type, occurring as it does in geographically debatable ground, or about at the limits of the extent of either variety. They occur in the lower part of the Cambrian, the upper sheet being 30 feet thick on the line of the section, above which is a long dike about three feet thick, probably an offshoot from it. The lower sheet, which on this line has a thin bed of quartzite included in its mass, is 15 feet thick, and is found a little farther west without any included quartzite. This lower porphyry sheet extends westward along the north face of Pennsylvania Hill as far as the London fault.

Pennsylvania Hill.—This name has been given to the broad, flat-backed spur included between Mosquito and Big Sacramento gulches. Like its neighbor, Loveland Hill, it is the locus of a slight synclinal fold, which forms a shallow ravine on its back drained by Pennsylvania Creek. Excepting along the cliff walls of the adjoining cañons, it affords but few good rock exposures, since its surface and that of the spurs which run down from it to the valley of the Platte are densely covered with forest growth and soil. The varying direction of dips observed in the sandstones of the Weber Grits which form the lower spurs gives evidence of one or more secondary rolls or folds in the outlying strata, as indicated in somewhat generalized form on Sections D and E, Atlas Sheets VIII and IX. The most definite evidence is found on the hill south of Park City, known to the miners as Baldhead. The northeast slopes of the hill and many of the lower hills extending eastward from it are made up of moraine material from the ancient Mosquito glacier. The various porphyry bodies found in this wooded region, of which only the more prominent are indicated on the map, are generally very much decomposed. When their character could be still recognized they were found to belong to the Sacramento type. They have generally a greenish color, due to the peculiar alteration of the basic constituents of the rock. Above timber-line the slope of the hill corresponds so closely with that of the stratification planes that good outcrops are only to be found, as a rule, on the cliff faces to the north, west, and south. The shallow ravine on its back divides it into two portions, on the northern of which the beds have the prevailing strike already observed, viz, about north and south. On the southern portion, on the other hand, the strike is about 20° west of north, and to this change of strike the synclinal structure observed may be in part due.

Along the northern wall, west of the Mosquito section just described, the Cambrian and Silurian strata form a thin capping to the Archean cliffs. At the western point of the hill decomposed porphyry is still traceable in the Cambrian, but at the very highest point, near the line of the London fault, only White Limestone is found at the surface. This can be seen to bend over in an anticlinal fold before it is cut off by the fault, and a prominent quartzite crag, which will be described later, is assumed to be a portion of the Parting Quartzite which has escaped erosion, standing in a vertical position on the west side of this anticline and adjoining the fault plane.

On the south face of the cliff overlooking Big Sacramento gulch an eminence of the ridge just east of the fault line is capped by a body of Sacramento Porphyry about one hundred feet in thickness. Over this, on the eastern flank of the ridge, whose slope is but little steeper than that of the strata, are further beds of white quartzite, succeeded lower down by the overlying White Limestone. This white quartzite therefore represents the Cambrian formation, and the Sacramento Porphyry an interbedded sheet, here locally developed in unusual thickness. At the foot of the steeper eastern slope of the ridge is found the Blue Limestone, over which is a bed of decomposed Sacramento Porphyry, almost identical with that which is characteristically developed in the Sacramento mine on the same horizon. Zones of decomposition are characteristically marked on this rock by concentric lines, stained red by oxide of iron, the very kernel of the larger blocks sometimes, though rarely, showing the original bluish color of the unaltered porphyry.

London fault.—The region thus far described has been one comparatively free from faults, the movements of displacement being, as it were, within the beds, and generally not more than one hundred feet in amount; movements which have exerted no perceptible influence on the character of the topography and have made comparatively little change in the geological outlines.

South of Mosquito gulch the eastern slopes of the range are divided by one great fault line running diagonally across them, and finally dying out at the southeastern corner of the map. This is the London fault, so called from the hill dividing the two heads of the Mosquito gulch, through which it passes. Its effects can be readily traced by the traveler who approaches Leadville over the Mosquito pass. The Mosquito pass road, following up the valley bottom of the north fork of Mosquito gulch, winds up the steep west wall of the gulch and, passing through the narrow notch between London Hill and the main crest of the range, ascends gradually in a southwest direction to the Mosquito pass. Up to the point where it reaches the northwest wall of London Hill the rocks around are of gneiss and granite; from there to the summit of the pass is a confused mass of huge loose blocks of coarse quartzitic sandstone and fine-grained porphyry, in which it requires a trained eye to distinguish any definite structure lines, although the change in the character of the rocks is evident to all. Looking south from the road across the broad basin of the South Mosquito amphitheater, the eye is at once attracted by the peculiar appearance of the ridge which forms its south wall. This is the summit of Pennsylvania Hill. As seen from this distance, parallel with the regular and comparatively gentle slope of its surface eastward there can be distinguished along its upper wall a few horizontal lines marking the bedding planes of the Paleozoic strata, below which the steep face of the hill shows no definite structure lines on its rocky surface, save those which mark the talus slopes of broken rock accumulated towards its base. The smooth, regular slope is broken at its crest by a dark knob, around which the rocks are greatly discolored, and the débris from which presents brilliant hues of yellow and red. West of the knob the outline of the hill presents terrace-like escarpments, descending nearly to the level of the amphitheater. The face of this portion of the hill shows regular stratification lines, dipping eastward at an angle of 20°, which can be seen with great distinctness to its very base, where they are concealed by the talus slopes. All end abruptly to the east before reaching the discolored knob. This break in the continuity of the stratification lines, or of the beds which they outline, is evident at the first glance, as marking the line of a great fault plane. The evidence of the existence of this fault can be seen with equal distinctness on the walls of the cañon gulches to the south of Mosquito gulch, although in either case the conditions vary, both in the horizon of the juxtaposed beds on either side of the fault and in other structural outlines. Although its existence is so evident, yet its actual position cannot be determined with absolute accuracy, the possible error of location varying under different conditions from ten to one hundred or even two hundred feet. The reason for this uncertainty is found in the fact that the surface rocks in the immediate neighborhood of the fault are generally so much altered and decomposed that their structure planes cannot be traced, and that the fault plane has not been cut by any underground explorations. The direction of the fault, as determined from points where it crosses ridges or gulches, varies from N. 15° W. to N. 45° W., its average direction being N. 30° W. or NW. magnetic. The great **S**-shaped anticlinal fold which is everywhere found in close proximity to the fault has the same general direction; nevertheless the two directions do not seem to be coincident for any long distance, but diverge a little from each other, so that the fault cuts the fold, now in one part, now in another, but generally west of the anticlinal axis. Thus from Pennsylvania Hill to Sheep Mountain it corresponds closely with the axis of the syncline to the west of the great anticline; south of Sheep Mountain it gradually approaches the anticline, until at the extremity of the ridge both fault and fold die out. North of Pennsylvania Hill the line of the fault has a more easterly direction than that of the fold, and on London Hill it cuts the fold east of the synclinal axis, and a little beyond it may very nearly coincide with the anticlinal axis; but, as the sedimentary beds have been entirely eroded away from above the Archean, it is no longer possible to determine the position of this axis. The amount of displacement occasioned by this fault can only be determined approximately, since the fact of its near coincidence with the anticlinal fold introduces an unknown factor, viz, the amount of apparent displacement that may be due to actual plication. The reason of this can best be understood by reference to Sections C, D, E, F, G, and H, on Atlas Sheets VIII and IX, which are drawn to scale and have been constructed with great care from observed outcrops, dips, and thicknesses of formations. The movement of displacement, as shown in these sections, which is probably a minimum, averages a little over two thousand feet.

The description of the geological character of the region west of the fault will now be resumed in topographical order as it has been carried on hitherto, taking up alternately the cañon sections and intermediate ridges in regular succession as one goes south.

Main crest from Mosquito Peak to Mount Evans.—On the main crest of the range, at the head of the south half of the North Mosquito Amphitheater, the fault line is well marked by a sudden change from limestone to a coarse red granite, in the saddle or notch between Mosquito Peak and the peak next north of it. The upper tunnel of the Little Corinne mine, on the north face of Mosquito Peak, is run near the top of the Blue Limestone; above this are 12 feet of White Porphyry, while the lower tunnel of the same mine is in White Limestone. The shales and quartzites of the Weber Grits formation form the summit of the peak, included in which is a thin bed of Sacramento Porphyry.

From Mosquito Peak southward to Mount Evans the main crest of the range is a nearly straight ridge, steeply escarped on the west. At the base of this escarpment runs the Mosquito fault, by whose displacement the Archean schists have been thrust up into juxtaposition with the beds of Weber Grits formation on the west. The beds of the lower Paleozoic series can be traced along the summit of this wall, descending gradually to the southward, until under Mount Evans, in the Evans amphitheater, they are found at the base of the slope. In this extent there is a slight break in their continuity, occasioned by a transverse fault in a little ravine just south of the zigzags of the Mosquito grade. The thin sheet of White Porphyry lying above the Blue Limestone, which is observed at Mosquito Peak, disappears before reaching Mosquito pass; but the sheet of Sacramento Porphyry 10 feet thick, which occurs in the lower portion of the Weber Grits, apparently at the summit of the shale division of this formation, gradually thickens to the southward, and on the eastern wall of the Evans amphitheater it suddenly widens out into a body five hundred to seven hundred feet in thickness. Owing to the sharp contrast of the angular and almost Gothic forms, into which this mass weathers, with the horizontal lines of the bounding sedimentary beds, its outlines can be readily distinguished even from so great a distance as Leadville itself, and would be seen in the heliotype view on page 6 had the photographic picture been equally distinct with that which is formed on the eye of the observer. At the point where the Mosquito grade descends this steep western wall the Lower Quartzite comes in contact with Weber Grits on the west of the fault, but to the north and south of this point Archean exposures intervene between the base of the Paleozoic and the line of the Mosquito fault

On the crest of the ridge are two irregular-shaped bodies of Sacramento Porphyry at a higher horizon than the sheet already mentioned, which are supposed to be the relics of a second intrusive sheet. The first of these forms the summit of the peak next south of the Mosquito Peak, and can be traced down its eastern slope across the Mosquito grade. The second forms the crest of the ridge for some little distance south of Mosquito pass. In the saddle west of London Hill the road crosses another exposure of porphyry, which is supposed to be the outcrop of the lower sheet of Sacramento Porphyry exposed along the western face of the crest; while in the sharp, prow-like point of London Hill is another interbedded sheet of Sacramento Porphyry, which, as indicated in Section C, is presumed to be a continuation of the upper body, which is found on the crest of the range.

South Mosquito amphitheater.—The bed of this basin is formed by coarse sandstones and grits of the Weber formation, dipping 20° to the east with its slope. On the exposed faces of these beds glacial grooves and striæ are often very distinct. In the sandstones are various beds of porphyry, and among the débris piles of huge rock fragments split off by ice and frost, which form the steep slopes of the eastern and southern walls, porphyry forms an important element. Time did not admit of tracing out the outlines and relations of all these porphyry bodies, and the structure given on the map and sections, which assumes that the lower sheet which outcrops along the west side of the crest of the range once extended over the whole basin, may be only partially correct.

Sacramento amphitheater.—Big Sacramento gulch, like those to the north of it, was once occupied by a glacier, and the amphitheater at its head, like that of the South Mosquito, has been probably but little deepened since Glacial time. The deeper cutting of the present stream extends some little distance above the fault; below the fault line the bottom opens out into springy meadows and then closes together, as it bends to the southward, between gravelly ridges which are evidently the remains of former moraines and which extend below the junction with Little Sacramento. Owing to the dense growth of forest on these ridges, however, the actual lower limits of the glacier are not easily determined. About a mile above the line of the fault the narrow bottom of the present stream ends in shelf-like terraces of white sandstone, above which the valley opens out into the broad basin of the Sacramento amphitheater. On the face of this terraced wall, and about opposite the western point of Pennsylvania Hill, are two dolomitic limestone strata: the lower one, a dark-gray semicrystalline rock, with clayey seams, is about ten feet in thickness; the second, sixty feet above this, is only six to eight feet in thickness, of similar color and also associated with clay shales, the intervening beds being of coarse Weber sandstones. Among the fossils found here were identified

Productus costatus and *Athyris subtilita.*

Ascending the stream farther, successive beds of white sandstone are crossed until the great body of Sacramento Porphyry is reached, which in a probable thickness of twelve hundred feet forms either wall of the amphitheater. The upper extremity of the amphitheater was not explored, but from information and specimens furnished by Mr. J. T. Long sufficient evidence was obtained to justify the indication of an outcrop of Blue Limestone below the Sacramento Porphyry at its deepest part. The fossils obtained by him from here, besides the uncharacteristic *Athyris subtilita*, included the new *Spirifera*, like *Spirifera Kentuckensis*, which has not yet been found at a higher horizon than the Blue Limestone. Among minerals small yellow crystals of pyromorphite were found with the specimens of ore obtained from this horizon.

London Hill.—The line of the London fault crosses London Hill diagonally about seven hundred feet west of the summit, in such a manner that the greater part of the steep northern slopes is occupied by Archean rocks, with only the extreme eastern end made up of easterly dipping quartzites of the Weber Grits formation, whereas on the south side the latter extend over two-thirds of the lower slopes. From the saddle north of Mosquito Peak the London fault runs southeast to a point in the raised basin north of the

London mine, then bends more to the southward across London Hill. Under Mosquito Peak the beds lie in a shallow synclinal, with the Blue Limestone rising up gently to the eastward against the line of the fault. On the south-east slope of this peak the limestone forms a cliff wall, rising abruptly above the granite on the other side of the fault, thus affording another illustration of the fact that flat beds resist erosion more from the fact of their horizontality than from any greater resisting power of the materials which compose them. Half way between Mosquito Peak and London Hill, near the New York mine, a thin bed of White Porphyry is found at the base of the cliff under the limestone; the outcrops of the formations cannot be traced continuously to London Hill, as its lower slopes are covered by a great thickness of débris.

The London mine at the time of visit was opened by two tunnels, one above the other, a short distance west of the line of the fault. The lower tunnel, at the base of the hill, after passing through a great thickness of débris, consisting of large rock fragments frozen into so solid a mass as to require blasting, follows the stratification planes of nearly vertical beds of light-colored limestone, whose strike is a little more to the west of north than the direction of the fault plane. The dip of the strata is a little west of the vertical. Between the beds of limestone is a compact White Porphyry, which can in the mine hardly be distinguished from the limestone, especially as it effervesces with acid; it contains, however, occasional dark flakes of mica, and chemical tests placed its character beyond a doubt, though it contains a percentage of soluble matter, mainly carbonate of lime with a little magnesia (10 per cent. in the specimen tested), which is too high to have come from the decomposition of feldspar alone, and must, therefore, be supposed to be an infiltration from the inclosing limestones. The limestones adjoining the porphyry to the east are very light colored and contain over 10 per cent. of silica, which is about the normal percentage of the upper part of the White Limestone. As the ore deposits follow the stratification planes, not much exploration has been done across the strata, and owing to the metamorphosed condition of the rocks exact determinations of horizon were not practicable. It may be assumed, however, that the ore deposits of the London mine occur in the upper part, if not at the very top, of the White Limestone. On the hill above, it can be seen that the fault line crosses the ends of the upturned strata at a very acute angle.

The point where the easterly-dipping Weber Grits beds change their inclination to a sharp western dip, as they must to allow of the coming up of the underlying Blue and White Limestones, as shown in Section C, is not very sharply defined. Some beds of Blue Limestone can be distinguished between them and the fault line, but, while there was not time for exact measurements, and these could hardly have been made without a map, which was entirely wanting at the time of field work, it seems most probable that these upturned beds have been actually compressed against the fault plane to a smaller thickness than they have in a more horizontal position.

The southwest slopes of London Hill contained no mine openings, and were too much covered by soil and débris to show clearly defined structure lines, though the sandstone beds of the Weber Grits formation were seen to change their dip from 20° to 50°. At the point where the old wagon road descends into the deeper valley of the south fork of the Mosquito gulch the actual fault line can be distinguished, a tunnel having been run in the decomposed and highly metamorphosed slates and quartzites, which here directly adjoin the granite beyond the fault. This point of contact bears only 10° W. of N. from the dark crag on Pennsylvania Hill, which is nearly on the line of the fault. It is evident, therefore, that there is a sharp bend in the direction of the fault at this point, even more marked, perhaps, than that which is indicated on the map, though, as the position of the tunnel has not been determined instrumentally, nor the old road located on the map, it is not possible to fix absolutely the position of this bend. Here for some distance to the west of the fault line the strata stand not only vertically, but have an inclination of 50° to the west; the strike, however, is approximately the same as elsewhere, viz, about N. 20° W. Thicknesses of about two hundred feet of vertical strata are exposed, so much altered that their lithological character can with difficulty be distinguished. They include shales and some silicious beds, with one bed of limestone. A short distance to the west of the fault the characteristic sandstones of the Weber Grits are met, with the regular dip of 20° to the northeast. It seems evident that the structure here is the same as that just described at the London mine, viz, that these much metamorphosed and vertical beds are the lower Paleozoic strata coming up from under a sharp syncline, compressed and altered beyond recognition by the dynamic movement at the time of and subsequently to the faulting. This would seem at first glance to be an explanation inconsistent with that which is offered for the conditions which obtain on Pennsylvania Hill, on the opposite side of the gulch; but the fact that the fault line comes in the one case east of the synclinal axis and in the other nearly coincides with it, and the supposition that compression subsequent to the faulting has not only produced sufficient heat to alter the original character of the beds, but has steepened the dips of the already inclined beds and actually made them thinner, sufficiently explain the apparent incongruity.

Pennsylvania Hill west of London fault.—The western end of Pennsylvania Hill, through which the London fault runs, is deserving of detailed description. Its structure is shown in section D, with the ideal position of the beds in depth. The observed facts are these: Ascending the wedge-shaped western point of the ridge from the saddle which divides South Mosquito from Sacramento amphitheater, one crosses a regular series of sedimentary beds, dipping 20° to the eastward, with two interbedded sheets of porphyry apparently conformable with the sedimentary beds. The ridge has almost perpendicular walls both to the north and south, on which the structure lines can be distinctly seen. The horizon of the beds which cap the dividing saddle at the base of the ridge is estimated to be 150 or 200 feet higher than the limestone beds which occur about the middle of the Weber Grits formation. About half way up the steep western slope, which is mainly composed of coarse sandstone with some few intercalated beds of shale, is a body of interbedded Sacramento Porphyry, of a thickness of 15 to 20 feet. Near the top of this steeper slope is a bed of black sandstone, composed of white quartz sand and fine grains of carbonaceous material in the nature of anthracite or graphite, which is very characteristic of this formation. The very summit of the steeper ridge is formed by a second body of porphyry, a fine-grained gray rock with conchoidal fracture, resembling the Silverheels Porphyry, whose thickness is 25 to 30 feet. Above the steeper slope of the ridge the surface is nearly flat and widens out so that the succeeding beds can only be observed along the cliff faces. Above the porphyry is a body of purple silicious shales, succeeded by white sandstone, with an occasional band of black sandstone similar to that already described. Prominent among these sandstones is a very coarse conglomerate, with large pebbles of quartz and fragments of Archean schists and granite. As one proceeds east the dip of the beds steepens slightly, perhaps to about 25°, till, on approaching within two hundred yards of the fault, it changes—apparently with great suddenness—to a practically vertical angle. At the same time the beds are found to be greatly decomposed and stained a reddish-yellow color. These beds being much more readily disintegrated, the structure lines, when seen close to, become indistinct, being masked by débris. They consist, as well as can be determined, of shales and sandstones, with one belt of blue limestone, immediately adjoining the dark knob on the west, which has a thickness of about eight feet, adjoining which is a bed of White Porphyry. The dark knob, which forms so prominent a feature on the north wall of the hill, is white quartzite, 50 feet or more in thickness, which on its eastern side is singularly altered. It has here become a light frothy mass of cavernous quartz. Careful examination shows that this quartzite, though the main mass stands vertical, probably arched over to the eastward, and therefore forms a part of the anticlinal fold which adjoins the fault on this side. The flat summit of the hill east of this point is made up of beds of White Limestone, included in which is a reddish decomposed porphyry. The actual curving of the White Limestone can scarcely be distinguished, inasmuch as decomposition has proceeded so far in the crest of the fold that a shallow ravine scores off the face of the hill adjoining the quartzite knob, in which all structural lines are obliterated by the sand resulting from that disintegration. Steep as are the north slopes here, it is useless to search for the actual fault line or the structure lines on either side of it. East of the fault there is no difficulty, and the Cambrian and Silurian beds overlying the Archean can be traced continuously along the wall of Mosquito gulch. Aside from the fact that the curve in the beds of this mass of white quartzite can be distinguished, its position adjoining the White Limestone would be sufficient to determine it as the Parting Quartzite, which forms the summit of the Silurian formation; but in the several hundred feet of vertical beds which adjoin this on the west it would have been difficult, had no other opportunity for studying these faults offered, to determine satisfactorily whether they belong to the series on the eastern or those on the western side of the fault. Blue limestone and White Porphyry are here—the former, it is true, represented only by a comparatively thin bed; and the other metamorphosed rocks might as well belong lithologically to the bottom as to the top of the Weber Grits formation

The actual succession of vertical beds adjoining the quartzite crag on the west is, as well as could be determined, the following:

	Feet.
Gap showing some black shale, about	40
White Porphyry	20
Blue limestone	8
Quartzitic sandstones	100
Blue limestone	8
Quartzitic sandstones and decomposed greenish argillaceous beds, also silicious	200

In the description given of faults it is generally stated that the flexing, occasioned by the movement of the faults, is reversed in the beds on either side. For instance, if the strata on the side of the fault that is lifted up are curved down by the dragging or friction of the movement, for the same reason those on the other side, which moves relatively downwards, would be curved upwards; or if, on the other hand, on the upthrow side of the fault the strata are curved upwards—as might be accounted for on the supposition of a force pushing from behind against the fault plane—then the beds on the downthrow side of the fault are curved downwards. This is the generally accepted theoretical explanation of curving of beds adjoining a fault. In this case, however, we have the alternative of assuming that the beds curve downwards on both sides, or, what under the circumstances is even more improbable, that a bed of limestone, which everywhere else in the region examined has a thickness of 150 to 200 feet, has in this single locality been reduced to eight feet. It was assumed therefore, as shown on section D, that these vertical beds, as far as the quartzite crag, belong to the series west of the fault and geologically succeed the Weber Grits in regular order; that is, belong to the Upper Coal Measure horizon.

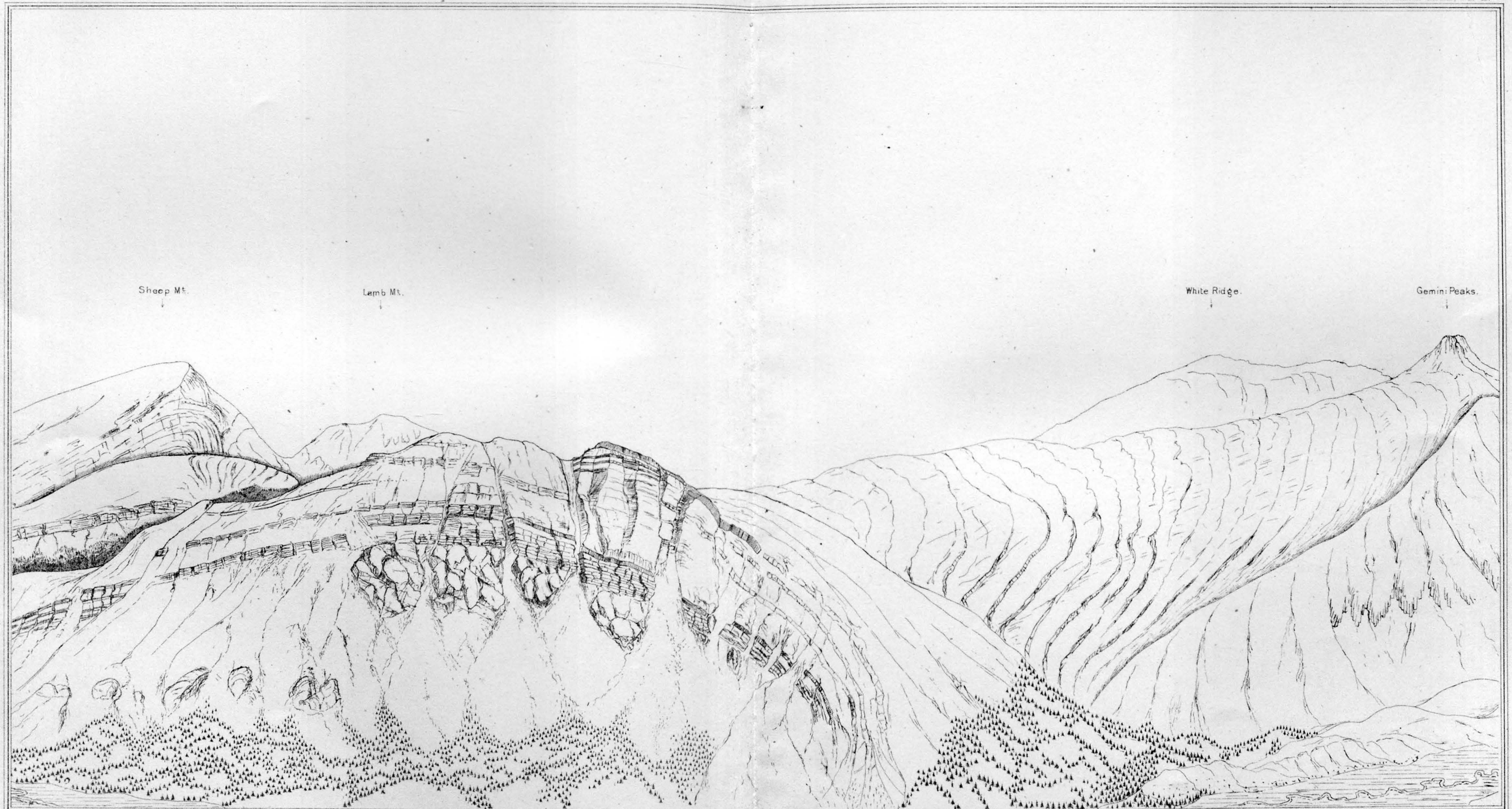
The correctness of this assumption, so far as the horizon of the beds goes, has been proved by analogy in other localities, as will be described later, notably in the case of Weston fault on Empire Hill, where similar structural conditions exist, but with less intense alteration of the beds adjoining the fault, and where, moreover, the strata of the Upper Coal Measure formation were recognized definitely not only by their lithological characteristics but by abundant fossil remains found in them. The dividing line between the great silicious series of Weber Grits and the Upper Coal Measure formation having been arbitrarily assumed at the first development of calcareous beds, this line has been drawn on the map at the base of the lower bed of limestone mentioned in the above section. A thickness of something over one hundred and fifty feet of Upper Coal Measure beds is thus assumed to have escaped erosion on the western side of the fault.

On the south wall of Pennsylvania Hill, facing Big Sacramento gulch, the beds which outcrop are practically identical with those on the north wall. They preserve the same strike of N. 20° W., with a dip of 20° to the east. The steepening of the dip as they approach the fault line is, however, not so apparent on the north wall of the hill, the surface being to a still greater extent obscured by débris. Near the line of the fault the wall, as on the north side, is scored by a shallow ravine, on whose steep slopes fragments of White Porphyry are mingled with those of almost equally white quartzite. The former belongs evidently to the same body mentioned already as occurring on the north wall to the west of the assumed line of fault. Owing to the uncertainty which exists with regard to the structural relations of this body of White Porphyry, it has not been indicated either on the map or section.

Sacramento arch.—The south wall of Sacramento gulch, a sketch of which is given on Plate XV, presents an even more interesting study of the great London fault-fold than that of Pennsylvania Hill. The cliff section, as the sketch shows, presents a broad and rather flat arch, which has but little resemblance to the sharp **S**-fold already indicated on London Hill or to that which can be distinguished in the background of the sketch on the north face of Sheep Mountain. At first glance the curve on either side of the arch seems to be nearly equal in degree; but a more searching examination discloses on the right or west a few steep lines, indicating the nearly vertical dip of the beds adjoining the fault which is found at other points. A comparison of the direction of the valley with that of the axis of the fold affords a ready explanation of this deceptive appearance. The plane of the cliff section stands at an angle of 60° instead of at 90°, or at right angles with the axis of the fold. So that nature has afforded a graphic illustration of the simple problem in descriptive geometry, the diagonal intersection of a cylindrical body by a plane.

The interior of the arch is made up of Archean rocks, mostly gneiss with white vein-like bodies of pegmatite running through it. Over these stretch the entire lower Paleozoic series, with some interbedded porphyries, the principal of which is the Sacramento Porphyry in the Lower Quartzite, corresponding apparently in horizon with that on the north side of the gulch. Blue Limestone, more or less eroded, forms the crest of the hill. On the east side the beds slope away with the angle of the hill at about 20°. On the west of the crest, towards the fault, the dip rapidly steepens and becomes vertical before reaching the fault plane. The structure can naturally be best seen on the cliff face. Here as elsewhere the stratified series seems much thinner in a vertical than when in a horizontal position. On the north face the Blue Limestone comes into contact with the fault instead of the Parting Quartzite, as on Pennsylvania Hill. The rock is much shattered and there is considerable development of black chert. Apparently some slight ore deposition has also taken place; but there is no evidence that this is the result of the faulting action. On the crest of the ridge, still east of the fault, are some shales and beds of impure anthracite, characteristic of the lower part of the Weber Grits formation.

West of the Sacramento arch the ridge is level for a short distance, and then rises in a regular slope to the Gemini Peaks, two little projections crowning the ridge opposite the head of Sacramento amphitheater, on the north, and of Iowa amphitheater, on the west. The regularity of the structure lines on the eastern flank or back of this ridge is extremely remarkable and is partially shown in the sketch. The dip of the beds, which to the west of the fault are entirely of the Weber Grits formation, is here steeper than in the adjoining amphitheater, averaging from 25° to 35°,



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S. F. Emmons, Geologist-in-Charge

SACRAMENTO ARCH

LOOKING ACROSS BIG SACRAMENTO GULCH FROM PENNSYLVANIA HILL.

and the lines of outcrop can be traced with the greatest distinctness. In the distant view of the whole range from Mount Silverheels, as shown in Plate III, these structure lines, as well as the curves of Sacramento arch and of Sheep Mountain fold, can be readily recognized. Immediately west of the fault the beds are perpendicular, and even bend over so that they have a slight inclination to the westward. The change from this steep dip to the average inclination of the whole hill seems to be less sudden than on Pennsylvania Hill; but, as there, it is somewhat obscured.

On the south side of the ridge facing Little Sacramento Valley is a slight synclinal fold, no evidence of which is found on the north face of the ridge. An explanation of this occurrence may be found in the fact that the line of fault from the Sacramento arch southward apparently diverges to the eastward, as compared with the strike of the beds, so that more space is left between the fault plane on the east and the unyielding masses of porphyry which form the crest of the ridge to the west.

Gemini Peaks.—In the long series of outcrops on the eastern slopes of the Gemini Peaks, which comprise almost the entire thickness of the Weber Grits formation, are some minor sheets of porphyry which have not been indicated on the map. The two peaks themselves form the crest of an immense body of Sacramento Porphyry which is exposed under the Weber Grits, both on the north and south walls, in apparent conformity with the overlying sandstones. The thickness shown, as derived from the angle of the slope, must be about 1,200 feet. The north branch of Little Sacramento Creek has cut to a great depth into this immense body of porphyry, leaving on either side walls nearly 1,000 feet in height, in which the same columnar structure in large masses or prevalence of vertical cleavage planes is found that has been already noticed in the porphyry mass on the summit of Mount Lincoln. It evidently represents what was originally a huge laccolite, and it is probable that it stands above the original vent from which the main flows of Sacramento Porphyry spread out into the adjoining rocks. Immediately to the south and west of this is the main body of White Porphyry, which forms the mass of White Ridge and of Mount Sherman. The junction of these two great bodies is extremely interesting, and was expected to afford definite evidence of the relative age of the two rocks. The actual contact is, however, obscured by broken masses which almost invariably cover the surface in these high regions. On the east side of the eastern of the Gemini Peaks, however, were found a few beds of Weber Grits, within which was a small body of White Porphyry, while at either side of the Weber Grits was found Sacramento Porphyry. It seems, therefore, that this fragment of Weber Grits, with the included White Porphyry, was caught up within the later outflow of Sacramento Porphyry. Such caught-up masses of sedimentary rocks entirely included in porphyry masses are by no means uncommon.

On the southwest face of the western of the Gemini Peaks are beds of Weber Shales, about fifty feet in thickness, consisting of gray limestone, quartzite, and green micaceous shales. About half a mile south of this, and in a shallow depression between the summit of Mount Sherman and the outlying shoulder to the east, is a similar succession of beds, dipping however to the west, which are entirely included in the surrounding mass of White Porphyry. On the east of this shoulder again, at the contact of Sacramento Porphyry and White Porphyry, are found thin beds of white quartzite, belonging undoubtedly to the same general horizon.

The most characteristic exposures of this great mass of Sacramento Porphyry can be seen at the heads of Little and Big Sacramento gulches and on the main ridge between Sacramento and Evans amphitheaters. On the eastern wall of the latter it covers the greater part of its steep surface, widening and rising to the southward, and sweeping up to the summit of Dyer Mountain, where a thickness of some four hundred feet still remains. Below this, and separating it from the Blue Limestone, is a remnant of the lower beds of the Weber Grits formation, a relic of which forms the summit of West Dyer Mountain. From the saddle between Dyer Mountain and Gemini Peaks both Weber Grits and Sacramento Porphyry have been removed, leaving the crest of the ridge composed of White Porphyry. The limits of the two bodies of White Porphyry and Sacramento Porphyry are well defined by a line running nearly northwest and southeast between Gemini Peaks and Dyer Mountain. To the northeast of this line the White Porphyry rapidly thins out and disappears. The occurrences of this rock, hitherto noted in the regions farther north, were generally in the form of dikes of inconsiderable magnitude, or of quite small intrusive masses which doubtless are the upper portion of similar dikes whose base is concealed. It is probable that these minor eruptions of porphyry are of later date than the main intrusive masses which prevail to the southwest of this imaginary line. Although the Sacramento Porphyry is not found upon the surface to the west of the main crest of the range, it is probable that it did not originally end abruptly there, but gradually thinned out in some such form as is indicated in Section D, west of the Mosquito fault, or as is shown more in detail in the sections accompanying the Leadville map. Lithologically it forms a definite type, whose general character has already been given in the chapter on Rock formations. Its distinguishing characteristics, as compared with the other porphyries, are its relatively large proportion of plagioclase feldspar and its carrying hornblende. These ally it in some degree to the porphyrites.

Little Sacramento gulch.—The observations made in Little Sacramento gulch, which time did not admit of repeating, were unfortunately not sufficiently detailed to afford data for an accurate outlining of all the bodies of porphyry found there. The principal uncertainties resulting herefrom are: first, as to the eastern limit in the gulch of the main body of the Sacramento Porphyry: whether it confines itself to the horizon which it follows with apparent regularity farther north or whether it cuts across the overlying beds; and, secondly, whether a body of the same porphyry observed on the north face of the ridge separating Little Sacramento from Spring Valley is connected with the main body as a transverse body, or whether it is a portion of an interbedded sheet, like those on the western face of London Hill, with which it might be possibly connected by the bodies observed, but not outlined, on the eastern flanks of the Gemini Peaks ridge.

East of the fault, it is evident that in the region included between Horseshoe and Big Sacramento gulches there is a lateral syncline similar to that observed on Pennsylvania and Loveland Hills, but broader and deeper. The surface of the region is too much covered to admit of this fact being determined by the observed dip of the beds, but it is evident by the fact that the erosion of Little Sacramento gulch, where it traverses the arch of the Sheep Mountain fold, has cut down either to a very little depth or not at all into the Archean keystone of the arch; whereas the erosion of the adjoining cañons, Big Sacramento on the north and Horseshoe on the south, has cut into this body to the depth in one case of about five hundred and in the other of nearly one thousand feet. The sandstone of the Weber Grits formation overlying the Blue Limestone sweeps up on the ridges between Little and Big Sacramento gulches for a considerable distance above their junction, as is shown by numerous prospect holes. The continuity of the intervening belt of Sacramento Porphyry cannot be definitely proved, owing to considerable spaces where the outcrops are masked by surface accumulations, but is reasonably probable.

Spring Valley.—The region between Little Sacramento and Horseshoe gulches is split by a little longitudinal valley, called Spring Valley, into two low ridges, either of which is capped by Blue Limestone. Their general form can be seen in outline on the Sacramento arch sketch, Plate XV.

On the eastern slope of the northern of these two ridges is the Sacramento mine, which has obtained rich silver ores from the Blue Limestone. At the mine itself the overlying porphyry has been eroded off; but extensive outcrops, covering a very considerable superficial area, are found to the east, and are well shown in the steep rocky ravine which carries the drainage of Spring Valley into the main Sacramento gulch. The same body of porphyry is found on the southern ridge, where it rapidly thins out, overlapping a similar tongue of White Porphyry; a portion of the Weber Grits formation is included between the two. It is evident that this body of porphyry was once a continuation of the main body of Sacramento Porphyry, although it occupies a lower horizon and necessitates the supposition that in separating out at a certain horizon a portion of the main laccolite body has cut down to a lower horizon. Improbable as this may seem, it can be practically proved to have occurred on the south of the Twelve-Mile amphitheater, as shown in Section H, Atlas Sheet IX. Moreover, the thickest portion of this body is opposite the thickest portion of the main body.

Horseshoe gulch.—Perhaps the most complete and instructive series of sections, and certainly those which have the most direct bearing on the geology of the immediate vicinity of Leadville, are afforded by the erosion of Four-Mile or Horseshoe Creek. In regard to its nomenclature, local usage is somewhat perplexing. The stream itself, when it debouches on the South Park, is called Four-Mile Creek. Its main cañon is generally known as Horseshoe gulch. At its head it divides into two branches; to the northern of these has been given the name of Four-Mile amphitheater; the southern branch heads in two adjoining cirques or amphitheaters, the northern of which has received, from its strikingly regular and complete curve, the name of the Horseshoe. (See Plate XVII.)

This gulch, like those to the north, is glacier carved; but the walls are less steep, as the upturned edges of the stratified rocks have been more susceptible to subsequent abrasion, so that the talus slopes, covered with shrubs and trees, reach a considerable height. The wide gulch above the fault still has traces of lateral moraines along its sides. Where below the fault it is carved out of the Archean rocks, however, these have been carried away by later erosion, the gulch being here considerably narrower. When the valley opens out again near East Leadville and bends to the southward, although there is moraine material on the lower slopes, the form of the ridges is not sufficiently distinct to show whether they are the original moraines or consist of rearranged material. On account of the importance of the district, the sections exposed will be described at considerable length. The appearance of the surface is shown in the accompanying sketches. That given on Plate XVI shows the more prominent outcrops on the ridge forming the north wall of Horseshoe gulch, from White Ridge, on the west, to the crest of the anticlinal fold, east of the London fault.

White Ridge.—The southwest face of White Ridge, as shown in the section, is a mass of White Porphyry. On its back and north and east slopes lie strata of Weber Grits formation, whose lines of outcrop can be traced as distinctly and regularly as those on the back of the Gemini Peaks Ridge. Their dip, however, is proportionately steeper, since the distance between the porphyry body and the line of fault is shorter. This dip, as shown in the sketch, varies from 30° to 45°, the latter being the angle immediately above the White Porphyry, which to the eastward decreases gradually to 30°, and then, in close proximity to the fault line, rapidly steepens to the perpendicular. East of the fault the curves formed by the beds of the anticlinal fold over the Archean are very distinct, the partially eroded Blue Limestone forming the present crest of the ridge.

On the south end of White Ridge, in the angle at the junction of Four-Mile amphitheater with the main gulch, is a prominent outcrop of dark-blue limestone, standing at an angle of 45°, directly above the porphyry. A short distance to the west of this outcrop, at the foot of the steep slope and at intervals along the southwest side of White Ridge, on a line rising gradually as it approaches the head of Four-Mile amphitheater, prospectors with their keen natural instinct have traced the same bed under the heavy talus slopes of débris which cover it.

In the very bottom of the Four-Mile amphitheater, as shown on the map, the Blue Limestone again outcrops in the bed of the gulch, and has been developed in the important Badger Boy mine and by numerous prospect holes. On the ridges around, White Porphyry forms the surface, which is in its normal position above the Blue Limestone. The line of the Blue Limestone, traced along the face of White Ridge, is however at a considerable distance above the actual level of the Badger Boy limestone, and at a still greater distance geologically, inasmuch as the normal dip is to the east. It is therefore evident that the limestone under White Ridge has been lifted up by a fault, as shown in Section F, Atlas Sheet IX. The White Porphyry forming the mass of White Ridge is there in its normal position above the Blue Limestone, except at the south end just mentioned, where occur the prominent outcrops of dark limestone shown in the foreground of the sketch. The thickness of stratified beds exposed at this point is between 150 and 200 feet, the upper members of which have the characteristics of Blue Limestone, while toward the base are light-colored silicious beds, largely of white quartzite. Although the lithological character of the beds does not correspond in every respect with similar sections elsewhere, there is no doubt that it represents the main body of the Blue Limestone, and very probably the Parting Quartzite with a portion of the White Limestone beneath it. This heavy belt of dark limestone does not extend very far up the ridge, but gradually thins out and disappears, the sedimentary beds adjoining the porphyry at the summit of White Ridge being quartzites and micaceous shales of the Weber Grits series. It is evident, therefore, that the White Porphyry mass here cuts diagonally up across the beds, and that

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S. F. Emmons, Geologist-in-Charge.

NORTH SIDE OF HORSESHOE GULCH

the dark outcrop is simply a portion of the Blue Limestone left above it at this point, the main mass being represented by the line of Blue Limestone along the southwest base of the ridge. The thickness of the porphyry body, as represented by the distance between these outcrops, may be roughly estimated at about six hundred feet at the south end and 1,000 to 1,500 under the summit of the ridge. It seems evident, therefore, that we have here in actual outcrop a portion of the main laccolitic mass as it ascended from below across the lower Paleozoic beds and spread out above the horizon of the Blue Limestone, as is shown theoretically in Section F.

In the shales and quartzites on the northern and eastern slopes of White Ridge are numerous bodies of White Porphyry, which in the neighborhood of the summit sometimes seem to ramify and intersect the beds, but in general show a tendency to spread out between them. As it was impossible to delineate all the varying outlines of these bodies, the prevailing form alone has been shown on the map, viz, that of intrusive sheets spreading out from the main laccolitic body along the stratification planes and gradually thinning as they depart from it.

North wall of Horseshoe gulch.—The section taken along the south face of the ridge eastward from the outcrop of Blue Limestone is approximately as follows: A covered gap of about three hundred feet, containing, as is shown higher up, a bed of 50 feet of White Porphyry directly above the Blue Limestone; then about one hundred feet of shales, both calcareous and silicious, but mainly quartzite and sandstone; then a second bed of White Porphyry 50 feet in thickness, 5 feet of quartzite, and 5 feet more of White Porphyry; then varying quartzites, micaceous sandstones, and shales, above which are fine black shales, carrying pyrites and some fossils, from which were obtained the following forms:

Productus semireticulatus.
Productus muricatus=*P. longispinus* Meek.
Productus cora.
Productus costatus.
Productus pertenuis.
Griffithides, sp. undet.
Spirifer cameratus.
Spirifer, sp.?
Aviculopecten carboniferus.
Fenestella, sp. undet.
Rhombopora, sp.?
Fragments of *crinoids* and *bryozoans.*

The above succession of beds, which is taken from notes by Professor Lakes, represents approximately what has been assumed as the Weber Shale division of the Weber Grits formation, viz, the fossiliferous and more calcareous and argillaceous beds at its base. The thickness represented is somewhat greater than that observed in other sections; but the upper limits of the division are in themselves somewhat ill-defined, and the measurements obtained here are uncertain, owing to the fact that they were not observed in a continuous series of outcrops and certain beds may have been reduplicated.

From here eastward to the fault the outcrops are those of the ordinary Weber Grits, coarse white sandstone predominating, with development of micaceous sandstones passing into shales, occasional thin seams of carbonaceous shales, and a limited development of limestone beds. Variation in the strike is noticed from N. 28° W., about midway in the series, to N. 5° W., near the fault. The latter direction corresponds more nearly with the average strike of the beds near the fault, and the former may be considered to be a bowing out of the strata, caused by the intrusion of the large masses of porphyry at White Ridge and Gemini Peaks.

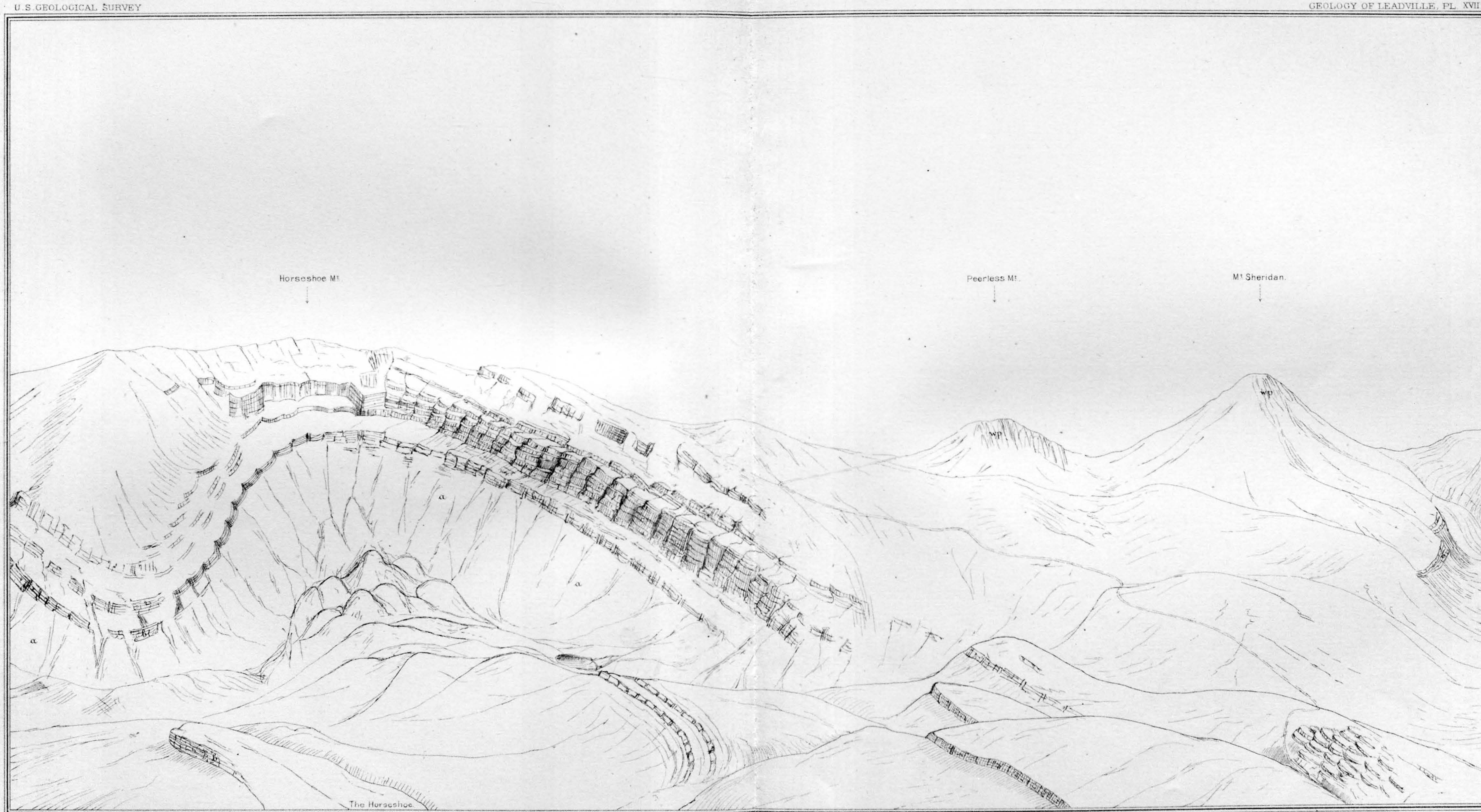
The actual fault plane is apparently exposed by a prospect hole on the low saddle overlooking the gulch, where the contact of a dense quartzite, in vertical position, with White Porphyry on the east, shows very marked slickensides surfaces and a clay seam. A little to the west of this point is a second contact of quartzite and White Porphyry, dipping 50° east. This White Porphyry may very likely be an intrusion in the beds of the Upper Coal Measure formation, as has already been assumed to be the case with a corresponding body on Pennsylvania Hill. This assumption and the fact that the thickness deduced from the angle of the dip and the transverse distance between this point and the base of the series necessitates the existence of a portion of the Upper Coal Measure beds, have been the reasons for their indication on the map and sections, since time did not admit of a sufficiently detailed examination to determine their existence on lithological and paleontological grounds. White Porphyry is found on the opposite side of the gulch, near the top of the Weber Grits formation, as will be shown later.

Directly east of the fault, which occupies a saddle in the ridge, is a considerable outcrop of White Porphyry, whose thickness may be estimated at 200 feet. Within the White Porphyry is a dark porphyry, very much altered, but similar in appearance to the Sacramento Porphyry, and which may once have been connected with the body of this rock already described above the Sacramento mine. These are succeeded by the Blue Limestone, whose beds, as shown in the section and sketch, curve up and cover, somewhat irregularly, the double-pointed ridge over the arch of the fold. From this limestone well-preserved specimens of *Spirifera Rockymontana* were obtained. In the Blue Limestone on the crest of the arch are, according to Professor Lakes, numerous vertical cracks, which may be cross fractures resulting from folding. The lithological character of the Blue Limestone varies greatly in different portions. Black chert concretions, which are as elsewhere most frequent at its summit, are also found well down in the formation. Many of the beds, especially near the base, are comparatively light-colored. No satisfactory continuous section was obtained of the lower Paleozoic beds, though the estimate of their aggregate thickness does not vary from that obtained elsewhere. At various points an included bed of White Porphyry, near the top of the Lower Quartzite, and averaging about thirty feet in thickness, was observed. The Archean is composed of gneiss and of red porphyritic granite with large orthoclase crystals.

On the eastern slope of the anticline, outcrops of beds above the Blue Limestone are exposed in the forest-covered region near the road leading from East Leadville to Spring Valley, where they are much obscured by surface accumulations, and, on the steeper slopes, by the relics of a lateral moraine. Above the Blue Limestone the White Porphyry can first be distinguished; next is an interval of coarse sandstone; then a body of Sacramento Porphyry, which apparently thins out rapidly to the southward. The White Porphyry, on the other hand, rapidly thickens in that direction, as shown by its section on the eastern slope of Sheep Mountain.

An attempt was made by Professor Lakes to obtain a continuous section from here eastward, through Fairplay, across the upper members of the Carboniferous and the overlying Triassic, Jurassic, and Cretaceous beds. The result was not very satisfactory, inasmuch as a great portion of the line of section is occupied by covered gaps, which could not be accurately filled by offsets. The thickness of the sedimentary series from the Cambrian up to the top of the Cretaceous along this line has therefore been assumed, in the ideal reconstruction of the surface, as that given by the section of the Hayden Atlas, viz, 10,000 feet. The data obtained by Professor Lakes afford no sufficient reasons for differing from this general conclusion.

Four-Mile amphitheater.—The description now turns to the exposures at the head of the gulch and along the main crest of the range from Mount Sherman to the head of Twelve-Mile Creek. The most striking of these are shown in the sketch on Plate XVII, which represents the Horseshoe and a portion of the Four-Mile amphitheater as seen from the junction of the two branches of the creek. The shapes of these two amphitheaters differ characteristically, in accordance with the differing characters of the rock out of which they have been carved. The erosion of the Four-Mile amphitheater, which has been practically parallel with the strike of the beds, has acted almost exclusively on the great mass of White Porphyry. Its slopes are generally more rounded and largely composed of talus slopes of angular fragments of this geologically brittle rock. In the bed of the stream erosion has denuded a narrow strip of the Blue Limestone, dipping 16° to the N. E. and striking N. 15° to 20° W. East of this outcrop a bed of Blue Limestone, as already mentioned, has been developed by a line of prospect holes along the face of White Ridge, whose elevation to its present relatively higher position must necessarily have been the result of faulting. Data are wanting, however, to locate definitely the line of this fault. That given on the map as the Sherman fault is determined principally from the theoretical considerations furnished by Section F, according to which it is assumed that a certain arbitrary thickness of White Porphyry exists under the Blue Limestone. The fault line would therefore have White Porphyry on either side of it, which necessarily renders its position difficult to recognize. That such a body does exist under the Blue Limestone is rendered almost certain by the fact that it is found at this horizon farther westward, along the western base of Mount Sheridan and throughout the Leadville region to the northeast of a line roughly drawn from Mount Sheridan to Fryer Hill.



Julius Bien & Co. lith.

S.F. Emmons, Geologist-in-Charge

HEAD OF FOUR-MILE CREEK.

Besides these two outcrops of limestone the only sedimentary beds observed are a lenticular body of Weber Grits at the head of the amphitheater on the south face of Mount Sherman. This body, which is several hundred feet in length and thirty or forty feet in thickness, consists of shales and sandstones, the former apparently somewhat baked and the latter changed to quartzite. It extends to within a few feet of the top of the dividing ridge between Four-Mile and Iowa amphitheaters, but does not outcrop on the wall of the latter.

The western slope of Mount Sherman, which forms the eastern wall of the Iowa amphitheater and is shown in the background of the frontispiece of this volume, consists, from the crest two-thirds way down, of a mass of White Porphyry from 1,200 to 1,500 feet thick. Separating this from the Archean in the bottom of the gulch are the lower Paleozoic series, whose beds rise to the southward as one follows the wall and curve round the west face of Mount Sheridan across the low saddle which separates it from West Sheridan. The sharp crest of Mount Sheridan and its eastern slope are covered with White Porphyry, as is also the little eminence south of it on the main ridge, called Peerless Mountain. On the saddle between the two the White Porphyry has been eroded off for a considerable distance down the east slope, and certain rather silicious beds resembling quartzite, which here form the upper portion of the Blue Limestone, have been exposed. South of Peerless Mountain the Blue Limestone is again exposed on the surface of the crest, as far as the top of Horseshoe Mountain, and also in a strip bordering the Horseshoe on the northeast. In this vicinity, especially along the western face of Peerless Mountain, the upper portion of the Blue Limestone shows evidence of considerable metamorphic action. Its outcrops are quite dark, and its upper part, as already mentioned, is very silicious and resembles quartzite. It has also a slightly brecciated structure, and in certain places is very much stained with oxides of iron and manganese. It is probable that this alteration is due to mineral waters, and is a commencement of decomposition such as has gone on in Leadville itself, though the amount of lead and silver ore as yet developed is comparatively inconsiderable. The darker color is due doubtless to oxide of manganese, and the silicification of the beds to percolating waters depositing granular silica, a form of vein material which, as will be seen later, is common in the Leadville mines and easily to be mistaken for genuine quartzite. The brecciation is doubtless due to the action of the porphyry at the time of its intrusion.

The Horseshoe.—Horseshoe Mountain, as is shown both on the map and on the sketch, is covered by a thin shell of easterly-dipping beds of the lower Paleozoic series, whose angle on the crest is about 10° and steepens to an average of 20° on the eastern slopes. The irregularity of the outcrops of the successive formations shown on the map represents the results of erosion on this thin shell.

The character of the outcrops in the Horseshoe itself is sufficiently shown in the sketch. Its peculiar form is a result of glacial erosion, which alone could have carved vertically across the inclined surfaces of hard sedimentary strata. The main body of the encircling cliffs is composed of the White Limestone and of the upper beds of the Lower Quartzite, which, owing to their peculiar weathering, received in the field the convenient name of "sandy limestones." On their weathered surface they resemble in all respects a sandstone, but a fracture of the mass shows the interior to have the compact semi-crystalline structure of limestone. The beds of Blue Limestone above these are more or less eroded off, while the pure quartzites at the base of the series are in places concealed under the talus slope of débris. In the very bottom of the amphitheater are two or three little shallow lakes or ponds of glacial origin, carved out of granite or the Lower Quartzite. Passing down the stream from the glacial amphitheater, one crosses successively an ascending series of outcrops which sweep round in graceful curves up the bounding ridge to join the beds on the crest of the range.

Intersecting these outcrops in a northeasterly direction, and in part following the line of contact between the Blue and White Limestones, is a small body of porphyrite; this and a similar outcrop in the Four-Mile Amphitheater constitute the only instances observed of the occurrence of this rock within the White Porphyry region. The rock is a grayish-brown, homogeneous-looking, fine-grained mass, showing small glistening black biotites and minute white feldspar crystals with round quartz grains. Under the microscope there seems to be no fresh feldspar substance left in the rock, although outlines of former crystals can often be plainly distinguished, the interior being replaced by a mixture of calcite and a cryptocrystalline substance, colorless in ordinary light, showing the alternations of light and dark points characteristic of a homogeneous aggregation of minute particles, probably quartz. The biotite leaves, both large and small, seem perfectly fresh and in remarkable contrast to the condition of the feldspar. From the great quantity of calcite present and the absence of muscovite or kaolin, it seems evident that the feldspar was a plagioclase rich in lime, and the rock a quartz-biotite-porphyrite, although in external appearance it is quite unlike any porphyrite observed elsewhere in the region.

The larger amphitheater at the head of the south fork of Horseshoe Creek has a less striking and regular form than the Horseshoe itself, but presents the same geological structure. From the crest of the range at its head, however, the Blue Limestone has been eroded off, and Silurian beds form the surface. These are succeeded, as one goes south along the crest to the head of Twelve-Mile amphitheater, by the Cambrian and Archean successively.

South wall of Horseshoe gulch. — On the ridge running from the crest of the range to Sheep Mountain, along the south side of Horseshoe gulch, an excellent continuous series of beds from the Archean up to near the top of the Weber Grits are shown. The north side of this ridge is most admirably delineated by a line sketch from the skillful hand of Mr. W. H. Holmes in the Hayden report for 1873.[1]

The same series of beds are here represented as were shown on the ridge north of the gulch, but they occupy nearly double the space in lineal extent along the side of the gulch; their angle of dip is consequently shallower, and midway in the series is a small synclinal fold which enables the same beds to cover a greater surface. The direct connection between the two sides is obscured by the detrital material in the gulch. It is evident, however, that the existence of a cross-fault is necessary to explain this discrepancy, since there is no evidence that the beds of the south ridge curve round to the east to join those on the north, their strike being the normal

[1] Page 230, Geological and Geographical Survey of the Territories. Washington, 1874.

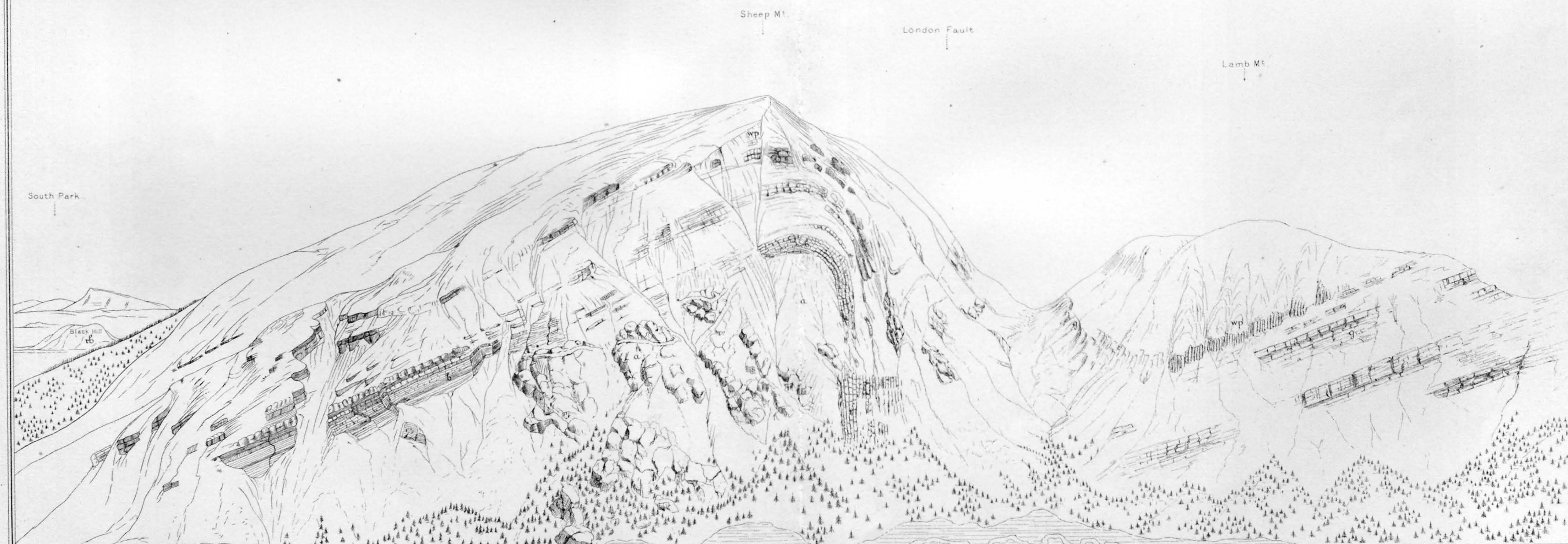
strike of the formations, N. 10° to 20° W. This fault has been assumed, therefore, to follow the bed of the gulch, and probably connects the Sherman with the London fault; its line is not given on the map, as it would be concealed by the Quaternary beds indicated in the bed of the gulch. The course of the gulch in this extent, which is unusually straight, has probably been determined by this fault.

The structure of this Sheep Mountain ridge, as deduced from careful observations made along its surface, is shown in Section G, Atlas Sheet IX. Of the White Limestone and Lower Quartzite, which are only exposed in the amphitheater south of the Horseshoe, measurements were not made, since those obtained from the exposures in the Horseshoe itself correspond with the thickness obtained elsewhere. The body of White Porphyry, which sweeps up at an angle of 20° opposite the opening of the amphitheater, has here a thickness of nearly two hundred feet, and shows a certain tendency to columnar structure at right angles to the bedding. The beds immediately above the White Porphyry contain a large proportion of shales, which, being easily disintegrated, show but few outcrops, the space occupied by them forming a saddle in the ridge. The thickness from the White Porphyry up to the more persistent sandstones and grits of the Weber series, which would correspond to the Weber Shale division, is here estimated at from two hundred to three hundred feet. The beds observed are as follows: Directly above the White Porphyry is a bed of black carbonaceous shales; from one hundred to one hundred and fifty feet above it is an outcrop of dark, impure limestone, from which were obtained a large number of fossils, among which the following were recognized:

Chonetes granulifera.
Productus cora.
Productus nodosus (variety of *Productus cora*).
Productus semireticulatus.
Myalina perattenuata.
Fragment of *Pinna*, sp.
Fragment of *Aviculopecten.*
Phillipsia, sp.
Phillipsia major.
Fragment of *Lingula*, sp.

About fifty feet above this there is a bed of black shales, from which were obtained impressions of *Lingula mytiloides*, the same form which is so abundant directly above the Blue Limestone near Leadville. For about three-fourths of a mile eastward along the crest of the ridge the beds dip regularly eastward at an angle of 20°. They consist mainly of coarse white or gray sandstones, passing into conglomerates composed largely of pebbles of white milky quartz, having a slightly pinkish tinge, and which, when weathered out, cover the surface for a great distance. Alternating with these are thinner beds of micaceous quartzite, passing into a mica-schist, the mica being always of the muscovite or potash type. Less frequent are thin seams of black carbonaceous shales. Near the upper part of this portion of the section is a single bed two feet thick of dark iron-stained limestone, seamed with carbonaceous shales. Between this and a little knob rising above the general level of the ridge is a synclinal fold in the beds, which rise on its western side at angles of from 50° to 70°. The beds included in the synclinal trough above the iron-stained bed are, first, a white quartzite conglomerate, then a brownish sandstone, then a white massive sandstone, then a second brownish sandstone with thin seams of clay and shale, and finally a green clay slate at the axis of the syncline. East of this axis the same succession of beds is passed over, which appear thinner, however, owing to their standing at a steeper angle. On the east side of the knob the iron-stained limestone reappears dipping 70° to the west, and a short distance farther can be traced somewhat indistinctly, dipping at the same angle to the eastward. Following the ridge eastward the beds assume the normal dip of 20° and have the same general character as that already described. For half a mile or more dark thin beds of quartzite and shaly beds are more frequent, but gradually pass up into massive, heavily-bedded, coarse white sandstones, whose dip shallows to about 10° or 15°. This little anticlinal and synclinal fold has the normal character of the folds in this region, viz, a steep west side to the anticline or east side to the syncline. It may also, as is often the case, be accompanied by a slight movement of displacement, but this could not be definitely proved. The synclinal structure can be traced on the broad ridge directly south of this point in the somewhat indistinct lines on its grassy surface which mark the outcrops of the beds. The fold here becomes broader and shallower, and probably soon dies out to the south.

Lamb Mountain. — Near the west end of the little prominence on the ridge called Lamb Mountain, an eruptive rock comes in above the sandstone, which weathers in large shaly blocks, with a remarkably beautiful conchoidal fracture and the peculiar sherdy habit which is common among volcanic rocks. The rock is white, slightly tinged with reddish yellow, due to minutely disseminated particles of hydrated oxide of iron. In the fresh fracture it shows a white granular homogeneous mass, with occasional grains of feldspar. It was first thought to be a later eruptive rock, probably a rhyolite, but careful microscopical study shows it to be a true White Porphyry, differing in no essential from the normal type. On Lamb Mountain, as shown in the sketch, Plate XVIII, this body has a maximum thickness of about four hundred feet at the summit of the hill, its lower limit corresponding in general with the bedding plane of the underlying sandstone. This correspondence, however, on close examination, is not absolute, inasmuch as it occupies a slightly lower horizon to the eastward, and on the north face of the ridge just west of the ravine between Lamb and Sheep Mountains it can be seen to cross the beds nearly at right angles, in the form of a dike. On the steep east side of Lamb Mountain toward the saddle are beds of slate and micaceous sandstone, curving up at an angle of 50° against the eruptive mass. In these slates were found abundant impressions of *Equisetæ*, or Horsetails, a plant characteristic of the Coal Measures. Sandstone outcrops can be traced on this saddle and across it to the base of the steep western slope of Sheep Mountain, where they soon disappear beneath the plentiful débris of White Porphyry. The White Porphyry from which they come is, as will be shown later, the body which belongs above the Blue Limestone; therefore the fault line must run very nearly at the foot of this steep western slope. That the Lamb Mountain body is itself a small laccolite, with a separate vent or channel, is evident from the fact that it ends abruptly on the east and that, while the steeply-dipping beds rest against it on the saddle east of the peak, lower down the slope of the hill the dike-like channel, which extends downward from the main mass of porphyry, is found to cross the shallow-dipping sandstone strata without perceptibly changing their angle. The steepness of the beds on the saddle might be explained by the expansion of the intrusive body of porphyry, which would push them up, but this explanation is rendered unnecessary, since, as we have already seen, the beds immediately adjoining the



Julius Bien & Co. lith.

S. F. Emmons, Geologist-in-Charge.

SHEEP M^{T} FOLD AND LONDON FAULT.

SOUTH SIDE OF HORSESHOE GULCH

fault on the west are always found to stand at a nearly vertical angle. The Lamb Mountain laccolite, it must be borne in mind, is at a higher horizon than the main sheet of White Porphyry. It may be an irregular offshoot from the White Ridge laccolite, or, as shown in Section G, simply an extrusion from the main sheet.

Sheep Mountain.— Sheep Mountain itself is an important peak, having an elevation of over two thousand feet above the bed of the gulch and forming the northern culmination of a ridge running in a nearly northwest and southeast direction, whose form is closely connected with its geological structure, since the line of fault south of Sheep Mountain follows approximately its crest. The internal structure of the peak is best exposed on the north face, a view of which is shown in Plate XVIII. The eastern slope of Sheep Mountain is a little less steep than the dip of the beds, for which reason the White Porphyry which crowns its summit is denuded over a considerable portion of the slope, and comes in again at the foot, where the slope becomes more gentle. The western side of the fold, as shown in the sketch, is very nearly vertical In point of fact, however, the angle is a little over the vertical, or, in other words, the beds dip slightly east, as shown in section G. This is not apparent, however, on the cliff, from the fact that its plane is not exactly at right angles with the axis of the fold. Here, again, as in the Sacramento arch, the series of beds when vertical appear thinner than when standing nearly horizontal; in other words, they seem to be compressed between the arch of the fold and the plane of the fault, which is not at all impossible or even improbable. Unfortunately, it could not be determined by actual measurement, as there was no continuous outcrop of the vertical beds.

A section was carefully made across the beds from the crest of the fold to the summit of the peak by Mr. Cross, from whose notes most of the following data are taken. The Archean exposures are mainly of gneiss and their bedding is comparatively distinct. As well as could be ascertained, the beds stand nearly vertical and have an east and west strike, or at right angles to the axis of the fold. Adjoining the vertical Cambrian beds was noticed a little irregular dike of White Porphyry about four feet in thickness, which comes out of the gneiss nearly parallel to the strike of the quartzite and then cuts obliquely into the latter for a short distance; it then follows the bedding-plane for a few yards, and, again cutting across the strata, disappears under the débris. The measurements were made with a pocket level, checked by observations with an aneroid barometer, taken at the base and again at the summit of the cliff; the discrepancy between the two measurements amounting to only a few feet.

Section from top of Sheep Mountain downward:

		Feet.	
	White Porphyry, 300 to 400 feet.		
Lower Carboniferous	Blue Limestone, brecciated at top, with abundant secretions of black chert	180	
	Lighter-colored limestone	20	
			200
Silurian	Parting Quartzite, fine grained, white	70	
	White Limestone, silicious at base, with white chert secretions	160	
			230
Cambrian	Red-cast beds	8	
	Shales, interbedded with "sandy limestones"	30	
	Reddish, fine-grained sandstones, with indistinct impressions	40	
	Gap	10	
	Quartzite	22	
	White Porphyry, 12 feet.		
	White contact quartzite	65	
			175
			605
Archean	Gneiss		

The total thickness here obtained of the lower Paleozoic series, which is 605 feet, is a little greater than that obtained at other points, which may possibly be due to the swelling of the beds that would naturally succeed a compression, if such exists, on the side of the fold next the fault. The contact of the White Porphyry and underlying Blue Limestone, which was here visible over a considerable distance, was carefully studied, especially on the side of the fold next the fault. The upper part of the Blue Limestone is particularly dark and full of black chert. The actual line of contact is marked by a breccia, whose character varies much. Now it is composed mainly of White Porphyry fragments, then of chert, and again of a mixture of both with black shale or limestone. Sometimes arms of the White

Porphyry penetrate the mass of limestone. On the steep southwestern slope of Sheep Mountain, overlooking Sheep Park, the brecciated surface of the Blue Limestone projects through the White Porphyry. A curious feature of this breccia is the character of its cement, which is crystallized gypsum and quite abundant here, though not noticed elsewhere. The existence of so much breccia at this point would strike the observer on first view as probably due to the action of folding and the friction occasioned by that and the displacement of the fault. Inasmuch as the same phenomena are observed, although on a lesser scale, at the contact in Leadville, where the folding action has been comparatively slight, it is probable that it was induced by a fracture of the more brittle portion of the surface of the limestone in contact with the molten intrusive mass at the time of its eruption. The fragments of porphyry in the breccia do not necessarily militate against the supposition, since the shell in immediate contact with the bounding beds might cool and harden and then be broken up by a fresh body of molten porphyry pushing over it. The gypsum cement is an evidence of the passage of sulphurous waters, which would form sulphate of lime by their contact with the underlying limestone, depositing it again in the crevices of the fragments on the surface. That it still remains here seems to be an evidence that the dissolving action of later waters has not been continued so long as in Leadville, where almost every trace of gypsum has been carried away.

On the southeast slope of Sheep Mountain, near the timber-line, are several rounded foot-hills, between which the White Porphyry and the Blue Limestone are exposed in the ravines, while the Weber sandstones form the surfaces of the intervening ridges. A number of prospect tunnels have been run in these sandstones, disclosing irregular shale formations in the beds and a local development of White Porphyry above the regular body. In one of the tunnels the end of this intrusive body is well seen, showing the beds curving around it, as in the intrusive mass of porphyrite on South Mosquito section. The average strike of the beds here is from N. to N. 10° W., and the dip from 27° to 30° eastward.

As this locality presents the most typical development of White Porphyry outside of the immediate vicinity of Leadville it may be well to describe somewhat in detail the rock as found here. That from the west face of Lamb Mountain (46), which is comparatively fresh, is a compact rock, of a light pinkish-brown color, whose only visible crystals are a few small and well-defined orthoclase individuals. No quartz is to be seen. Minute cavities lined with yellow ocher indicate a former constituent, but the forms of the cavity are not sufficiently well preserved to indicate its character. It may have been pyrite. Under the microscope the rock appears granular, with easily determinable quartz, orthoclase, plagioclase, and muscovite. There is no trace of a microscopic groundmass between the grains. Both orthoclase and plagioclase are abundant, but muscovite is less developed than is usually the case in White Porphyry; contrary to the usual rule, it is as often found forming in plagioclase as in orthoclase. With a low power, the feldspars seem full of fine dust or specks, which in many cases are evidently arranged on the cleavage plane. These specks are also seen, though less frequently, in the quartz. By the use of a higher power it is seen that some of these specks are fluid inclusions, with rapidly moving bubbles, and it is therefore probable that a sufficiently high power would prove that all are similar inclusions. No glass inclusions were found. The main rock on the northwest slope of Sheep Mountain (47) is of porphyritic appearance, owing to the large development of muscovite; otherwise it does not differ microscopically from the Lamb Mountain rock. A contact specimen of this body is so fine grained that its exact composition cannot be made out, yet it does not seem to differ essentially from the average rock. Portions of the body are perfectly white and homogeneous, and when breathed on have a strong earthy smell. The specimens examined contained little, if any, plagioclase and almost no muscovite. The body included in the Weber Grits formation (49) is exactly the same as the ordinary rock. That from the saddle between Sheep and Lamb Mountains contains even more plagioclase than the Lamb Mountain type. That from White Ridge (44), in the Four-Mile amphitheater, is extremely white and very compact, so that the constituents are mostly indistinguishable. The process of alteration from feldspar to muscovite can readily be distinguished by the naked eye.

SOUTHERN DIVISION.

The remaining portion of the eastern slopes of the range included in the map, south of Horseshoe gulch, presents but few good exposures as compared with the region already described. Its altitude is generally lower and the surface is covered with forest growth and very considerable accumulations of Quaternary gravels; still, the general outline of its structure is not difficult to seize.

Sheep Ridge.—From Sheep Mountain to Round Hill the crest of this ridge becomes gradually lower, and beyond the latter it disappears under the plain. Immediately south of the summit of Sheep Mountain is a slight depression, from which the White Porphyry has been eroded off, exposing the underlying Blue Limestone. Again, at the first prominent saddle in the ridge, Blue Limestone forms the crest and the eastern slopes, and beyond this to Warm Spring pass White Limestone outcrops along the crest, showing that the topographical slope descends more rapidly than the geological. At Warm Spring pass fragments of Red-cast beds on the crest indicate that the whole thickness of the Silurian probably comes to the surface here, although no actual outcrops of Cambrian beds could be detected. The steep western slopes of the ridge toward Sheep Creek, in this extent, are formed of easterly-dipping Weber Grits, and are therefore on the western side of the London fault. On the eastern slope the White Porphyry sheet appears to be continuous above the Blue Limestone, and at the Warm Spring pass has thinned out to 20 feet. The so-called Warm Spring furnishes a considerable flow of water, of a temperature of about 60°, from the upturned strata near the base of the Blue Limestone. South of Warm Spring pass, judging from the meager data afforded by outcrops, the geological slope becomes greater than the topographical. The Blue Limestone forms a cliff half way up the slope on the south side of the pass, and beyond this the only rocks found on the surface are those belonging to the Weber Grits; these on Round Hill have an anticlinal structure, dipping to the east, south, and west, although along its extreme western face an eastern dip is again found, which is the commencement of the slope of the beds upwards toward the crest of the main range. The explanation of the structure of this portion of the hill is that the fault movement has died out and only the fold remains.

The surface of the South Park, east of Sheep Ridge, is uniformly covered to a considerable depth by Quaternary gravels, the only outcrop of underlying beds within the limits of the map being north of the bend of Four-Mile Creek, where an anticline in the Weber Grits can be seen, a continuation of the secondary roll already noticed to the north. East of the limits of the map the approximate location of the Triassic beds is indicated by the red color of the soil, and the more resisting beds of this and the higher formations form low north and south ridges, which rib the surface of the park. With these are associated sheets of eruptive rock, probably analogous to the intrusive sheets already described. On one of these ridges was found the rhyolite tufa which is described in Appendix A.

Black Hill.—Out of the South Park plain, at the extreme southeast corner of the map, rises to a height of about 600 feet an isolated, forest-covered hill, nearly circular in shape, known as Black Hill, only the northern edge of which comes within the limits of the map. It is entirely composed of rhyolite (140). The occurrence is interesting on account of the rarity of Tertiary eruptive rocks in the region under consideration. It is noticeable that it is on a direct line with the continuation of the London fault, and that the prolongation of the same fault to the northwest would nearly pass through the other occurrences of rhyolite in Chalk Mountain, on the northern edge of the map. The whole mass of the hill is composed of rhyolite, as far as can be distinguished. The outflow has apparently taken place through the upturned sedimentary beds and spread out over their edges, without, however, exercising any very marked influence on their structure lines, as is the case with the secondary intrusive masses. The outcrops of these sedimentary beds are somewhat obscure, being mostly covered by surface accumulations, but, from their lithological character and from the succession observed along the valley of the Little Platte, south of the limits of the map, they are assumed to belong to the horizon of the Upper Coal Measure formation. On the northern base of the hill is a considerable accumulation of impure gypsum in mud shales. Directly south of the hill, along the basin of the Little Platte, quite a succession of thin-bedded clay shales, with some limestone beds, is found, standing nearly vertical and striking due north and south. In a prospect hole these shales are seen to be remarkably contorted, which is probably due to the original compression of the beds, and not dependent on the outflow of rhyolite. The lines of strike, so far as observed, run continuously through the hill, and do not curve round it. Almost the whole surface of the hill is covered with loose fragments, detached through frost and atmospheric action, but its south and southeast faces present steep cliffs. On the lower northeastern slopes of the hill are two or three large bowlders of coarse reddish granite, half buried in the soil, in company with quartzites and sandstones, which are evidently erratics and show that at one time the glacier from Twelve-Mile Creek reached down as far as this.

The rhyolite of Black Hill is remarkably uniform in general character. It has a delicate pinkish-gray color, a conchoidal fracture, and shows in the unaltered specimen white glassy feldspars, fresh black mica, and some hornblende, with prominent and rather smoky quartz in a distinctly marked groundmass. The existence of this groundmass makes a marked distinction from the rhyolite of Chalk Mountain, which is seen macroscopically to be made up entirely of crystalline elements. To the naked eye it is apparent that the quartz contains many bays of the groundmass. Under the microscope the groundmass is seen to be entirely microcrystalline, being composed mainly of quartz, with some rather cloudy feldspars. The large feldspars are plagioclase in part and contain a few gas pores and some fluid inclusions, which often carry cubes of a mineral like salt. Undoubted glass inclusions are not visible, but there are some dihexagonal in form, which are either devitrified inclusions or represent the character of the groundmass at a time prior to its complete crystallization. In decomposition the feldspars seem to tend more to a kaolin substance than to muscovite.

Twelve-Mile Creek.—In the region between Sheep Ridge and the main crest of the range are the valleys of Twelve-Mile and Sheep Creeks. The surface is covered with outcrops of Weber Grits formation, or, in its lower portion, with surface gravels, either actual moraines or rearranged drift material. At the head of Sheep Creek, near the south base of Lamb and Sheep Mountains, is a little valley or park, bounded on the north and east by steep talus slopes of débris from these peaks, and by forest-covered spurs of Weber Grits on the south and west. On the broad ridge between Horseshoe and Twelve-Mile Creeks the shallow syncline in the Weber Grits, already mentioned, can be traced as far as the Twelve-Mile gulch. It is only in the deeper cuts near the crest of the ridge that the details of structure are distinctly visible. Twelve-Mile Creek heads in four separate basins or amphitheaters, to the distinctness and grandeur of whose forms the scale of the map can do but scant justice. The exposures of Archean rocks in these amphitheaters present a great variety of gneiss and granite, the most noticeable of which have already been described in Chapter III. The deeper of these amphitheaters is that to the north, whose northern wall is capped by beds of the lower Paleozoic series, the Lower Quartzite forming, as shown on the map, the crest of the range at its head. The sheet of White Porphyry above the Blue Limestone has a broad outcrop, prominent by its white color, extending across from Horseshoe Ridge and sweeping down the wall across the mouth of the amphitheater. On the ridge between this north amphitheater and the one adjoining it, a shell of Lower Quartzite still remains at its eastern end. South of this, Paleozoic outcrops are confined to the meadows at the lower extremity of the amphitheater, where a number of springs come from them. On the south wall of the southern amphitheater the lower Paleozoic beds again sweep up for a considerable distance on the spur, the white quartzite of the Cambrian and the interbedded White Porphyry being prominent by their color. The eastern end of this ridge is formed by the continuation of the main White Porphyry body; while along its wall can be traced an offshoot from this body, cutting across the Blue Limestone and occupying the horizon between the Blue and the White Limestone. The white quartzite extends nearly up to the prominent shoulder of this spur, and is found again on the very summit of Weston's Peak, at the head of the spur. Here it lies nearly horizontal, bending over slightly on its western edge. This mass of quartzite is evidently, as shown in Section H, a remnant of the crest of the anticlinal fold, whose axis relatively to the present slope of the ground is descending to the southward. The outcrops of the sedimentary beds on the east of the axis, therefore, gradually rise along the eastern slopes of the ridge; their outlines as shown on the map present a series of regular curves, due to the erosion of the ravines which score the surface, which are distinguishable in the field from a considerable distance through the whiteness of the quartzite and of the interbedded White Porphyry. The anticlinal fold of the main crest, like that of Sheep Ridge, gradually dies out to the south of the map, and at Buffalo Peaks has entirely disappeared, being merged into a single monoclinal continuation of that to be described on South Peak.

Weston's pass.—On the steep western face of the crest, towards the valley of the Little Platte below Weston's pass, the Lower Quartzite and White Limestone beds lie at an angle of 45° to 50°, resting against the steep slope of the hill like tiles on a roof. The valley of the Little Platte presents a somewhat singular structure. At first glance it is a simple synclinal fold. On the east side are the beds of the Lower Quartzite and White Limestone dipping steeply westward, while on the west they rise with the slope of the next ridge, which from South Peak southward forms the main crest of the range. More careful examination, however, shows that the series of beds on either side of the syncline do not exactly correspond, and that the change from eastern to western dip is abrupt and not gradual, as it should be in a normal syncline. The bottom of the valley, where outcrops are visible, shows the Blue Limestone dipping eastward, and above it a thin bed of White Porphyry, succeeded higher up by sandstones and black shales of the Weber Grits formation. Through the latter, near the head of the Little Platte, and just at the boundary of the map, a branch from the northeast has cut a deep, picturesque gorge. Climbing the eastern slopes of the gorge to the main ridge, across easterly dipping Weber Shales, one comes suddenly, at the foot of the steeper slope, upon beds of White Limestone dipping steeply to the westward. It is evident, therefore, that the movement of the Weston fault has been continued somewhat beyond the boundary of the map, though it dies out before the Little Platte takes its bend to the eastward, just south of this boundary.

On the summit of Weston's pass the structure can be more clearly seen, though it is complicated here by a sudden curve in the beds which form the western member of the fold, giving them for a short distance a strike nearly east and west, instead of northwest and southeast. This pass, which has an elevation of only 11,930 feet, was formerly the main approach to Leadville from the east. Its summit is a low saddle, on the east of which the steep granite wall of Weston's Peak rises over 1,500 feet in a distance of about half a mile. At the very summit of the pass is a thin bed of White Porphyry, overlying considerable outcrops of Blue Limestone, very much metamorphosed and iron-stained, and dipping from 35° to 45° to the north and east. West of this the underlying White Limestone and Lower Quartzite sweep up, at a gradually shallowing angle, almost to the very summit of South Peak. On the eastern side of the pass black shales and quartzitic sandstones of the Weber Grits can be traced for several hundred feet up the face of the slope. These are suddenly cut off by a bed of white quartzite, standing at an angle of 70° to the westward, and succeeded on the east by granite and gneiss. Between the two is the line of the Weston fault. Following this line southward around the angle of the upper spur to the basin at the foot of Weston's Peak, the quartzite becomes steeper and finally bends over with an angle of 50° to the westward. The actual fault line cannot be traced, inasmuch as it is covered by the talus slope. The thin bed of fine-grained brown conglomerate which forms the base of the Lower Quartzite, in contact with the Archean, is, however, not to be mistaken. In the Archean itself there seems to be a tendency to a bedded structure parallel with this lower bed of the Cambrian, and, moreover, a sort of actual passage from sedimentary into crystalline rocks, as shown by an increasing development of well-defined crystalline feldspars. These transition beds pass into a peculiar granite of yellowish-red color. It belongs to the coarsely crystalline type, and apparently owes its color to the hydration of the oxide of iron, which gives the flesh-colored tint to the orthoclase of the normal granite of the region.

South Peak ridge.—From Weston's pass southward the South Peak ridge, which follows approximately the direction of the major strike of the formations, viz, S. 20° to 30° E., constitutes the main crest of the range. The summit of this ridge and its eastern slopes are covered with a thin shell of Lower Quartzite beds, whose dip, quite gentle on top of the ridge, steepens to 45° on the eastern spurs. Archean exposures cover the whole western slope of the range south of Weston's pass and are disclosed in the deeper cañon cuts on the east side by erosion of the overlying quartzites.

From Weston's pass to the north base of Buffalo Peaks, a distance of about 10 miles, the upper valleys of the Little Platte and of Rough-and-Tumbling Creek form a continuous line of depression parallel to this ridge. These two streams bend to the eastward and flow together at the southern end of the Weston's Peak ridge, where the anticlinal fold dies out as the ridge disappears under the plain. It is here that the geological structure of the range changes from a double anticlinal to a single monoclinal ridge, a change which is shown in the varying strikes and dips of the low hills at the junction of these streams. Along upper Rough-and-Tumbling Creek the Paleozoic beds all dip eastward in apparent conformity, though with some variation of angle, and continue their regular southeast strike, not only close up to the base of the Buffalo Peaks mass, but apparently beyond it, without any sensible change of direction. It would appear, therefore, that the flows of andesitic lava, of which these peaks consist, have been poured out through the upturned strata and spread out across their edges, covering thus a geological horizon extending from the Archean up to the Upper Carboniferous, or possibly the Trias, in marked contrast to the manner in which the intrusive sheets of the earlier eruptives have been formed.[1]

Western slopes.—From Weston's gulch southward beyond the limits of the area mapped, the western slopes of the range are composed of Archean rocks, among which granite is very prominent. There are doubtless many eruptive dikes cutting through them in this area besides those of White Porphyry at the mouth of Granite Creek, represented on the map, but time did not admit of a sufficiently detailed examination to determine their outlines and location.

Weston's gulch, below the junction of its two heads or forks, which run with the strike of the formations northeast and southwest, is a straight narrow gorge cut out of Archean granite and gneiss. Its form suggests partial glacier carving, but later erosion has removed all traces of moraine material except a few erratics. Below this narrow gorge it passes into an open country, occupied by partially eroded terraces of the Quaternary Lake

[1] A more detailed description of the Buffalo Peak region will be found in Bulletin No. 1, United States Geological Survey, Washington, 1883.

beds, which will be described later. The Archean area, with its covering of Lake beds on the lower spurs, extends north as far as Empire gulch, but beyond that line it no longer outcrops, except where brought to the surface by faulting and erosion in the deep amphitheaters near the crest of the range.

Weston fault.—From Weston's pass northwestward the Weston fault follows the foot of the steep western slope of the main crest of the range, approximately parallel to and a little east of the valley bottoms of the two forks of Weston's Creek. East of it are Archean exposures, capped, either on the crest of the range or on its eastern slopes, by easterly dipping Paleozoic beds. To the west is a fringe of successive outcrops of the same beds, also dipping regularly eastward, whose varying outlines, as shown on the map, are entirely due to the relative depth of erosion of the various gulches Were the structural conditions studied on a single transverse line in this area they would be naturally supposed to be those of a simple monoclinal fault; but the unmistakable evidence of the synclinal fold, as already described on Weston's pass, and the conditions found on Empire Hill, which will be described below, show that before erosion had removed it there must have been a fold somewhat as indicated by the dotted lines in Section G, Atlas Sheet IX. From the pass down the south branch of Weston's Creek nearly to the forks, the Lower Quartzite extends up the west slopes of the valley, while the Blue Limestone forms a decided shoulder on the eastern slopes; the White Porphyry body, which is only about twenty feet thick at the pass, thickens to the northward and by its white color forms a prominent feature in the landscape.

Just above the forks the north branch of Weston's Creek runs in a narrow ravine, in which the dip of the beds is somewhat steeper than in the south branch, which may be explained by its proximity to the fault line. On the northwest side of this ravine the Paleozoic beds sweep up on a broad flat shoulder, which forms the southern continuation of Empire Hill, gradually assuming a shallower dip as they extend farther westward.

Empire Hill.—This name is given to the upper part of the spur between Weston's and Empire gulches and the broad shoulder or secondary ridge lying between the branches of these gulches and the head of Union gulch.

Along the steeper western face of this shoulder the Cambrian and Silurian outcrops rest on the Archean, and the top of the shoulder is at the contact of the Blue Limestone and overlying White Porphyry, which has been quite extensively prospected, without, however, disclosing any considerable ore bodies.

At the head of the north branch of Weston's gulch the ridge which separates it from Empire gulch presents a steep slope to the southward, which affords a good section of a series of limestones, shales, and sandstones in a thickness of from 300 to 600 feet, belonging to the Upper Coal Measures, from which the following fossils were obtained:

Archæocidaris, sp. undet.
Polypora, sp. undet.
Fenestella perelegans.
Synocladia, sp. undet.
Rhombopora lepidodendroides.
Palæschara, sp. undet.
Streptorynchus crassus.
Chonetes granulifera.
Productus costatus.
Macrocheilus ventricosus.
Phillipsia, sp. undet.
Productus Nebrascensis.
Chonetes glabra.
Spirifera Rockymontana.
Athyris subtilita.
Productus Prattenanus.
Nucula, sp. undet.
Astartella, sp. undet.

Section F, Atlas Sheet IX, which passes through the ridge, shows the structural conditions which prevail here. Where these beds join the fault they stand quite vertical and give evidence of having been subjected to great pressure, as shown in the specimen represented in Fig. 2, Plate V (page 60); but at a little distance from the fault it can be seen that near the top of the ridge they gradually bend over to the westward, until a few hundred yards west they assume the normal dip of 20° to the eastward. Below these, both on the ridge and in geological succession, are the sandstones of the Weber Grits, which form the mass of a low rounded hill. Along the western face of this hill, and immediately above the White Porphyry, is a considerable thickness of compact black argillaceous shale, impregnated with pyrites. This black shale has been opened in several places by prospect holes, and from it were obtained numerous casts of fossils, in which the calcareous matter of the original shell has been entirely replaced by very minute crystals of iron pyrites, so minute that the form of the shell is still distinctly visible in those which are newly opened, though they rapidly decompose on exposure to the air. The contrast of the glittering yellow of the pyrite with its dull-black background of shale is extremely beautiful. This bed of black shale represents the base of the Weber Shale formation. From it were obtained the following forms:

Discina Meeki.
Orthis carbonaria.
Chonetes granulifera.
Streptorhynchus crassus.
Aviculopecten rectilaterarius.

Below the black shales is the main sheet of White Porphyry in considerable thickness, succeeded by the Blue Limestone which forms the eastern edge of the spur or shoulder, while the White Limestone and underlying quartzite can be traced along the steep slopes below. The series is here, therefore, complete from the Lower Quartzite up to the Upper Coal Measure; and, even had the fossils obtained in the latter not been found, the existence of such considerable thicknesses of limestone above the Weber Grits would have been enough to determine their horizon. The gradual passage observed from the shallow dip of 20° to the vertical dip adjoining the fault is proved by actual observation and furnishes an analogy for the vertical dips already observed at the London fault. The fault line itself is exposed in a tunnel and is exceptionally distinct on the ridge, its direction being here N. 25° to 30° W.; the adjoining rock on the east is a coarse-grained granite and on the west shales and grits. Where opened, the fault shows slickensides and a considerable development of clay selvage, with a fine breccia of very dark color, the result of friction. In the granite adjoining the fault there is visible decomposition for some ten or fifteen feet, consisting in a partial kaolinization of the feldspars and a hydration of whatever oxides of iron it contains, which is evidently due to the action of waters which have followed the plane of the fault.

In the basin at the head of the north fork of Weston's gulch, only a few feet east of the line of the fault and apparently parallel with it, is a vein of quartz in granite, some six or eight feet in thickness, which can be traced up the wall of the ridge. In the first saddle of the ridge above Empire Hill is a dike of White Porphyry about twenty feet thick, in the vicinity of which the granite is decomposed in a manner similar to that near the Weston fault. This saddle is on a line with the fault which runs between Sheridan and West Sheridan, and although at this point, owing to the fact that granite is on either side and the surface is largely disintegrated, the fault could not be visibly distinguished, it is supposed that the Sheridan fault crosses this saddle to connect with the Weston fault. The White Porphyry dike would thus at first glance seem to be due to an eruption which had taken place along the plane of an already existing fault; but the evidence obtained elsewhere all goes to show that the time of eruption of the White Porphyry was entirely antecedent to the action of faulting; and it is therefore more probable that the White Porphyry dike had followed a line of weakness or possible fracture, which in the subsequent dynamic movements would have been more susceptible to faulting than other portions of the formation.

Between the head of Union gulch and Empire gulch, below the steeper slope of Empire Hill, is a triangular area in which are relics of the lower Paleozoic series, with included porphyries, which have been folded and faulted in an extremely intricate manner. A simple expression of their structure is shown in Section E, in which it is seen that at the foot of the steep slope of Empire Hill a second fault has cut off a portion of a synclinal basin. The upper member in the trough of the syncline is the White Porphyry, immediately overlying the Blue Limestone. A shaft has penetrated this porphyry into the Blue Limestone below. On the east of the syncline the beds dip 25° to the westward, while on the west side they dip at an average of 10° to the eastward. The southern extremity of the fault is seen near the forks at the head of the north branch of Union gulch, where a little patch of Lower Quartzite rests against the fault, with granite on either side.

Here occurs a singular eruption, apparently in the form of an interrupted dike, of a rock whose lithological characters ally it to the Tertiary eruptives. It has been colored on the map as a rhyolite, though it might more strictly be classed as a quartziferous trachyte. It is a rather fine-grained grayish rock, of thoroughly trachytic texture, whose most prominent elements are small glistening hexagonal leaves of biotite; a few rounded grains of quartz are also visible, and the rest of the rock is made up of small, rather glassy grains of feldspar. Between the crystalline elements is an ill-defined groundmass of gray color. The rock has included fragments of quartzite. Parts of the groundmass are truly microfelsitic, and in some places undoubted glass substance is present. The rock also contains fragments of another eruptive rock, in some respects resembling the Gray Porphyry, and in whose cryptocrystalline groundmass are numerous aggregates of tridymite.

From the head of Union gulch northward, on the west of the syncline, the outcrops of Lower Quartzite and White Limestone grow wider, owing to shallowing dip, till they are cut off by the valley of Empire gulch, and are succeeded on the west by the underlying granite. On either side of the syncline the Blue Limestone forms prominent outcrops or ridges. On the north end of the syncline, toward the ravine which runs down to a little lake adjoining the meadow of Empire gulch, is a small body of Gray Porphyry, apparently occurring between the Blue and the White Limestone. Following the line of the fault northward from the head of Union gulch, the Lower Quartzite, White Limestone, and Blue Limestone are found successively in contact with the granite; and finally the White Porphyry almost touches it. Farther north the series is reversed, until in the bed of the ravine at the foot of the north end of Empire Hill granite is exposed on either side of the fault. There is here an anticlinal fold whose axis corresponds with the major strike and from whose crest the sedimentary series have been removed down to the Lower Quartzite. Continued north, the line of the axis of this anticline nearly corresponds with the Mike fault, which is first seen on the north wall of Empire gulch and which will be described in detail in the chapter devoted to the vicinity of Leadville.[1]

Union fault, which thus far has followed the foot of the steep slope of Empire Hill, now cuts across the northwest spur of this hill, and beyond Empire gulch, after crossing Long and Derry Hill, joins Weston fault. The displacement of this fault, like that of most of the faults of the region, is an upthrow to the east. Consequently in ascending the steep northwest spur of Empire Hill from the meadows in Empire gulch or from the anticline above mentioned, one crosses a double series of easterly-dipping lower

[1] By an error of the engraver, overlooked in proof-reading, the line of Mike fault has been carried across Empire gulch to a connection with Union fault, following what was intended to be simply the dividing line between the Cambrian and Silurian formations.

Paleozoic beds. At the foot of the steep slope, between the Lower Quartzite and the White Limestone, is a small body of eruptive rock whose outcrops are so obscure that its structural relations could not be accurately determined. It is a fine-grained, nearly white rock, with minute specks of biotite and small white feldspars macroscopically visible as porphyritic constituents. Microscopical and chemical examinations show it to be an orthoclastic rock, containing 68 per cent. of silica. Glass inclusions occur in both quartz and feldspar, but no fluid inclusions. It has been classed as a rhyolite and is chiefly interesting on account of its isolated occurrence and want of resemblance to any other rocks found in the region.

Empire gulch. — Empire gulch is one of the glacier-carved valleys of the western slope of the range. At its head is a grand amphitheater cut out of granite and gneiss, with a rim of sedimentary strata and intrusive porphyry sheets crowning its wall. Two faults theoretically cross its upper portion — the Sheridan fault and the Mosquito fault—which, however, are not visible in its Archean bed, as there is no distinction in the character of the rock on either side to mark their position. At the Weston fault, however, the Lower Quartzite occurs in the bed of the gulch, with an eastern dip, and its outcrops sweep up the wall on either side; these outcrops are partially masked by two very well defined lateral moraines which border the immediate bottom of the valley.

On the south side of the gulch, in the basin inclosed by the north arm of Empire Hill, is a shallow glacier lake, dammed up by one of these moraines. In this basin prospect holes prove the existence of black shales and overlying Weber Grits above the lake, while below it is the Blue Limestone, succeeded by the White Limestone and Lower Quartzite, the line of the Union fault being marked by the sudden appearance of White Porphyry, which adjoins either of these two formations. Above the White Porphyry, on the steep slope at the north point of Empire Hill, immediately west of the fault, is a little remnant of Weber Shale.

The moraine ridges terminate about a mile below this north point of Empire Hill. Here the valley of Empire gulch opens out into a broad alluvial meadow, below which it is cut mainly out of Quaternary Lake beds, and consequently loses the distinctive form due to glacial erosion. The succession of beds crossed in descending the ridge from the north point of Empire Hill to this meadow is sufficiently indicated on the map.

On the north side of the gulch the structure is even more complicated than on the south, and the rock surface is more obscured by morainal and other detrital material. Were it not for the numerous prospect holes this structure could hardly have been unraveled. It is shown in much more detail on the large map of Leadville and vicinity, and its description is reserved for the chapter which treats of that region.

Leaving aside then, for the moment, the region included within the limits of this map, the crest of the range and that portion of its western slope not included therein will next be described.

Main crest north of Ptarmigan Peak.—At Ptarmigan Peak and for some distance north the entire ridge is composed of Archean, in which granite and coarse porphyritic gneiss are the main components; thence north to Horseshoe Mountain successive shells of Lower Quartzite, White Limestone, Parting Quartzite, and Blue Limestone form the crest. Round the head of Empire gulch their outcrops form a semicircular rim, sweeping round the western point of Mount Sheridan, while the crest of the ridge is covered by the main body of White Porphyry. Under Peerless Mountain a second body of White Porphyry comes in between the Blue and White Limestones, and extends as far north as the base of Dyer Mountain, where it seems to pass down to successively lower horizons, until in Dyer amphitheater it is found quite at the base of the lower Paleozoic series. Remnants of this second body of White Porphyry form the cap-rock on the western spur of Mount Sheridan, known as West Sheridan, whose mass, by the slight movement of displacement of Sheridan fault which runs through the saddle separating these two peaks, has been let down relatively to the mass of Mount Sheridan itself; in other words, its upthrow is to the eastward. This rather singular fault passes partly across the head of Iowa Amphitheater, where it is joined by a fault at right angles to it, or running nearly east and west; as the result of their movement, a little segment of beds of the Lower Quartzite, White Limestone, and overlying White Porphyry is left in the bed of the gulch at the entrance to the north branch of this amphitheater, their northern and eastern continuations being found near the top of the adjoining cliffs.

Lake beds.—From a little south of the mouth of Weston's gulch north to the valley of the East Arkansas, the gently-sloping, flat-topped, lower spurs of the range are formed of the Lake bed deposits already described. Actual outcrops of these are only found in the southern portion of this region, as in the neighborhood of Leadville they are covered by rearranged moraine material, which has received the local name of "Wash." The best opportunities for observing these within the area of the map are on a narrow ridge south of Little Union gulch and along the south wall of Lower Empire gulch. At the former locality is exposed a thickness of 300 feet of outcropping beds sloping regularly 3° to the westward, which is also the slope of the adjoining mesa-like ridges. They consist of gravel and coarse sand, alternating with beds containing large subangular or partially rounded fragments of the various rocks which make up the higher portions of the range. On the top of the ridge facing lower Empire gulch they have been opened by prospect holes, and show a conglomerate with lime cement overlying a bed of granite sand, with one iron-stained streak between. Here the dip is still 3° to the westward, but in the bed of Empire gulch, where the stream is deflected from its course by a knob of Archean granite projecting about 150 feet above the valley, they are found to have a dip of 15° to the northeast, showing that there has been some local movement since they were deposited. There are several outlying patches of these beds left high up on the spurs in the region shown on the Leadville map. Since the presence of the beds within this area could only be proved by underground workings, the outlines there given are necessarily somewhat hypothetical, and may be subject to change when they shall have been pierced by shafts at other localities. The highest points at which their existence has been proved in this area are on the western slopes of Long and Derry and Printer Boy Hills, respectively, where they extend up to the 11,000-foot curve. This is just 1,000 feet above the outcrops between Little Union and Empire gulches, and higher than the dip of 3°, already a very considerable inclination for an average angle of deposition over a large area, would carry them; this, taken in connection with the observed angle of 15°, leads to the inference that the mountain mass has been elevated to some degree above the Arkansas Valley since the beds were deposited.

NORTHWESTERN DIVISION.

The northwestern division comprises the area west of the Mosquito fault and north of the area of the Leadville map. It is a region which is comparatively unbroken by faults, and from its lower elevation one in which the structure lines are more difficult to read, owing to want of continuity in the outcrops. Between this and the area last described lies the complicated region represented on the Leadville map, which will be treated in the following chapter. Its broad general features, so far as are necessary for the comprehension of what follows, may be given in a few words. The sedimentary beds, within which was an enormous development of eruptive rocks, largely in the form of intrusive sheets, have by the force of contraction been com ressed into a series of anticlinal and synclinal folds, and broken by tiansverse fractures or faults, only two of which extend out to any considerable distance beyond this area, viz, the Weston fault on the south and the Mosquito fault on the north, which are practically part of one great displacement. As shown on the western ends of Sections D and E, by these faults the area is broken into blocks, which have been successively lifted one above the other toward the crest of the range. These faults have in general some definite relation to the axis of the folds, and as they pass northward merge into them. Thus out of the six faults represented on Section E two have already disappeared before reaching the line of Section D, and on the line of Section C, which passes through Prospect Mountain along the northern edge of the Leadville map, the structure has simplified itself into two broad anticlines, with an included syncline, and there is no visible fault west of the Mosquito fault.

Prospect Mountain.—The surface of the massive of Prospect Mountain, which lies between Big Evans and Bird's Eye gulches and extends from the Mosquito fault to the east fork of the Arkansas, is covered to a considerable depth by broken masses of porphyry and of sandstones and schists of the Weber formation, so that but few outcrops are found. Fortunately there are many prospect holes, showing the character of the rock beneath the covering of débris, by means of which the general outlines of its structure can be determined. These are shown in Section C, Atlas Sheet VIII, and in Section K, Atlas Sheet X, the former of which follows the crest of the ridge in an east and west direction, while the latter crosses it in a northwest direction. From these it is seen that from the summit of Prospect Mountain eastward to the Mosquito fault the surface is occupied by beds of the Weber formation, with a general easterly dip. They are crossed by a few dike-like masses of eruptive rocks, the most prominent of which are two dikes on the crest of the ridge: the one a coarse-grained quartz-porphyry, with large crystals of orthoclase, which resembles a Gray Porphyry; the other a fine-grained micaceous rock resembling a diorite, but yet containing a large proportion of orthoclastic feldspar. The latter rock also occurs on the north slope of the massive near the head of Indiana gulch, and in an important body at the mouth of Bird's Eye gulch where it debouches into the East Arkansas Valley. West of the summit of Prospect Mountain, however, the slopes toward the adjoining valleys are very steep and cut through the Weber beds, disclosing a somewhat complicated anticline, or rather the intersection of two systems of anticlines, and the development of a large body of porphyry found only in this mountain and on Mount Zion, which is separated from it by the deep cut of the East Arkansas Valley. This porphyry, which has already been described as a more crystalline variety of the White Porphyry and which is designated by the color of that rock on the map, is called, from the locality of its principal development, Mount Zion Porphyry.

Mount Zion Porphyry.—This porphyry is exposed in great thickness under the Weber Grits on Mount Zion and on the northeast slope of Prospect Mountain; it is also denuded at the head of the north fork of Little Evans by the deep erosion of the gulch. It apparently replaces in part the main sheet of Gray Porphyry, which directly underlies the Weber Grits to the north and south of it and thins out as the former grows thicker. For this reason it has been indicated on the sections as a rapidly thickening sheet, though it is not at all improbable that it may be a laccolitic body, like those of White Ridge and Gemini Peaks, and have its vent, or channel through which it came up, somewhere under Prospect Mountain. It varies much in external appearance: in its most unaltered form, as obtained at a depth of 200 feet in the Hattie bore-hole, it resembles a fine-grained granite or granite-porphyry, while in the extreme of alteration, as found in some of the shafts on the southwest slope of Prospect Mountain, it is hardly to be distinguished from decomposed White Porphyry. It differs microscopically from the fine-grained granites by the absence of microcline and by the presence of prismatic microlites of plagioclase with rounded ends, which are particularly abundant in the quartz and orthoclase.

The structure of the southern slopes of Prospect Mountain, which is somewhat complicated, is described in detail in Chapter V, and the relations of the White and Mount Zion Porphyries are shown on the map of Leadville and vicinity, where they have distinct colors. The outcrops of the thin sheet of the former and of the underlying Blue Limestone, which occur along the East Arkansas Valley at the foot of Prospect Mountain, are only proved by prospect holes, the actual rock surface being buried under débris slopes.

Mount Zion.—The mountain mass of Mount Zion and its southwestern shoulder, known as Little Zion, presents a somewhat similar structure to Prospect Mountain, of which it originally formed a part, and shows better outcrops by which to trace its geological structure. Towards the valley of the East Arkansas, on the southeast face of Little Zion, are fine cliff sections showing an arch of Archean, over which the Paleozoic beds and included sheets of porphyry are folded, with a steep dip to the northeast and a more gentle one to the southwest. Along the south face of Little Zion the Blue Limestone outcrops can be distinctly traced, gradually descending the hill with a southeast dip until, opposite the brewery in the Arkansas Valley, they come down to the level of the flood plain and furnish raw material to several lime-kilns. At the western extremity of the Little Zion Ridge, beyond the limits of the map and opposite the junction of the East fork with the Tennessee fork of the Arkansas, is a little hill of granite, which is remarkable as being the only place where direct evidence is afforded of any considerable inequalities in the Paleozoic ocean bottom.

In every other case where the junction of the Paleozoic outcrops with the Archean has been observed, practically the same bed of quartzite has been found at the contact. In this case, however, on the saddle east of this little hill, the White Limestone is found to abut against the granite, while the Lower Quartzite sweeps around its northwest and southwest slopes, showing that this point projected as a submerged island above the level of the Cambrian beds at the time of their deposition. In the bed of the stream opposite this saddle the Lower Quartzite beds are exposed in a little cañon gorge, with a strike of N. 30° E., and dipping 20° to the southeast under the Lake beds which cover the spurs up to the steeper slope of the hills near Leadville.

The valley above has alluvial meadows, with flood-plain benches on either side. In these benches on the northwest side is the Dugan quarry, whence limestone was formerly taken as a flux for the Leadville smelters. Higher up the valley, where the beds bend up over the arch of Archean, a careful measurement was made of the cliff-exposures at two points, which, in descending order, are as follows:

1. *Cliffs back of toll-gate.*

		Feet.	
	White Porphyry	?	
Lower Carboniferous	Quartzite and shale	25	
	Blue Limestone, with chert at top and bottom and with breccia at the base	125	
			150
Silurian	Sandstone, eroded, with limestone breccia in eroded hollows	15	
	Space covered	15	
	Bluish limestone	8	
	White Limestone, bluish at base	66	
	Sandy limestone	28	
	White calcareous quartzite	22	
	Reddish sandy limestones	27	
	Limestone, gray at top, white at bottom	40	
			221

Débris slopes to valley bottom.

2. *Section across arch of Archean.*

Cambrian	Débris slopes above cliff.	
	Saccharoidal quartzite, white and thin-bedded	60
	Saccharoidal quartzite, like above, but stained and discolored	60
	Coarse quartzite, with fragments of feldspar	1
		121

Archean................Red granite; upper beds very much decomposed; red feldspars turned yellow by hydration of iron oxide; 250 feet to base of cliffs.

The White Limestone seems relatively thicker and the Blue Limestone thinner than usual. The evidence of erosion on the sandstone underlying the latter, which consists in hollows and ridges two or three feet in depth or height filled by a limestone breccia, is important as indicating a land surface at the close of the Silurian. Unfortunately this was the only point at which it was detected, so that it cannot be said with certainty that the land elevation at that time was very widespread, although the apparent absence of Devonian beds is indirect evidence that it was, as is also the great variation observed in the thickness of the upper member of the Silurian, the Parting Quartzite.

The White Porphyry above the Blue Limestone has a maximum thickness of about fifty feet on the west point of Little Zion and rapidly wedges out to the north and east It has the usual appearance of the normal rock, but the fresh-looking hexagonal crystals of dark mica are rather more abundant than usual, for which reason they were separated and analyzed, and found to be muscovite instead of biotite, with which determination their optical properties agree. (See Appendix B, Table I, Anal. II.) Above this is the Gray Porphyry, which readily disintegrates and crumbles into coarse sand, and therefore can be traced along the west slope of Mount Zion by the gentle slope which it forms at the foot of the steeper slope of Mount Zion Porphyry above it. It has here a thickness of about 100 to 150 feet, which increases to the northward; it evidently connects with the immense sheets of Eagle River Porphyry at the northern limits of the map. The Mount Zion Porphyry has a thickness of about 800 feet on the crest of the ridge, but rapidly wedges out to the north. In its upper part, near the summit of Mount Zion, is an included sheet, about one hundred feet thick, of sandstones and shales of the Weber formation, which can be traced down the south slopes to the East Arkansas Valley.

Tennessee Park.— From Little Zion northward the Lower Quartzite beds form a flat shoulder along the lower slopes of Mount Zion facing Tennessee Park for a distance of several miles. Below this shoulder the steeper slopes, scored by shallow ravines, are in the granite of the Archean, while above are successively White Limestone, Blue Limestone, and Gray Porphyry, with Weber Grits capping the whole and covering all the hills to the east and north. Between No Name and Tennessee gulches there is a discrepancy in the outcrops of the lower beds, which can only be explained by a fault, approximately as shown on the map, by which their northern continuation is thrown more to the westward. All these western slopes are thickly covered with timber, and it is not always possible to determine accurately the outlines of the formations. Tennessee gulch heads on the western slopes of Buckeye Peak and, flowing first westward past Cooper's Hill, takes a bend to the southward, afterwards bending again westward into the open valley of Tennessee Park, beyond the limits of the map, where it joins the main branch of the Arkansas, which descends from the slopes of Homestake Peak. Between the south bend of Tennessee gulch and the main Tennessee Valley, just west of the map, is a low ridge of granite, gradually covered, as one goes north, by nearly horizontal beds of Lower Quartzite. These beds can be traced across Tennessee pass westward to the northern flanks of the Sawatch Range, where they cover the spurs extending northwards to the valley of Eagle River.

Along the western borders of the map northwards from Tennessee gulch a fringe of outcrops of lower Paleozoic beds follow the foot of Cooper's Hill and cross the upper valley of Piney Creek, which flows into Eagle River through Tennessee pass. The body of Gray or Eagle River Porphyry overlying the Blue Limestone becomes very much thicker in this region, and on the slopes of Buckeye Hill rises in horizon, leaving a portion of the Weber Grits formation, consisting of shaly beds, beneath it. On El Capitan Creek there is also a portion of the Weber Grits included in the body of porphyry. On Taylor Hill, north of the head of Piney Creek and just beyond the extreme northwestern corner of the map, is the El Capitan mine, which is of interest as being the only considerable ore deposit thus far developed in this region at the Blue Limestone contact. In the Weber Grits, which form the surface rocks from Piney Creek eastward across Chicago Ridge to Chalk Mountain, as shown in Section A, are numerous bodies of porphyry, which doubtless originate in an immense laccolitic body which occurs just north of the limits of the map, near the head of Eagle River, and on a line with Chicago Ridge.

East Arkansas Valley.—The flood-plain deposit, which forms benches on either side of the alluvial bottom of the east fork of the Arkansas, extends up a little distance beyond Howland post office, above the lower bend. Under this no rock outcrops are visible. The south wall of the valley, formed by the slopes of Prospect Mountain, is mostly covered by débris, but the north wall on the Mount Zion side has cliff-faces and abundant outcrops. Above the arch of Archean, already described, the successive beds of the lower Paleozoic series, the Gray and Mount Zion Porphyries, and the thin bed of Weber Grits included in the latter descend into the valley at a steep angle. The dip of the beds rapidly flattens out, however, as one ascends the valley, and near the mouth of Buckeye gulch the Weber Grits have become nearly horizontal.

Between Buckeye gulch and the bend of the valley below Howland an important body of Lincoln Porphyry, with characteristic large orthoclase feldspars, comes in, which can be traced up the valley wall for a distance of two miles, apparently conformable with the bounding beds of Weber Grits. A similar body exists on the east side of the valley, extending from the mouth of Bird's Eye gulch up to a terminal moraine ridge half way between Howland and Chalk ranch. It would seem that these two outcrops are parts of the same great sheet of porphyry, though their connection across the valley is not very distinct. The prevailing dip of the inclosing sandstones is generally to the southeast. On the ridge between Arkansas Valley and Buckeye gulch this dip is quite pronounced and in places as steep as 45°. Towards its north end the eastern body forms a prominent hill, called the Dome, with a steep face toward the valley, which shows a tendency to columnar structure. The porphyry body is here much thicker than at any other point, and it is not improbable that this is the laccolite from which the rest of the body has spread out. The rock of this porphyry mass (72) is a fresh-looking, light-gray rock, containing large pinkish crystals of orthoclase, abundant quartz (showing generally a crystalline form), and small hexagonal leaves of biotite. The groundmass is gray and subordinate to the crystalline constituents in quantity. Under the microscope it is seen that nearly half of the smaller feldspars are triclinic and much altered, while the larger ones are comparatively fresh. This porphyry is as nearly the equivalent of the Lincoln as of the Eagle River type, and is one link in the chain of evidence showing that all these allied types constitute one large group. (See Appendix A.)

At the base of the Dome is an outcrop of quartzite dipping to the southeast, which rises as one follows the cliff southward. In the little ravine next south is a second body of porphyry, separated from the main sheet by quartzites and shales through which it penetrates somewhat irregularly; it may be an offshoot from the main body, though it differs somewhat lithologically and is moreover impregnated with secondary pyrite; as it is very much decomposed, its character cannot be definitely determined. At the mouth of Bird's Eye gulch the porphyry body has risen to a considerable height on the ridge; while below it, between the mouth of Bird's Eye gulch and Indiana gulch, is a body of the finer-grained dioritic-looking porphyry already mentioned, which crosses over into the bed of Indiana gulch higher up, in the direction of the dike of the same rock on Prospect Mountain Ridge.

The slopes of Mosquito Range between Bird's Eye and English gulches, east of the porphyry body, are mostly made up of sandstones and occasional beds of black shale of the Weber Grits formation, whose prevailing dip is 10° to 15° a little to the south of east. On the summit of the ridge between the head of Bird's Eye gulch and the Arkansas Valley, however, the beds have a shallow dip to the west, giving evidence of a slight synclinal roll, as has been indicated in Section B.

On the west face of the ridge separating the head of Bird's Eye gulch from that of English gulch is an outcrop of limestone, which is probably one of the beds that occur in the middle of the Weber Grits series. Associated with this is a porphyry different from those hitherto described, and characterized by small feldspar crystals of a deep purplish-red color. This and a decomposed green mineral, which are its only porphyritic components, lie in a light-green groundmass. Under the microscope the green mineral is seen to be altered to chlorite, so that its original condition cannot be determined, though it was probably biotite. The coloring matter of the feldspar is a reddish substance in small flakes, possibly oxide of iron. From the limestone outcrop eastward to the Mosquito fault the ridge is made up of coarse white sandstones, having a gentle easterly dip. Beyond the fault line the steeper slopes of the range are made up of fine-grained granite, which resembles an eruptive granite. In this about half way up the slope is an irregular dike of porphyrite.

At the mouth of English gulch, just north of the Dome, are several bodies of porphyry, and the structure of the sedimentary beds is extremely irregular, the dip being rather to the northeast or away from the porphyry mass, while on the ridge between English and French gulches the beds dip to the west and southwest, giving further evidence of the synclinal fold shown in Section B.

In the lower portion of French gulch the south and west dips still continue, and several small bodies of limestone are found between beds of quartzite or altered sandstone. About a mile up the gulch, at the Mountain Lion claim, is a body of diorite of blue-gray color and largely impregnated with pyrites. It has a thoroughly granitic texture and shows macroscopic crystals of feldspar, hornblende, biotite, and quartz. At the head of the gulch easterly dips again come in; but these change again to the west before the fault line at the foot of Mount Arkansas is reached, showing a second syncline, which may be a continuation of the syncline adjoining the fault that is so well developed at the north edge of the map, though the general strike of that fold would carry it to the west of this. On the divide between the head of French gulch and the Arkansas was observed a body of Lincoln Porphyry, opened by a prospect hole to a depth of twenty feet or more, which is so thoroughly disintegrated that when cut down by a pick it crumbles in the hand.

Buckeye Peak.—On the west of East Arkansas Valley, between it and Eagle River, is a broad-topped mountain mass, whose highest point is Buckeye Peak, at the head of the gulch of the same name. To this peak, on the Hayden map, no name is given, but a minor point of the ridge to the north is called Mount Arkansas—a name which has been given by the miners, with more propriety, to the prominent peak west of the Arkansas amphitheater; this transfer of the latter name has therefore been adopted on the present map. On the south face of Buckeye Peak, forming the wall of its amphitheater in a height of nearly 1,000 feet, is exposed a great mass of Eagle River Porphyry, whose prominent vertical cleavage planes and joints give the appearance of columnar structure observed on the summit of Mount Lincoln. On the débris-covered slopes and grassy ridges its outlines could not be traced with perfect accuracy, but it seems probable that it is a laccolite body, from which the other irregular bodies of the same rock in the vicinity may be offshoots. It is somewhat lighter colored than the porphyry observed in the Arkansas Valley, and under the microscope shows no glass inclusions, but otherwise is identical with that rock. A dike-like offshoot from the body extends to the west along the ridge at the head of Tennessee gulch. To the south the beds of the Weber Grits formation seem to dip away from it for a short distance and then resume their southeasterly dip. Above it, on the summit of the peak, these beds lie nearly horizontal. On the eastern base of the peak, at the head of the spur which runs down between Buckeye gulch and the Arkansas, is a small outcrop of decomposed porphyry, so white that it might be taken for Nevadite or White Porphyry. Microscopical examination, however, shows that it is probably a portion of the Eagle River Porphyry body. Across the northern ridge of Buckeye Peak runs a dike-like mass of porphyry about 200 feet in thickness, which can be traced almost continuously down the bed of Delmonico gulch in a steep wall, through which the present stream has cut a steep, narrow bed. Its outcrops are obscured by moraine material. This gulch, as well as the other main gulches which radiate out from Buckeye Peak, bears evidence of having been once filled by a minor glacier, both in the fact that relics of moraines can be found along its sides and in that its slope is not such a continuous one as would result from the erosion of running water, but is comparatively gentle for a considerable distance from the head and then descends abruptly into the valley of the Arkansas.

Along the western slopes of Buckeye Peak, as already mentioned, are two principal bodies of quartz-porphyry, apparently interstratified in the Weber Grits, which extend northward beyond the limits of the map. East of these are several irregular bodies of the same rock, whose outlines are given on the map with tolerable accuracy. They are probably connected in origin with the large laccolitic mass of Eagle River Porphyry which lies just beyond the border of the map to the north. They are in part interstratified, but little satisfactory evidence was obtained bearing upon their underground extension. In the basin between Chalk Mountain and Chicago Ridge, whose waters drain into Eagle River, a synclinal fold can be distinctly traced, which basins up to the southward. Its outlines are well marked by an interbedded sheet of Eagle River Porphyry. The inclination of the fold is comparatively shallow on the west, though in some places dips of as high as 25° are observed; while on the east the angle is still steeper, as shown in Section A, Atlas Sheet VIII. In its trough above the porphyry is a small bed of limestone.

Chalk Mountain.—From the head of the straight north and south portion of Arkansas Valley projects a singular ridge, like a huge railway embankment, prominent by its brilliant white color in the somber surrounding of pine trees. From the material of which it is composed and which, in the fact that it is soft and white, has a certain resemblance to chalk, the person who first settled at its base gave to his home the name of Chalk Ranch. At this point the Arkansas Valley bends sharply to the eastward and its level rises abruptly 100 feet or more; while the direct northern continuation of the valley below is formed by a still more elevated valley, the bed of a little stream known as Chalk Creek, which a short distance above Chalk Ranch falls in a picturesque cascade from the upper valley level into a deep narrow basin and flows in a narrow gorge to join the Arkansas just below the ranch. The Denver and Rio Grande narrow-gauge railway, in order to gain grade enough to overcome this sudden elevation of the valley level, climbs gradually along the western wall of the Arkansas Valley, reaching the gorge a few feet below the falls, and then curves sharply to the east, spanning the chasm with a picturesque bridge, and, emerging through a 66-foot cut in the ridge beyond, reaches the south slopes of Chalk Mountain completely above the Chalk Ridge.

Between the valley of Chalk Creek on the west, the Arkansas Valley on the south, and the head of Ten-Mile Creek on the east, is a table-topped mountain of rudely triangular shape, presenting steep escarpments to the south and east. This low mountain mass, which forms part of the continental divide, is also formed of a very light-colored eruptive rock, and has from this fact received the name Chalk Mountain. Both the rock of Chalk Mountain and that of the white ridge below are rhyolite, but of somewhat different types. The former is coarse in texture, and, though seen to be distinctly porphyritic when closely examined, it seems in some cases almost granitic in structure. It is of the variety known as "Nevadite." Upon the southern and northwestern edges of the plateau of Chalk Mountain the surface is strewn with huge blocks of Nevadite, in which the large sanidine crystals, with their brilliant satiny luster, and the dark smoky quartz crystals are especially noticeable. Over the remainder of the surface the rock is somewhat finer grained, the quartz crystals being the most prominent constituent.

The rock of Chalk Mountain is different from that of all the neighboring bodies, not only in the character of its constituents, but in the time and manner of its eruption. It has disturbed the adjacent strata to an extent not noticed in connection with any other eruptive of the region, and by cutting off bodies of Eagle River and other porphyries its later age is proven. The masses of débris upon the steep southern slopes cover its contact with the sedimentaries, but upon the east, north, and west numerous outcrops appear, which illustrate the disturbing influence of the Nevadite mass. The map shows an arm of the Weber Grits projecting up the eastern slope to the level of the plateau, and in these elevated beds is a dike of older quartz-porphyry, cut off to the west by Nevadite. Fig. 1 of Plate XIX shows this relation in detail. The strike of the beds is indicated by the lining on the sketch, and the easterly dip measures about 70° at the extremity of this arm, declining to 30° at the edge of the cliff. South of this arm is another small area of quartzites, which seem to be entirely inclosed by the Nevadite. Farther north, upon the eastern side of the body, the strata are much disturbed and show varying strikes and dips, and upon the northern slopes, within the Ten-Mile district, the strike of the Weber beds is found to be east to west, with a northerly dip of 80° near the Nevadite, which lessens to 25° at a distance of half a mile. At the northwest corner of the mass, just beyond the line of the map, the eastern extension of the Eagle River Porphyry sheet shown in the synclinal fold is found to be cut through by the Nevadite. Along the western contact steep westerly dips are found in the sedimentary beds, and several thin sheets of Eagle River Porphyry seem to be cut by it, but the relations are not clear. A branch of Chalk Creek cuts deeply into the Nevadite and testifies to the thickness of the body upon this side.

Three of the smaller outlying bodies of rhyolite are apparent offshoots from the Chalk Mountain mass, but the rock of Chalk Ridge is of another type, allied closely to the body shown in the synclinal fold on the north line of the map east of Ten-Mile Creek. This rock is fine grained, showing only a few quartz grains and minute feldspars, and disintegrates readily into a gravel-like mixture. The outcrop of Chalk Ridge is only a few hundred yards in length, forming a sharp point between the mouth of Chalk Creek and the Arkansas. Above it are sedimentary beds, dipping at a shallow angle to the north and east and inclosing thin beds of Eagle River Porphyry.

Opposite Chalk Ridge, on the west bank of the creek, a white rock is disclosed in a little tunnel, which at first glance might be mistaken for rhyolite, but which on close examination proves to be simply altered Weber sandstone, composed of limpid grains of quartz, white muscovite, and kaolinized feldspar. In the gorge of Chalk Creek the first outcrops above the Chalk Ridge are thinly-bedded limestones and shales. Higher up, where the chasm is spanned by the railway bridge, are sandstones and quartzites, with intrusive bodies of porphyry, generally interbedded, but also crossing the strata. In the railroad cut on the eastern side of this gorge a section is exposed, showing one of these intrusive masses crossing transversely the beds and spreading out above. Figs. 2 and 3, Plate XIX, represent sketches taken on the spot at the time when the cut was freshly

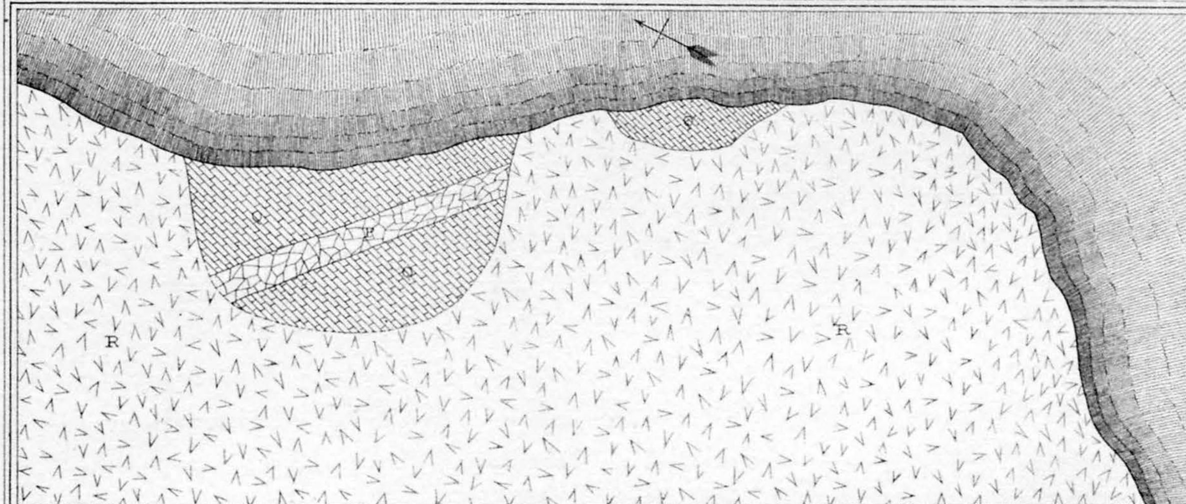


FIG. I. PLAN OF EASTERN EDGE OF MOUNTAIN. SHOWING QUARTZITE AND PORPHYRY DIKE ENCLOSED IN RHYOLITE
R. RHYOLITE Q. QUARTZITE. P. PORPHYRY.

FIG. II. NORTH SIDE OF R.R. CUT AT SOUTH END OF CHALK M^T. SHOWING PORPHYRY CUTTING THROUGH SANDSTONE.

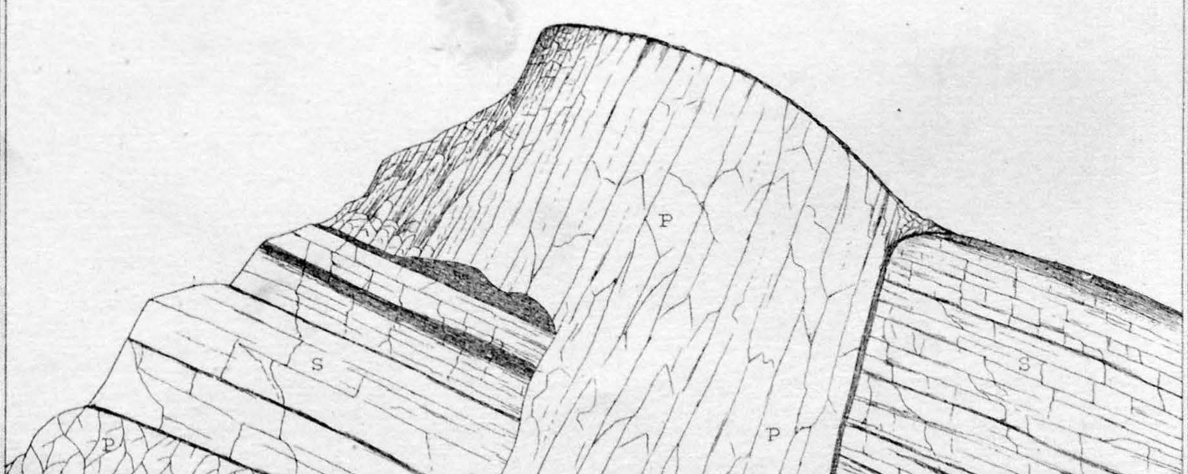


FIG. III. SAME CUT. SOUTH SIDE. P. PORPHYRY S. SANDSTONE Sh SHALE.

Julius Bien & Co. lith. S.F. Emmons, Geologist-in-Charge.

RHYOLITE AND PORPHYRY

CHALK MOUNTAIN

made. The porphyries exposed here are quartz-porphyries, not closely allied to any particular type; but on the slope of the hill about one hundred yards above the cut is an outcrop of lavender-colored rock, which in its fresh fracture shows characteristic features of the Eagle River Porphyry. In the railway-cut on the western side of the gorge both sandstones and porphyries are thoroughly decomposed, but it can be seen that the latter both spread out between and cut across the beds. On the spur which extends from Chalk Ranch up to the Buckeye Peak ridge the sedimentary beds dip conformably to the northeast at an angle of 20° to 25°. This dip continues across the creek and up to the Nevadite at the southwest extremity of Chalk Mountain, the disturbance produced by it being slight at this point. A blue-gray limestone 6 feet thick is seen in the third railway-cut east of Chalk Ranch, where it has an apparent northwesterly dip. On the eastern side of the Arkansas Valley, just below and also a little above Chalk Ranch, the beds dip 45° to the west and southwest. The evidences thus afforded in regard to the structure of the sedimentary formations in this region are not very satisfactory, showing simply that the beds are much broken up and indicating that the influence of the intrusive Nevadite mass has not been felt beyond narrow limits.

Upper Ten-Mile Valley.—The remaining area of sedimentary rocks is embraced between Chalk Mountain on the west, the Arkansas Valley on the south, and the Mosquito fault on the east. Through it passes the continental divide, separating the waters of the Ten-Mile from those of the Arkansas. The low, wooded Frémont's Pass has an elevation above sea-level of 11,350 feet, and over it passes the Blue River branch of the Denver and Rio Grande Railroad, the steep rise of 500 feet from the Arkansas Valley being overcome by means of a long loop, as shown by the map. Ten-Mile Creek has its head in a small rugged amphitheater in the Archean, just east of the Mosquito fault, whence it flows directly west to the base of Chalk Mountain, then turns abruptly northwest, and soon after passing the limits of the map bends to the north and then to the northeast. The gentle slopes near the creek are wooded, and outcrops are rare until the neighborhood of the great Mosquito fault is reached.

The geological structure of this small area is the expression of the ending of the great synclinal fold which is the predominant feature in the structure of the Ten-Mile district on the north. The beds taking part in this fold basin up to the southward, as they pass within the limits of the Mosquito map. In the central part of the fold occur strata of the Upper Coal Measures, the highest horizon represented west of the Mosquito fault within the limits of this map. Forming the dividing line between the Weber Grits and the Upper Coal Measures is the Robinson Limestone, the tracing out of which gave the key to the structure represented. Above the Robinson Limestone is an intrusive sheet of quartz-porphyry, which has also been folded, and thus assists in bringing out the basin-like form of this fold. The observed dips upon the western and southern sides of the basin vary from 25° to 60°, the strike curving as shown upon the map. Upon the east the proximity of the great fault has somewhat complicated matters and the strata dip very steeply westward. Section A A, Atlas Sheet VIII, represents the relations at this point. The intrusive quartz-porphyry mentioned does not resemble the Chalk Mountain Nevadite, and yet it is a coarsely porphyritic rock, whose prominent constituents are large sanidine-like feldspars and well-formed quartzes, and whose general habit is that of a comparatively recent rock. The facts that on the one hand this body appears as an intrusive sheet which has been folded and that on the other it is cut by a rhyolite of the type occurring in Chalk Ridge have led to its classification as a quartz-porphyry. In the center of this fold are several minor bodies of rhyolite, of quartz-porphyry, and of a hornblendic porphyrite. These rocks, as well as the fold in which they occur, are much more important features in the geology of the Ten-Mile district, and the further discussion of their relations will be reserved for the report upon that region.

Mosquito fault.—The line of the Mosquito fault is well defined along the base of the steep slope of Bartlett Mountain by the abrupt transition from sedimentary to crystalline rocks; but farther south, where it crosses the opening of the Ten-Mile amphitheater and the valley of the Arkansas, owing to the covered nature of the surface, its exact location is difficult to determine.

At the foot of the steep western slope of Bartlett Mountain, and on the very northern edge of the map, a small cliff-face of rock juts out from the débris slopes east of the fault line. Its material is a silicious rock, more or less iron-stained and of somewhat cherty nature, in some places honeycombed and porous like the quartzite knob adjoining the London fault on Pennsylvania Hill. Its structure lines, though somewhat indistinct, appear to indicate a vertical dip in the stratification, and among the fragments at the upper part of the cliff are some of limestone, resembling the base of the White Limestone. All this material is too much metamorphosed to permit of an absolute identification of its original character, but it evidently belongs neither to the Archean on the east side of the fault, nor to the Upper Coal Measure beds on the west. It is fair to assume, therefore, that it represents a portion of the Cambrian and, possibly, of the Silurian beds belonging to the steep western side of the fold, which once arched over the top of Bartlett Mountain (as indicated by the dotted line in Section A), and which, by the friction and pressure that accompanied the displacement of the Mosquito fault, have been compressed and metamorphosed until they are no longer recognizable. Further evidence in favor of this view is found on Little Bartlett Mountain, a continuation of the Bartlett Mountain ridge just beyond the limits of the map, upon which a fragment of Cambrian beds, consisting of characteristic saccharoidal quartzite, is found capping the summit and extending part way down the western slope, with a dip of 45° to the northwest. They end in a little cliff a few hundred feet above the fault line, on which the contact with the underlying granite is well exposed; a bedding parallel to that of the quartzite can be traced for some distance into the granite, with an apparent arrangement of the feldspars in layers parallel to this bedding. The actual contact consists of the usual fine-grained conglomerate, with small rounded pebbles of limpid quartz. The quartzite at the summit of Little Bartlett Mountain alternates with Lincoln Porphyry in such manner as to make it probable that the latter is a relic of an interbedded intrusive sheet.

Arkansas amphitheater.—In the Arkansas amphitheater, remarkable for its semicircular form and magnificently steep eastern walls, which rise 1,500 to 2,500 feet above the stream bed, the débris in its bottom gives evidence of a very large development of eruptive dikes, among which hornblende-porphyrites and biotite-porphyrites play an important part. Nearly all the larger masses of this rock contain numerous rounded fragments of Archean schists, gneiss, and granite. One of the most prominent features is a body of porphyrite, near the summit of the eastern wall of the amphitheater, which can be traced continuously from below as a dark horizontal line. Near the head it sends down a branch across the cliffs to the bottom; and what is probably a continuation of the upper branch was observed, as already mentioned, in Buckskin amphitheater, on the southeast side of Democrat Mountain. In the bottom of the amphitheater, near its head, is a remarkable dike of porphyrite, from 20 to 50 feet wide, which has a straight northeast and southwest course and cuts through the narrow wall separating this from the amphitheater at the head of English gulch. The main body of the dike is a fine-grained, dark-colored rock, more or less impregnated with pyrites. Irregularly contained within its mass is a second body of darker shade, characterized by inclusions of rounded orthoclase pebbles and large crystals or rounded grains of quartz. A specimen of this singular rock is shown in Plate VII (p. 86). It is evidently a later eruption within the mass of the previously existing dike. Both rocks and their relations are described in Appendix A.

In the Archean rocks here exposed are found all the types previously described, and from a face of rock at the head of the amphitheater was made the sketch, which is shown in Fig. 1, Plate IV (p. 52), to illustrate the relative ages of the different varieties, normal mica-gneiss being the oldest, which is penetrated by the even-grained eruptive granite, and this again in its turn crossed by veins of white pegmatite. There are evidences of extensive mineralization, but no ore bodies have been sufficiently opened to afford an opportunity for systematic study. Parallel with the dike in the bed of the creek, at the head of the amphitheater, was observed a deposit of galena, following the wall of one of the larger pegmatite veins.

In the mass of Mount Arkansas are many eruptive bodies which could not be traced out, although their existence was shown by the numerous fragments in the débris. On a northern spur of the mountain two dikes were seen, one of a quartz-porphyry, allied to the Lincoln type, the other a hornblende-biotite-porphyrite.

Ten-Mile and Clinton amphitheaters.—The Archean types represented in the area embracing these basins are as varied as those which have already been described from the adjacent region to the east and south. In Clinton amphitheater there is an unusually large amount of the rudely porphyritic granite referred to earlier in this chapter, and in both are numerous dikes of eruptive rocks, among which the Lincoln Porphyry and a dark hornblendic porphyrite are the most frequent. These bodies cannot be indicated upon the map with satisfactory accuracy, and are for the most part omitted. A rhyolitic rock of coarse grain in Ten-Mile amphitheater seems more closely related to the Chalk Mountain Nevadite than to any other.

Bartlett Mountain, which separates the two amphitheaters, has a dike of dark-green porphyrite running through its summit and down into the Ten-Mile basin. Upon the western slopes of this mountain are large masses of white quartz which might at first glance be considered as derived from a remnant of the Cambrian strata left on the east side of the Mosquito fault, but they are quite homogeneous and have no trace of the granular or sandy structure which is found even in the most glassy quartzites; they were probably derived from some of the vein-like masses of quartz which are found developed on a large scale in the Archean of other parts of the Rocky Mountains, and which have been removed by erosion. Abundant evidences of glaciation exist in these as in other amphitheaters which have been described.

CHAPTER V.

DESCRIPTIVE GEOLOGY OF LEADVILLE AND VICINITY.

GENERAL STRUCTURE.

The central region of the general map is, as has already been seen, the region of the greatest dynamic as well as eruptive action. A section across the range at Leadville shows, as the result of dynamic action, five anticlinal folds and six principal faults. On the east side of the range, as already seen, the structure is relatively simple. The beds sloping back to the eastward are broken by one main anticlinal fold and its accompanying fault, the London fault. On the west of the crest, however, instead of one main fault, as in the regions north and south, the continuity of the beds is broken up by six principal and several minor faults.

The map of Leadville and vicinity (Atlas Sheets XIII and XIV) shows the most important features of the geology of that region. Its eastern border extends to within two or three miles of the main crest, which consists of Archean rocks capped by easterly dipping Paleozoic beds and intrusive porphyries. For a better comprehension of the description which follows, the reader is requested to refer constantly to this map and its accompanying sections. He will there see that its area is divided into a series of irregular zones or blocks by the lines of six principal faults having a general north and south direction. For purposes of description these have received the following names, commencing on the east: 1, Mosquito fault; 2, Ball Mountain fault; 3, Weston fault; 4, Mike fault, with a branch called Pilot fault; 5, Iron fault; 6, Carbonate fault, with a branch called Pendery fault. Besides these there are the following minor and cross faults: 1, on the southern edge of the map, the Iowa gulch cross-fault, which connects the Weston and Ball Mountain faults; 2, the Union cross-fault, which extends from the head of Union gulch across upper Long and Derry Hill and joins Weston fault in the bed of Iowa gulch; 3, the Colorado Prince fault, north of Breece Hill, a diagonal cross-fault approximately parallel to South Evans gulch, which connects Ball Mountain and Weston faults; 4, on the west slope of Breece Hill another cross-fault, the Breece fault, running nearly east and west, joining the northern end of Mike fault with Weston fault; 5, a little farther west the Adelaide cross-fault, which connects Iron and Mike faults; 6, at California gulch the southern continuation of Iron fault is formed by three different faults: Dome fault, connected with Iron fault by the California cross-fault, following the line of the gulch, and Emmett fault, which connects California fault with Iron fault. Pilot fault, already mentioned, is a short north and south fault, crossing California gulch above Mike fault, running across the west end of Printer Boy Hill, and joining Mike fault in Iowa gulch. The Pendery fault, already mentioned, and the South Dyer fault, a cross-fault running eastward from the Mosquito fault along the south slopes of Dyer Mountain, raise to seventeen the total number of faults represented on the map.

In ground broken by such a complicated network of fractures and subjected since to the enormous erosion which is shown to have taken place in this region, it is extremely difficult even for a trained geologist to reconstruct ideally the original folds into which the sedimentary beds and their included sheets of porphyry were once compressed. As, however, the action of faulting was so intimately connected with that of folding and the displacements in many cases pass into simple folds, it is essential, in order to obtain a clear idea of the relative position of the different beds below the surface and the depths at which they may be found, that one should be able to reconstruct in his mind the original folds, and then figure to himself the faulting action which has brought the beds into the discordant juxtaposition in which they are now found on the surface, as shown on the map. For this purpose the general structure along certain east and west lines will be first described, and after that the present condition of the surface and the underground structure, as revealed by shafts in each zone or block of ground included between the principal fault-lines, will be described in detail. The three cross-sections of the general map which cross the area of the Leadville map will serve perhaps best to show the general outlines of structure.

In Section E, Atlas Sheet IX, which is drawn approximately through the middle of the map, and which may, therefore, be considered as a type-section, the effect of displacement is more prominent than that of folding. Its line runs through the southern edge of the town of Leadville itself, across Carbonate, Iron, and Breece Hills, passing just north of the crests of Ball Mountain and of East Ball Mountain to the summit of West Dyer Mountain. Along this line, going from west eastward, the following are the main features of folding: In the region under Leadville, or from the western edge of the map to the Carbonate fault, a shallow syncline; under Carbonate Hill, or from Carbonate to the Iron fault, a second shallow syncline; and from Iron Hill eastward, a third; in all of which the prevailing dip is eastward, only a small portion of the easterly edge of the basin having a westerly dip. In the region between Iron Hill and Ball Mountain, or, in other words, on the western slope of Ball Mountain, the surface is so uniformly covered with Pyritiferous Porphyry that there is no direct evidence of any folding, although a slight anticlinal fold might be expected near the line of the Pilot fault, from the fact that one exists on its strike both north and south. At Ball Mountain is a sharp anticlinal fold, and east of that the beds slope back in a monocline to the eastward. The effect of displacement produced by the faults has been to lift each successive block of ground up to the east of the fault, except in the case of a wedge-shaped portion included between the Mike and Pilot faults, in which there has been a slight downward movement.

On an east and west line south of this (Section I I, Atlas Sheets XIX and XX), the beds of Blue Limestone would be first met about due south of the summit of Carbonate Hill, sloping east in a shallow synclinal basin and rising again in an anticline whose axis corresponds to the southern continuation of the Dome fault. The crest of this fold having been planed off by erosion, the contact would be wanting for something over half a mile, and be found at the head of Thompson gulch dipping to the eastward, but rising gently as it approached the continuation of the Mike fault. The ground east of this fault having been lifted up, the Blue Limestone has been in part removed by erosion and would next be found at the Long and Derry mine, sloping again eastward as far as Union fault. Beyond this fault it has again been removed by erosion, a little remnant only being found above the White Porphyry in the uplifted portion adjoining the Weston fault. Between this and the Mosquito fault is the arch of an anticlinal fold on which only Lower Quartzite is left. Beyond the Mosquito fault erosion has cut down to the Archean rocks, the Blue Limestone being next found on the western face of Mount Sheridan, along either of whose sides it may be traced, sloping back to the crest of the main ridge.

On the line of the section north of the first described (Section D, Atlas Sheet VIII), which passes through Fryer and Yankee Hills, the faulting action is less prominent, owing to the fact that many of the faults have in their northern continuation merged into folds. On the north of Leadville, extending from the western limit of the map to the eastern edge of the town, is the same broad syncline noticed in the first section. From here to the western edge of Fryer Hill is a short anticline, from whose crest the Blue Limestone has been planed off. It is succeeded by a shallow synclinal fold under the western half of Fryer Hill, followed by a short anticline at its crest, while in the gulch back or east of the hill is found the rim of a deep synclinal basin which passes under Little Stray Horse Park. At the west foot of Yankee Hill the ore-bearing horizon rises to the surface and descends to the eastward again just beyond the summit of this hill, the crest of the intervening anticlinal fold, into which the northern continuation of the Iron fault merges, having been eroded off. From this point the strata descend to the eastward, rising in a gentle wave near the Great Hope mine, but not reaching the surface, and then sloping again eastward until they rise on the South Evans anticline or are cut off by Weston fault. East of Weston fault, in the region around the mouth of South Evans gulch, is another anticline or quaquaversal fold, whose summit has been worn away, leaving the outcrops of succeeding beds in a series of concentric rings. On the east of this fold the beds slope continuously to the eastward at angles of from 15° to 20°, a conformable series, extending high up into the Weber Grits, being still left uneroded on the summit of Little Ellen Hill.

In Section C, Atlas Sheet VIII, which follows nearly the northern boundary of the map, the faults have apparently all been eliminated, and the outlines of formations shown on the map owe their form entirely to folding and erosion. One broad anticline under the west slope of Prospect Mountain and a shallow syncline in the Arkansas Valley express the broader general features of folding. Near this line, at the mouth of the east fork of the Arkansas, are found the westernmost actual exposures of Paleozoic rocks within the area surveyed. These consist of beds belonging to the Lower Quartzite formation, exposed in the bed of the stream and in the cliffs south of it, dipping to the southeast. They constitute the most definite evidence of the synclinal basin supposed to underlie the town of Leadville.

DISTRIBUTION OF PORPHYRY BODIES.

Before proceeding to the detailed description of this region it will be well to give a brief outline of the distribution of the various porphyry bodies, which form so important an element in its structure and have had so great an influence upon its ore deposition. It is first to be observed that the features of this distribution have a certain uniformity along northwest and southeast lines in approximate parallelism with the line of major strike of the sedimentary beds. As by far the greater portion of these bodies are in the form of sheets either actually or approximately conformable with the bedding of the inclosing sedimentary rocks, in cases where explorations were insufficient to determine whether they were sheets or transverse dikes the former has been assumed to be the case in drawing the ideal portion of the various sections, and dikes have been indicated only when actual explorations have proved that they were coming up directly from below. It may readily happen, therefore, in the case of imperfectly explored bodies, that future explorations may show the latter form to be more common than has been indicated in the sections.

White Porphyry.—The most important of these bodies is the White Porphyry, which is generally found as a sheet immediately overlying the Blue

Limestone. As it forms the surface rock over a great part of the area, and has hence been subjected to considerable erosion, it is impossible to determine its maximum thickness. Its original extent to the southwest is also completely unknown, since it, together with the inclosing sedimentary beds, has been entirely eroded off from this portion of the area. Along a certain zone, moreover, it occurs below as well as above the Blue Limestone. This lower body is connected with the upper or main sheet along a line running diagonally through the south edge of Fryer Hill, in a southeast direction, toward upper Long and Derry Hill and West Sheridan, to the northeast of which there are two sheets of porphyry, and to the southwest only one. On this line, which is rather a zone than a line and can, in the nature of things, be only approximately determined, it is found that there is a cross-cutting sheet of porphyry connecting the two sheets to the northeast with the one sheet to the southwest, and the Blue Limestone is in consequence found to be split into wedge-shaped and partially-overlapping bodies. The greatest development of White Porphyry appears to be a little southwest of this zone of cross-cutting, on a line passing through Carbonate, Iron, Printer Boy, and Long and Derry Hills, where it attains in places a possible thickness of 1,000 feet. To the northeast of this zone both sheets thin out rapidly, the lower one before reaching a line running through the forks of Little Evans and along the general course of South Evans gulch, and the upper one at a little distance beyond this line. Along a line running N. 50° W. from the saddle east of Ball Mountain to the East Arkansas Valley, at the foot of Canterbury Hill, this upper sheet is entirely wanting for short distances, coming in again, however, northeast of that line.

Besides these two main sheets there is a very considerable development of White Porphyry along a southeast zone, passing just east of the crest of Ball Mountain, where it occurs in the White Limestone and extends down to the contact of the Archean. It is a significant fact that in this zone it has been proved in two instances to be cutting up through the Archean, in the one case in South Evans gulch, near its mouth, and again on the north side of Iowa amphitheater.

Gray Porphyry.—Next to the White Porphyry the most important body is the main sheet of Gray Porphyry, which, northeast of the Fryer Hill–Sheridan line, is found directly over the upper sheet of White Porphyry in very considerable thickness. How great this thickness may have been there is no direct means of determining, since, except on Prospect Mountain (where no shafts have been sunk to any great depth), no sedimentary rock remains above it to give its upper limits. Its greatest observed thickness is 420 feet in the Independent shaft. What was the original extent to the southward of this Gray Porphyry sheet before any portion of it had been removed by erosion, there is also no means of determining. At present it extends but little beyond the median line of the map. Its source must probably be looked for to the northward, beyond the limits of the map, since in that direction it passes into Lincoln or Eagle River Porphyry, of which it seems to be merely a decomposed variety.

Pyritiferous Porphyry.—Next in importance in point of superficial extent, and possibly of greater importance in its bearing on the ore deposits of the region, is the Pyritiferous Porphyry. The main sheet of this porphyry, which covers the lower slopes of Breece Hill, seems to be a stratigraphical replacer of the Gray Porphyry, which however, along the line of the Breece fault, it overlaps. It may therefore be supposed to have been in point of time a later intrusion. As is shown in Section G, one of the vents, and possibly the sole vent, probably existed beneath California gulch Its extent to the north and east could not have been much greater than at present. To the south and west, however, it may have covered a considerably larger area immediately above the White Porphyry. Of the upper sheets in the Weber Grits no opinion can be formed, so completely has all trace of this formation been removed by erosion. It is perhaps fair to assume that it extended to the south as far as the present crest of Long and Derry Ridge, and to the westward over Iron Hill, and, possibly, as far as Carbonate Hill.

Other porphyries.—Of the other bodies of porphyry, the most important in their bearing upon the ore deposition of the region are those which are essentially of the same rock as the main sheet of Gray Porphyry, though having no apparent connection with it. The most extensive sheet of this rock is found under Iron and Carbonate Hills, near the base of the Blue Limestone, and cutting up across this horizon to the westward; various irregular, dike-like bodies found in the different mines are, doubtless, offshoots from this sheet. A small sheet is found above the Blue Limestone on Iron and Dome Hills. A large body, probably coming up from below, occurs on the southeast face of Yankee Hill, extending across Adelaide Park. Several small sheets are found in the White Limestone on the north end of Iron Hill and in California gulch, and three well-developed dikes cross Printer Boy and Long and Derry Hills.

On the northwest slope of Printer Boy Hill the Printer Boy Porphyry forms an important mass; in Iowa gulch is the Green Porphyry, under the White Limestone; and on Long and Derry Ridge, the Josephine Porphyry, above the Blue Limestone. Mount Zion Porphyry, which is closely allied to the White Porphyry, forms a body of great thickness in the Weber Grits on Prospect Mountain, and is found also in Evans gulch, but seems to be simply a local occurrence which reaches its greatest development beyond the limits of the map, and has apparently had little or no influence upon the ore deposits of the district.

In what follows will be given in detail the various facts upon which the geological deductions represented on the map and sections have been founded, which will probably prove of interest only to those who wish to verify these deductions on the ground or examine into their soundness. For convenience of description the region will be divided into the areas naturally blocked out by the lines of the principal faults, and these will be treated in topographical order, proceeding from the east westward, and in each block from the south northward.

AREA EAST OF MOSQUITO FAULT.

Between Mosquito fault and the crest of the range is a considerable area, occupied principally by Archean exposures, whose description properly belongs to that of the Leadville region, although only a small portion of it is actually shown in the extreme southeast corner of that map. In it, immediately below the main crest, are the two great glacial amphitheaters in which headed the glaciers that carved out Evans and Iowa gulches, and which offer the best opportunities in the immediate vicinity of Leadville for the study of the relations of the ancient crystalline rocks and of the eruptive bodies that have been intruded through them into the overlying Paleozoic formations. Their scenery is moreover of an imposing and Alpine character that would hardly be expected from the somewhat tame appearance of the immediate vicinity of the city itself. For this reason a view of the more picturesque and instructive of the two, that of Iowa amphitheater, has been chosen for the frontispiece of this volume.

Frontispiece. — Iowa amphitheater, as will be seen on the Mosquito map, is a bowl-shaped depression some 2,500 feet deep, with three main branches or subsidiary amphitheaters extending up to the north, northeast, and south between the bounding peaks, Dyer Mountain, Mount Sherman, and Mount Sheridan. The view given in the frontispiece is the reproduction of a not altogether satisfactory photograph taken from a point on the north side of Iowa gulch, at the foot of the steeper southern slope of East Ball Mountain. The spur in the foreground, on the right, is a portion of the north slope of West Sheridan, formed of Archean rocks capped by Lower Quartzite; that on the left is the south spur of East Ball mountain, along which runs the Mosquito fault; while the background is formed by the west face of Mount Sherman, an almost vertical wall 2,400 feet in height. On this wall the up per 1,400 feet are occupied by the main sheet of White Porphyry, overlying the lower Paleozoic beds, in which are also several minor sheets of the same rock, too small to be indicated except in a general way on the Mosquito map; and the base of the cliff is formed by Archean rocks. In the view the horizontal lines of the stratified beds can be readily distinguished from the somewhat gothic forms of weathering of the great mass of porphyry above, but the lower portions of the cliff are almost entirely hidden beneath talus slopes of débris, through which only here and there projects a portion of the Archean granite.

In the granite exposures on the south bank of Iowa Creek, a little above the point from which the frontispiece view is taken, are the best examples of glacier action on rock surfaces in this region. The granite bosses here have a gentle slope to the east and are steep on the west, the whole upper surface of the rock being beautifully polished, grooved, and striated, and the lines being parallel with the direction of the gulch. These striation lines are particularly fine on the surface of the large feldspar crystals, where, when closely examined, they are seen to resemble the parallel lines of a steel engraving.

Mosquito fault.—The average course of Mosquito fault, which forms the western boundary of this area, is magnetic north or north 15° east. From the point where it branches off from the Weston fault, in the bed of Empire gulch, it runs across Upper Long and Derry Ridge at the foot of the steep face of West Sheridan, through Iowa gulch, along the west face of East Ball Mountain, and through the narrow saddle on the ridge between West Dyer Mountain and Little Ellen Hill into Evans amphitheater, which it crosses diagonally, near if not actually through the shaft of the Best Friend mine, to the foot of the zigzag road descending from Mosquito pass. Owing to the absence of shafts in the region, its location can only be determined by actual rock outcrops, and where these are obscured by débris it may vary a little one way or the other from that given on the map. Its throw, which varies somewhat at different points, may be taken at an average of 4,000 feet.

Minor faults.—Of the minor or cross faults in this area only one, the South Dyer fault, appears on the Leadville map. By its movement, which was an upthrow to the north, a fragment of the Lower Quartzite beds, with an included sheet of White Porphyry, has been left on the southwest spur of East Ball Mountain, where it forms a shoulder half-way down the slope and is entirely surrounded by Archean outcrops. Beyond the line of the map it crosses the south foot of Dyer Mountain, where a dike of White Porphyry cuts through the Archean on its probable continuation and joins the Sheridan fault in the bed of Iowa gulch. The Sheridan fault runs at right angles to the former in a southwest direction across the saddle between Mount Sheridan and West Sheridan, and is supposed to join Weston fault in the north head of Weston gulch. Its movement is a slight upthrow to the east, and the combined displacement of these two faults explains the existence of a singular triangular-shaped mass of White Limestone and Lower Quartzite at the entrance to the north branch of Iowa amphitheater, in the very bed of the gulch. As the normal continuation of these beds is found high up on the face of the surrounding mountains, it might seem at first to have been dropped down here by a sudden sinking of the ground. Nearly parallel with the South Dyer fault is the Dyer Mountain fault, whose presence is indicated by a slight discrepancy in the stratified beds at the head of Dyer and North Iowa amphitheaters. Its extent as well as its movement is apparently small, as it could not be traced beyond these valleys in either direction, and in the Dyer amphitheater is shown only on the east wall, there being apparently no break in the lines of stratification on the West Dyer Mountain side. The amount of displacement caused by these two faults is shown in Section M, Atlas Sheet X.

West Sheridan.—West Sheridan Mountain, which is in point of fact simply a Y-shaped spur extending out westward from the main Mount Sheridan, has, as it were, three summits, two of which are capped by the remains of the White Porphyry sheet, which here separates the Blue Limestone from the White. The remainder of the crest of the ridge is formed by beds of White Limestone, under which is a fringing outcrop of Lower Quartzite. In those on the north and west slopes are several small bodies of White Porphyry. An estimate of the thickness of White Limestone and Lower Quartzite on the western face of the south and north spurs of West Sheridan, respectively, gave 250 and 275 feet, the difference being accounted for by included sheets of White Porphyry.

Dyer Mountain.—Dyer Mountain, as shown in Section M, whose line runs from the summit of the mountain southward through the spur represented in the photograph, is composed of the following beds in descending series:

Sacramento Porphyry.
Weber Grits.
White Porphyry (main sheet).
Blue Limestone.
White Limestone.
Lower Quartzite.
White Porphyry.
Archean.

The main sheet of White Porphyry is the cap-rock of that portion of spur shown in the frontispiece. The lines of stratification on the face of the spur toward the observer, dipping gently to the north toward the head of Dyer amphitheater, belong to the Lower Quartzite and to the underlying bed of White Porphyry, which is here two hundred to three hundred feet in thickness. On the south face of this spur, toward Iowa gulch, in the Archean apparently near or on the line of the South Dyer fault, is an irregular outcrop of White Porphyry, somewhat in the form of a dike, parallel to the fault, but with ramifying branches extending in various directions. This body is interesting as being one of the few cases where the White Porphyry could be seen to have been directly erupted through the Archean, and is very probably the source from which the lower sheets of this rock have spread out between the lower Paleozoic beds below the horizon of the Blue Limestone; it seems hardly of sufficient size, however, to account for the immense thickness of the main sheet of White Porphyry above that horizon, and whose source, as already shown, is supposed to exist in the White Ridge near the head of Four-Mile Creek.

On the east wall of Dyer amphitheater, in the upper part of the White Limestone near the Parting Quartzite, are the deposits of the Dyer mine, from which the mountain has derived its name. This mine is one of the earliest discoveries of the district, antedating by many years that of the carbonate mines, but owing to its great altitude and difficulty of access it has been but intermittently worked. A section measured along a steep hillside, with a slope of 32°, just south of the Dyer mine, gave the following thicknesses:

		Feet.	
Lower Carboniferous	*Blue Limestone:*		
	Dark blue, weathering black, with black chert	150	
			150
Silurian	*Parting Quartzite:*		
	Sandstone and silicious limestone	10	
	White Limestone:		
	Thin-bedded, bluish limestone	35	
	Light-blue limestone, conchoidal fracture, passing into pinkish, clayey material	15	
	Gray, semi-crystalline limestone	40	
	Sandy lime tone, with some sandstone	30	
	White, silicious limestone	10	
			140
Cambrian	*Lower Quartzite:*		
	Red-cast beds	10	
	Reddish-brown quartzites	50	
	White, saccharoidal quartzite	100	
			160
	White Porphyry, 200 feet.		
Archean	Granite		

Just below the Dyer mine a bed of limestone of a light steel-blue color is singularly changed into a light-pink, clayey material, so different in appearance from the unaltered rock that a partial analysis of the two was made in order to determine the chemical change that had produced this appearance. The following figures were obtained:

	Unaltered limestone.	Altered limestone.
Lime	20.31	19.21
Magnesia	10.35	9.58
Alumina and iron	6.23	5.23
Insoluble	31.27	34.56

From which it is seen that the alteration consists mainly in the removal of a portion of the soluble bases and a consequent relative increase in the proportion of silica. It also shows that a very essential change in the physical character of a rock may be made by the action of percolating waters, with very little actual chemical change.

The break in the beds north of the Dyer mine, caused by the movement of South Dyer fault, is very evident in the Blue Limestone, but cannot be traced much below that horizon. On the west wall of the Dyer amphitheater the beds slope up the face of West Dyer Mountain in an unbroken line, showing no trace of the fault; the main sheet of White Porphyry which forms the saddle between Dyer and Evans amphitheaters thins out very rapidly to the northwest, and on the face of West Dyer Mountain shows an outcrop of only about ten feet, the summit of the peak being formed by a few remaining beds of Weber Grits.

Evans amphitheater.—The basin at the head of South Evans gulch, as well as the main Evans amphitheater, shows mainly outcrops of Archean rocks, those of the Weber Grits, which adjoin them west of the fault line, being generally covered by débris. The wall of Mount Evans facing the amphitheater presents similar conditions to the wall at the head of Iowa gulch, namely, an eruptive mass underlaid by horizontal stratified beds, and the same strong contrast in their weathered forms, the difference being that in this case it is the Sacramento instead of the White Porphyry that forms the intrusive mass. In a shallow ravine on this wall just south of the Mosquito pass there is a slight break in the continuity of sedimentary outcrops, caused by a small cross-fault with a slight upthrow on the north.

East Ball Mountain. — The crest of what is known as East Ball Mountain, which is in reality only a spur of West Dyer Mountain, is capped by Lower Quartzite, with a sheet of White Porphyry between it and the underlying Archean. This sheet is evidently the same which has already been noticed on the south spur of Dyer Mountain; in the recess of Dyer amphitheater, however, it must cut partly across the Lower Quartzite, since on the west wall of the amphitheater there is a considerable thickness of Lower Quartzite below the White Porphyry.

AREA BETWEEN MOSQUITO AND BALL MOUNTAIN FAULTS.

Ball Mountain fault. — The direction of the Ball Mountain fault is somewhat to the west of north, nearly parallel with that of the Weston fault, and therefore convergent with the Mosquito fault, which it joins on the crest of the Upper Long and Derry Ridge at the foot of the steep slope of West Sheridan. From here it runs in a direct line across Iowa gulch, through the top of Ball Mountain, and bends sharply to the west on its northern slope, passing through the End Squeeze or Cleopatra shaft (F–12).[1] Its movement is defined here by the Fat Purse (F–17), which is in Weber Grits on the west of the fault, and the John Mitchell (E–11), which is in Lower Quartzite on the east; it then runs northward across South Evans gulch, through the Nevada tunnel, which has been driven nearly three hundred feet on its line, and just west of the Seneca shaft, which is in the White Limestone. Farther north its existence is shown only by the widening of the outcrop of Weber Shales and by a slight discrepancy in the outlines of the body of Mount Zion Porphyry in Evans gulch. Its movement of displacement is an upthrow on the east, which has a maximum at the southern end, or in Iowa gulch, of 2,250 feet, and gradually decreases to the northward, being only a few feet in Evans gulch and disappearing entirely in Prospect Mountain.

Prospect Mountain Ridge. — On the spur from Prospect Mountain west of the Prospect amphitheater, which is on the line of the fault, there is a slight variation in the regular easterly dip of the Weber Grits, which suggests

[1] The letters and numbers following the names of shafts indicate, respectively, the square and the number within that square, by means of which the shaft may be found on the Leadville map.

that the influence of the fault has produced a slight anticlinal fold. Prospect Mountain, from its summit eastward to the foot of Mosquito pass, is made up of coarse sandstones and micaceous shales of the Weber Grits formation, which dip a little north of east.

Little Ellen Hill.—The same beds are found to extend through the main portion of Little Ellen Hill and across the upper part of South Evans gulch, and outcrops where visible have a prevailing dip of 20° to the eastward. The lines of structure in a series of beds of such uniform composition are difficult to trace in a country where the surface is so much obscured as here. It is possible, therefore, that the eastern ends of Sections A, B, C, and D, which pass through this region and have been constructed somewhat theoretically, give too great a thickness for this formation; in other words, place the ore horizon at too great a depth below the surface, since the structure lines obtained from other portions of the region, where definite data are more frequent, show no such extent of regular slope, but much more frequent waves or folds. Such, however, have not been indicated here, as in the absence of definite data they would be purely imaginary.

Eruptive dikes.—In this area are several outcrops of eruptive bodies, which apparently belong rather to the dike type than to that of intrusive sheets. Two of these occur on Prospect Mountain ridge, the easternmost of which is a coarse-grained quartz-porphyry, with large orthoclase feldspars, resembling the Lincoln Porphyry; its feldspars are partly reddish and partly light green, the coloring being due to iron oxide on the one hand, or to light-green mica as an alteration product on the other. The western of these dikes is a fine-grained, dioritic-looking rock, similar to that found in the Arkansas Valley between Indiana and Bird's Eye gulches and at the heads of these gulches. On the north slope of Little Ellen Hill is an outcrop of the same coarse-grained porphyry that is found in the eastern dike. In the bed of Evans gulch, above the Virginius mine and extending up some distance on the north side of the gulch, is an eruptive mass of rather irregular form, whose outlines are somewhat obscured by surface accumulations. It belongs, as well as could be ascertained from the partially decomposed specimens obtained, to the Mount Zion type of porphyry.

Coal in Weber Shales.—The carbonaceous beds of the Weber Shales series are unusually well developed in this region and often contain considerable impure anthracite. The greatest developments of this coal are found in the Ellesmere (B–2) and Little Providence (C–8) shafts, in the former of which it is said to have a thickness of eighteen inches and in the latter of seven feet. The coal, however, has thus far proved too impure to be of economic value. Similar beds of coal have been observed by the writer at what is very probably nearly the same horizon in the Pancake Mountains west of White Pine, a short distance from Argenta on the Central Pacific Railroad, and some 30 miles north of Elko on Coal Creek, in Nevada. Explorations at all these localities have, however, failed to develop any workable beds of good coal. In a region like Colorado, therefore, where the Cretaceous formations which are known to contain abundant beds of excellent coal are so widely developed, it seems scarcely advisable to spend much labor in searching for coal at this lower horizon. The name "Carboniferous," which was given to this formation in the early days of geology, when it was supposed to be the only coal-bearing horizon, is a practical misnomer in the Rocky Mountain region, and apt to mislead the untechnical.

Blue Limestone.—The outcrop of Blue Limestone from the point where the Ball Mountain fault crosses South Evans gulch, just below the Seneca shaft, follows up the north bank of the gulch and then bends to the south up Alps gulch to the saddle between Ball Mountain and East Ball Mountain. Its existence is proved by explorations of the Little Rische (G–6), Little Ellen (G–5), Lulu (G–4), Izzard (G–3), Gnome (G–2), Wall Street (G–1), Dauntless (C–13), and Alps shafts, which have cut through the overlying White Porphyry to the contact. In the Little Ellen alone has any considerable body of ore been discovered at the contact. Iron vein material of considerable thickness has been found on the contact in the workings of the Alps group of mines, but as far as known little rich ore has been developed. The White Porphyry is here very thin, and at the head of Alps gulch disappears entirely, coming in again on the south side of the ridge. From this saddle the outcrop of the Blue Limestone sweeps round to the eastward to the Black Hawk shaft. This shaft passed through 80 feet of White Porphyry and a little black shale before reaching the Blue Limestone. Beyond this the Blue Limestone is cut off by the Mosquito fault at the sharp spur running out southwest from East Ball Mountain toward Dyer gulch. Actual outcrops of Blue Limestone and Parting Quartzite, dipping steeply to the east, are found on the saddle east of Ball Mountain. The summit of Ball Mountain, from the saddle westward to the fault, is formed of White Porphyry, of which a thick body here separates the Parting Quartzite from the White Limestone.

The structure of the area between the crest of Ball Mountain and the south slope of Ellen Hill below the outcrop of Blue Limestone is somewhat obscure; but the explanation presented on the map, viz, that of a quaquaversal or anticlinal fold in part cut off by the Ball Mountain fault, is one which best fits the following observed facts.

On the north slope of Ball Mountain, immediately under its crest, can be traced outcrops of White Limestone and of a portion of the Lower Quartzite beneath it. The prominent ridge which extends out on the steep slope towards the valley of South Evans consists entirely of fragments of quartzite derived from the above-mentioned outcrop. Shaft F–6, however, which has penetrated this covering of débris, shows that the underlying rock is White Porphyry. The John Mitchell shaft, west of this, has gone through another body of Lower Quartzite and a second underlying White Porphyry to granite. North of the John Mitchell, at the base of the hill, is a small outcrop of granite, with a little white quartzite resting on it. Still north of this are the Ocean and Seneca shafts, the former in Lower Quartzite, the latter in White Limestone, dipping to the northward. It seems, therefore, that the White Porphyry is here splitting the Lower Quartzite into several distinct bodies, and it may naturally be inferred that somewhere in this region it has been intruded into the Lower Quartzite from the underlying Archean.

The Nevada tunnel discloses a body of White Limestone, resting on quartzite, east of the fault, which dips at 45° to the north. This dip is somewhat abnormal to the quaquaversal structure deduced from observations in other shafts of this region, but its proximity to the fault may account for the irregularity.

South slope of Ball Mountain.—On the south slope of the Ball Mountain Ridge, towards Iowa gulch, the White Limestone is also split into three distinct sheets by intrusive masses of White Porphyry. They might perhaps be considered to be simply caught up and included in the porphyry body. One or more of these sheets can be traced on the upper slope of Long and Derry Ridge, in the angle between Ball Mountain and Mosquito faults. South of the crest of Ball Mountain the Emma tunnel (C–10) is run on the contact of White Porphyry and White Limestone, following some iron-stained vein material. West of this and adjoining the fault, the Lower Quartzite outcrops under the White Limestone, dipping at an angle of 50° to the east. Another portion of the Lower Quartzite is found adjoining the fault on the shoulder south of Ball Mountain, and in the bed of Iowa gulch erosion has exposed the full thickness of the Lower Quartzite, with a small area of Archean rocks next to the fault on the east, the quartzite dipping east at an angle of 18°.

The distribution of the White Porphyry bodies in this area is rather exceptional, as they are principally developed in the lower horizons, forming several sheets within the Lower Quartzite and White Limestone, while the bed above the Blue Limestone is comparatively thin, and at one point entirely wanting. It might be inferred from this that near here is one or more of its vents or points where it has been intruded through the Archean into the overlying Paleozoic beds.

AREA BETWEEN BALL MOUNTAIN AND WESTON FAULTS.

This area presents a still more complicated structure than the one just described, owing, first, to the existence of a well-defined anticlinal or quaquaversal fold, the South Evans anticline; second, to the disturbance produced by the Iowa gulch and Colorado Prince cross-faults, which run transversely across the area; third, to the peculiar movement of displacement of the Weston fault, which has the normal upthrow to the east at its northern and southern extremities, but in the intermediate region has partly a reversed throw or to the westward, and in one portion no displacement at all; and, fourth, to the branching of the Weston fault at its southern end, by which part of its movement of displacement is distributed to the Union fault. The prevailing dip of the formations is to the east, except in the vicinity of the South Evans anticline.

Weston fault.—This fault is approximately parallel with Ball Mountain fault, and follows the same general direction that it had in the area already described outside the limits of the Leadville map. From its intersection with Mosquito fault in Empire gulch, it crosses the Long and Derry Ridge, near the foot of the steeper slope of the Upper Long and Derry Hill, and descends into Iowa gulch just east of the Ella Beeler tunnel (E–7), where it is joined by the Union fault; it runs thence diagonally up the southwest slope of Green Mountain, a little east of the North Star (E–23) and Alta (E–22), and crosses the head of California gulch between the Tiger shaft (E–24) and the Ella tunnel (F–39). From here up the slope of Breece Hill its position cannot be exactly defined, owing to the fact that Pyritiferous Porphyry forms the rock surface on either side. In the ground of the Highland Chief No. 2, however, it passes between two shafts of that claim (F–40 and F–41), the former of which is in the Weber Grits and the latter in Pyritiferous Porphyry, and just east of its main shaft (F–59); it then follows the crest of the ridge to its north point and down its steep north slope between the Chemung tunnel on the east and the Fenian Queen on the west, along the line of the west fork of Lincoln gulch to Big Evans gulch, which it crosses just above the mouth of Lincoln gulch. On the south slope of Prospect Mountain its movement of displacement becomes very slight, and is proved only by the discrepancy in the position of the dividing line between Weber Shales and Gray Porphyry, as shown in the Stillwell (K–11), La Harpe (K–12), and other shafts in Little Evans gulch on the one side and in the Mary Able (K–35) on the other.

The movement of displacement of this fault is quite remarkable, being an upthrow to the west of about six hundred feet in Iowa gulch and about the same amount of displacement reversed, the upthrow being on the east side, near the mouth of Lincoln gulch, opposite the South Evans anticline. This movement becomes null between these two points somewhere in the neighborhood of the Yates shaft (F–66) on Breece Hill.

Iowa fault.—The Iowa cross-fault runs east and west along the foot of the cliff, on the north face of Upper Long and Derry Hill, and connects Weston and Ball Mountain faults. The shafts and tunnels between it and the bed of the gulch are either in Weber Grits or Pyritiferous Porphyry, while Archean granite forms the cliff above it on the south. The estimated displacement of this fault is an upthrow of 2,700 feet to the south. It might perhaps be better considered a downthrow to the north, since that portion of the area which immediately adjoins it on that side is in the abnormal position of being relatively lower than the corresponding block of ground on the west of Weston fault.

The uplifted block of ground inclosed by Iowa and Weston faults consists of Archean rocks, principally coarse red granite, with a narrow strip of Lower Quartzite resting on them along the crest of upper Long and Derry Hill. This quartzite is apparently the crest of a shallow north and south anticlinal fold, now almost entirely eroded away. The curve of the strata can be readily seen on the cliff from Iowa gulch; at the western end, toward the fault, the dip steepens to 30°. At the eastern end, on either side of the ridge, is an outcrop of a much decomposed, coarse-grained quartz-porphyry, which apparently forms a sheet between the quartzite and underlying granite.

Southwest slope of Ball Mountain.—From Iowa fault northward, across Iowa gulch and up the southwest slope of Ball Mountain, the surface is mainly covered by Pyritiferous Porphyry, with occasional outcrops of the sandstones and shales of the Weber Grits. The sedimentary beds all have a gentle dip to the northeastward and are separated by intervening porphyry sheets into three distinct series, the lowest of which is classed as Weber Shales, although black shales are found to a greater or less extent through all the beds.

This lowest series, which crosses Iowa gulch opposite the Ella Beeler tunnel and extends part way up the slope of Green Mountain, comes in juxtaposition with the White Porphyry beyond the fault to the west, and is overlaid by a thin body of Pyritiferous Porphyry, which is cut in a tunnel (E-21) on the slope of Green Mountain.

The base of the Weber Grits, consisting of quartzite, conglomerate, and shale, is shown on the south side of Iowa gulch in the Little Hercules tunnel (E–6), and on the north side in the Black Cloud shaft, which cuts through it into the underlying porphyry. On Green Mountain the Hoosier (E–19) and adjoining (E–20) shaft are sunk in it, and the Equator (E–17) tunnel runs on the contact breccia material between it and a second sheet of Pyritiferous Porphyry above. The outcrops of this body, consisting of iron-stained decomposed porphyry, can be easily traced along the slope of Iowa gulch, but the underlying Weber Grits are obscured by débris. South of the gulch it is shown in the Mount Carbon tunnel and on Green Mountain in the Tiger shaft and in the Ontario and Bloomington (E–9) tunnels. The former passes at 200 feet from its mouth into micaceous sandstones and shales of the second sheet of Weber Grits, while the shaft (E–18) shows breccia material between the sandstones and the underlying porphyry.

The outcrops of the second body of Weber Grits sweep round the upper part of Green Mountain, where the Green Mountain and Lawrence (E–10)[1] shafts have reached it after crossing the lower part of the upper body of Pyritiferous Porphyry; it widens out in the vicinity of the Little Frank (D–2) shaft and the Alleghany and Pine Forest tunnels, and again thins to thirty or forty feet as it crosses Iowa gulch to the Iowa fault below shaft D–4. Above this body of Weber Grits the main sheet of Pyritiferous Porphyry extends up to the crest of Ball Mountain and east to the fault, broken only by isolated outcrops of Weber Grits, apparently representing fragments of this formation caught up in the mass of the porphyry at the time of its intrusion. Such a fragment, consisting mainly of black shales, is cut in the Silver Queen tunnel on the hill slope above the Pine Forest.

The weathered surface of the Pyritiferous Porphyry in general shows no pyrites, but only the cavities from which its crystals have been dissolved out. The old Mariner tunnel, above the Silver Queen, has been run 125 feet from the surface in porphyry thus decomposed, and at the mouth of the former is a deposit of needles of spruce, cemented together and partly

[1] Wrongly named Leavenworth on the index sheet of the Atlas.

replaced by limonite resulting from the leaching out of the pyrites. The Weber sandstones at the contact with the porphyry are often brecciated and so impregnated with pyrites as to be scarcely distinguishable from the porphyry. To understand the distribution of the various bodies of this porphyry and their supposed continuation below the limits of exploration it will be necessary to refer to Section G, Atlas Sheet XX. According to this it will be seen that there are three distinct sheets of porphyry above the Weber Shales, while a fourth occurs beyond Weston fault, between the Weber Shales and White Porphyry, which connects with a fifth body found in California gulch, where it crosses the White Limestone and White Porphyry along the cross-cutting zone already mentioned. It is supposed, as shown in the section, that it is in this vicinity that the porphyry came up through the Archean.

Northwest slope of Ball Mountain.—The bodies of Pyritiferous Porphyry thin out towards the north, and on the upper part of Breece Hill, or the northwest slope of Ball Mountain, all except the upper one disappear before reaching the Colorado Prince and Ball Mountain faults. No trace of Pyritiferous Porphyry has yet been found east of the latter fault. To the north the lower sheet is stratigraphically replaced by the main sheet of Gray Porphyry, since farther west they are each underlaid by the main body of White Porphyry. In the few cases where underground explorations have disclosed the relations of the Pyritiferous and Gray Porphyries the former is found to overap the latter.

In this region the beds whcih have been assigned to the Weber Shales horizon are found to have a much larger proportion of sandstone than the corresponding beds on Little Ellen Hill, but in either case the data are somewhat meager, as no shafts are so situated as to afford a complete or continuous section. The Antelope shaft found 100 feet of white quartzite immediately above the Gray Porphyry. The Quandary shaft found micaceous sandstone; the Garbutt, sandstone and shale; and the shafts of the Ontario (F–50 and F–51), a coarse sandstone. The Capitol (F–57) and the Highland Queen (F–56) shafts passed in depth into a body of quartz-porphyry of different character from the Pyritiferous Porphyry. It were too long to enumerate all the other shafts on this slope, the information obtained from which is sufficiently indicated on the map and sections. The Gray Porphyry sheet under the Pyritiferous also thins out to the eastward and cannot be traced beyond the Colorado Prince fault.

Colorado Prince fault.—The movement of displacement of the Colorado Prince fault is an upthrow to the southwest, which is about two hundred feet in the middle and reaches a maximum at its junction with the Ball Mountain fault and a minimum at that with the Weston fault. By this movement the southern portion of the South Evans anticline has been cut off and leaves, along the cliff at whose foot the fault runs, a succession of beds dipping generally to the southward; to the faulting and consequent exposure of the edges of these beds the steepness of the cliff is doubtless due.

The White Porphyry sheet immediately over the Blue Limestone is here very thin and in places entirely wanting. The Chemung tunnel at the western edge of this area, near the Weston fault, runs in a southeast direction on the contact between the Gray and White Porphyries, and, cutting across the latter, passes into the Blue Limestone. The Highland Chief and adjoining shafts, a little east of this, pass through the Gray Porphyry directly into silicious vein material, which is the replacement here of the Blue Limestone. North of this the Eliza No. 2 (K–3) strikes Blue Limestone, the Little Alice (K–2) Parting Quartzite, and the Eliza No. 1 (G–58) White Porphyry after passing about twenty feet of Wash, the last reaching White Limestone at a depth of 180 feet. Shaft No. 2 (G–51) of the Miner Boy finds a small body of black shales directly above the limestone, between it and the overlying Gray Porphyry. The Uncle Sam shafts (F–32 and F–33), at the east end of Idaho park, find vein material between Gray Porphyry and Blue Limestone. The Rattling Jack and Little Johnny, still farther east, find a sheet of White Porphyry between the Gray Porphyry and Blue Limestone, with vein material at its contact with the latter. The body of White Porphyry cut in the Little Alice and Eliza No. 1 shafts is evidently of limited extent, as it has not been seen in any other workings.

The White Limestone and Lower Quartzite are cut by the various shafts and tunnels of the Black Prince, Miner Boy, and Colorado Prince claims, the tunnel of the last running south through a body of White Porphyry between the granite and Lower Quartzite and in close proximity to the Colorado Prince fault. A more detailed description of the structure in the immediate vicinity of these mines will be found in Part II, Chapter V.

In the east fork of Lincoln gulch, according to Mr. Jacob, the Boulder incline is sunk on the line of the Colorado fault at an angle of 45° to the north, with granite in the roof and White Porphyry in the foot-wall; while the Cumberland shaft, a short distance east, is sunk 150 feet in White Porphyry. The evidence of the former would prove, therefore, that the Colorado Prince fault at this point is a reversed fault, viz, that the upthrow is on the hanging-wall side, instead of, as is usually the case, on the foot-wall; and the fact that the latter was sunk to so great a depth in White Porphyry without reaching granite would be explained by the nearly vertical position of the sheet. This explanation, which considers the White Porphyry as an interbedded sheet, is supported by the apparent continuity of White Porphyry north of the Colorado Prince fault, around the outcrop of Archean. It seems possible, however, that these shafts may be sunk in the actual channel through which the porphyry came up across the Archean. The Fitchburg incline, on the south side of Lincoln gulch, opposite the Boulder, was run down on the contact of Lower Quartzite and White Limestone, which here dip 20° to the southwest.

South Evans anticline. — The granite body which forms the crest of South Evans anticline, extending from the north fork of Lincoln gulch to the mouth of South Evans, is shown wherever prospecting has stripped the rock of the overlying soil; also, by the Caledonia (G–59) and Slim Jim (G–46) shafts and by the Silver Tooth bore-hole (G–45) This bore-hole was sunk 314 feet, cutting in its passage downwards 49 feet of White Porphyry, probably a small dike within the granite. The granite in the Caledonia is red and coarse grained; that from the bore-hole, compact and fine grained. The White Cloud shaft (K–15) on the west side of the fold in Lincoln gulch was sunk in the Lower Quartzite, which also outcrops near the road, showing a western dip. A shaft (K–14) on the north side of Evans gulch has found quartz-porphyry directly under the Wash. The Hoosier Girl (G–44), on the east, is in Lower Quartzite, which must be a portion separated from the main body by the lower sheet of White Porphyry. This lower sheet of White Porphyry forms the western point of

Little Ellen Hill, between South Evans and Evans gulches; it is coarser grained than the normal rock and contains numerous quartz crystals. The successively higher horizons of Lower Quartzite, White Limestone, Blue Limestone, White Porphyry, and Weber Shales are crossed as one ascends the hill to the eastward, their existence being proved by the numerous shafts which dot this point of the hill. A small body of quartz-porphyry is found on the slope of the hill toward South Evans gulch, between the Parting Quartzite and White Limestone, which may correspond to that found on the other side of the anticline in K–14. The contact of the Blue Limestone with White Porphyry has been proved in the Virginius, Tenderfoot, and Cleveland shafts, where it is more or less replaced by vein material, and in the first is said to have contained large bodies of low grade and some rich ore. Southward across South Evans gulch this contact is practically unprospected.

The north slope of the anticline is proved on the north side of Evans gulch, in the United States Mint shaft (G–38), which is sunk in the shaly beds at the top of the Lower Quartzite. The northern rim of the anticline is buried below 400 feet of gravel of the Evans moraine, and it is only on the steeper slopes of Prospect Mountain, adjoining Little Evans gulch, that rock in place is found. Here the workings of La Harpe, Stillwell, Little Louise, Golden Eagle, and other claims have proved the contact of the main Gray Porphyry sheet and the overlying Weber Shales. The main Gray Porphyry sheet is not found east of the South Evans anticline, and therefore must thin out rapidly beyond these claims. The body of Mount Zion Porphyry, which crosses Evans gulch above the Ball Mountain fault as already described (if, as supposed, an interbedded sheet), comes between the Weber Shales and the Weber Grits, commencing opposite where the Gray Porphyry sheet dies out.

AREA BETWEEN WESTON AND MIKE FAULTS.

Mike fault.—The Mike fault runs more nearly parallel with the Weston fault than the Ball Mountain fault. On the south it extends a short distance beyond the limits of the map, as shown in discrepancy of outcrops on the south slope of Long and Derry Hill, but it cannot be traced beyond the alluvial deposits of Empire gulch, and apparently passes into an anticlinal fold on the west slope of Empire Hill.[1] On Long and Derry Ridge it is defined at the Kenosha tunnel, where a body of greenish quartz-porphyry on the east comes into juxtaposition with White Porphyry on the west; the former body belongs below the horizon of the White Limestone, the latter above that of the Blue. It descends into Iowa gulch near the point where the Long and Derry grade reaches the crest of the hill, crossing the gulch just west of the Now-or-Never (M–49) shaft; passes the western foot of the Printer Boy Hill to California gulch between its junctions with Eureka and White's gulches, and along the western slope of Breece Hill, through the workings of the Mike and Star mine, from which it receives its name.

In the latter region the surface indications do not prove its existence, since White Porphyry is found on both sides; but its movement is proved by the relative depths of the Blue Limestone horizon under the White Porphyry in the two shafts of the Park mine (O–1 and O–4). Its movement cannot be traced north of Adelaide park, and it is supposed to end at its junction with the Breece Iron fault.

Its movement of displacement at the south end is an upthrow to the east, which is about one thousand feet on Long and Derry Ridge and decreases to the northward. North of its junction with Pilot fault, in Iowa gulch, as above stated, the only data are derived from the Park mine, from which it is inferred that the movement is reversed and is an upthrow on the west, gradually increasing from that point to a maximum of about three hundred feet.

Pilot fault.—Pilot fault might in one sense be considered the normal continuation of the main Mike fault, from the fact that its upthrow is the same and that the amount of its displacement decreases continuously to the north until its movement is entirely lost in the body of Pyritiferous Porphyry on Breece Hill. Its direction diverges at first very sensibly from that of the Mike fault, being a northeasterly direction across the western slope of

[1] On the Mosquito map (Atlas Sheet VII), by an error of the engraver, which had been overlooked, it has been continued south of Empire gulch to a junction with Union fault on a line which is simply the boundary between White Limestone (*c*) and Lower Quartzite (*b*).

Printer Boy Hill and bending to the north beyond the Pilot tunnel, from which it receives its name. It crosses California gulch a little above the Lower Printer Boy mine, and White's Hill just east of the shaft L–34. Beyond that point its position can no longer be defined, but it seems probable that it passes through a slight anticlinal fold under the Breece Hill body of Pyritiferous Porphyry, the continuation of a fold farther north which is proved by the explorations of the shafts in the neighborhood of the Great Hope mine, above Evansville.

Union fault.—The Union fault, which is principally developed south of the limits of the map, has a direction nearly parallel with the Mosquito fault. As described in the preceding chapter, it crosses the western slope of Empire Hill and disappears to the southward in the granite area adjoining lower Weston gulch. Its displacement is an upthrow to the east, which from a null point at its south end increases towards the north, reaching a maximum of about one thousand feet at its junction with the Weston fault, in Iowa gulch below the Ella Beeler tunnel, where the Archean comes in contact with the upper portion of the White Porphyry above the Blue Limestone.

In the bed of Empire gulch Archean is exposed east of this fault, and the overlying Cambrian and Silurian beds can be traced, sweeping up the slopes on either side of the gulch, where not covered by the Empire moraines. A few shafts and tunnels have penetrated the moraine material to the underlying quartzite and silicious limestone. Such is the Little Annie tunnel, just east of the fault, on the south slope of Long and Derry Hill, which ran through moraine material into White Porphyry, and at whose end a winze was sunk into the underlying limestone. Farther east the Coffee, Louis Tell, California Rose, and Caledonian tunnels are run upon the contact of White Porphyry and Silurian limestone, which beyond them abut against the granite on the other side of Weston fault.

Long and Derry Ridge.—The structure of this ridge is best explained by Section I, Atlas Sheet XX. The actual line of the Union fault on the crest of the ridge is undefinable, since White Porphyry is found on either side. Two small outcrops are found near the crest of the hill, adjoining the Weston fault, which represent portions of the Blue Limestone above the lower beds of White Porphyry that have escaped erosion. Of these the more northerly one is entirely replaced by iron-stained chert, which forms a rocky outcrop near the crest of the ridge

On the north slope of the ridge, in the sharp angle formed by the two faults, the Ella Beeler tunnel ran in on granite and struck a coarse quartzite dipping southwest, which forms the base of the Lower Quartzite.

From Union fault down to the Long and Derry mines the ridge is covered by the upper main body of White Porphyry, in which are included two comparatively thin beds of sandstone and shale belonging to the Weber Shale formation, associated with which are two small bodies of later quartz-porphyry. The dip of these beds is at a low angle to the eastward, the upper being shown by actual outcrops; the lower, which consists of shales with some sandstone, is shown in the Pride of the West (E-15), Campbell (E-25 and E-26), Gildersleeve (E-27), and Hoosier shafts on the south slope, and by the Herculaneum (E-14) tunnel on the north slope of the hill.

The Blue Limestone is proved on the south slope of the hill by the workings of the Aerial Queen (E-34), Homestake (E-36), and other shafts, which have reached it through the overlying White Porphyry, and by the Himalaya (E-35) tunnel; and on the north slope of the hill by the workings of the Long and Derry group of mines.

On the steep face of the ridge facing Iowa gulch, above Long and Derry grade, is found one of the few distinct outcrops of the two bodies of limestone, the Blue and the White. Here they dip regularly to the eastward at an angle of 10° to 15°, and are underlaid by a body of Green Porphyry. The Belcher[1] tunnel (M-5) runs in on an ore body in the lower part of the Blue Limestone. Above this and a little to the eastward is a prominent black rock-mass resembling at a little distance the outcrop of a body of iron ore. This is the upper portion of the Blue Limestone body, which is here largely replaced by chert and oxides of iron and manganese. Immediately above this and directly under the porphyry is a body of conglomerate, from 25 to 30 feet thick, which is assumed to be a portion of the Weber Shales cut off from the main body by the porphyry sheet.

[1] Wrongly given in the Index of Shafts, etc., as Beecher.

Long and Derry mines. — The Long and Derry workings consist of a number of shafts and tunnels, the former of which—the Dana (M–3) and Porphyry (E–37)—reach the contact through the overlying White Porphyry. Two tunnels on the Faint Hope claim (M–2 and M–4) start in the limestone, the latter reaching the contact between porphyry and limestone at 183 feet, while the Long and Derry tunnel (E–32) is run in through the porphyry for a distance of 400 feet. Mineral action has here extended down into the limestone body, and ore is found not only at the contact, but in irregular chambers, at considerable depths below it.

Dikes. — Immediately in front of Faint Hope tunnel (M–4) is an outcrop of Gray Porphyry almost identical lithologically with the main sheet of Gray Porphyry. This is part of a vertical dike fifty to sixty feet wide, which can be traced past the Belcher Mine, across Iowa gulch, to the Minor tunnel on Printer Boy Hill. There are three of these vertical dikes, which can be most distinctly seen on the steep slopes of Printer Boy Hill, where in some cases they stand as projecting outcrops, the adjoining rock having been eroded away. They vary from thirty to fifty feet in thickness, and, as well as could be traced on the surface, are nearly parallel and all of the same character of rock.

For some distance from the Long and Derry mines westward no actual rock outcrops are found on the surface of the ridge. Along its southern slope the presence of the White Limestone and of an included body of coarse-grained quartz-porphyry, somewhat resembling the Josephine Porphyry, was detected by means of several small prospect holes, too unimportant to have been indicated on the map. The fine-grained Green Porphyry is much decomposed and of lighter color than in Iowa gulch. The secondary ridge or shoulder of the main ridge, at the very edge of the map, overlooking Empire gulch, is formed by the Empire north moraine, through which few, if any, prospectors have succeeded in reaching the underlying rock. On the north slope of the ridge, as already mentioned, the White Limestone forms continuous outcrops, crossing which can be detected the vertical dikes which cut the strata at right angles.

Iowa gulch. — In the bed of Iowa gulch, as shown in outcrops along the creek at the foot of the Long and Derry grade, and in the Minnehaha (M–15 and M–16) and other shafts, is a considerable body of compact Green Porphyry, apparently part of an interbedded sheet underlying the White Limestone. This extends some distance above the bridge, but opposite the Belcher tunnel the outcrops of gray limestone belonging to the Silurian formation are found resting on it, dipping 12° to the northeast. In this limestone can be seen the outcrop of a body of coarse-grained quartz-porphyry similar to the rock of the dikes. For several feet from its contact the limestone seems to be hardened and silicified, with small veins of porphyry running into it. It is probably either an offshoot from one of the dikes already mentioned or a separate dike.

From the steep cliff of White Porphyry above the Long and Derry tunnel an immense talus cone of tabular and sherdy fragments of White Porphyry spreads out into the valley, so as almost to block it up and to completely cover the outcrops of the Blue Limestone. At first glance it would seem that this immense accumulation of débris must be due to some unusual cause. As none such could be found, the great height and steep slope of the ridge which is occupied by the body of White Porphyry and the peculiar weathering of this particular rock, which, under the influence of atmospheric agents, disintegrates very rapidly into tabular sherdy fragments, must be considered an adequate explanation. These fragments, which are very light in proportion to their superficial area, slip down rapidly under the influence of rain, snow, and frost, and soon accumulate in very considerable talus cones at the foot of any steep slope whose surface is largely composed of White Porphyry. Owing to the depth to which the rock surface is buried under this débris, the contact has not been prospected between the Long and Derry mines and the First National.

Printer Boy Hill.—On the north side of Iowa gulch, along the south slope of Printer Boy Hill, the contact of the Blue Limestone and White Porphyry is well marked by a series of tunnels and shafts. The First National shaft finds ore at the contact after sinking through 75 feet of White Porphyry. The Seek-no-further (E–38), Mammôth (E–39), and some other shafts have also reached the contact through the porphyry. The Minor tunnel and the upper tunnel of the Florence are at the highest part of the contact, while the J. D. Ward shaft, on the summit of the hill, sinks 300 feet through porphyry to reach it. From the Florence westward the contact slopes down again towards Iowa gulch through the Sangamon (M–24) tunnel, Brian Boru, Wilson (M–38), Blacktail (M–40), G. M. Favorite (M–44), and other claims and crosses the gulch.

On the north bank of the creek southeast of the G. M. Favorite are found outcrops of Parting Quartzite, consisting here of sandy beds with some purplish shale, and of the top of the White Limestone, dipping 20° to the westward. These facts and the outline of the Blue Limestone on the north side of Printer Boy Hill and along California gulch show that under this hill is an anticlinal fold whose axis runs north and south through the west end of the hill, and which, like the other folds, has a steeper slope to the west. On Long and Derry Ridge its western half has been cut off by the Mike fault. The White Porphyry above the Blue Limestone, on the western side of this fold, is cut in the Now-or-Never (M–49) and other shafts in Iowa gulch; and the Nestor (M–28) shaft, on the crest of the ridge, has reached limestone after passing through 170 feet of White Porphyry.

On the north side of Printer Boy Hill, along the upper portion of California gulch, the presence of the Blue Limestone is proved in the Lovejoy shaft (M–29) and in the workings of the Eclipse mine (M–7 and M–9). The Lovejoy passes through the limestone into an underlying bed of quartz-porphyry, which is also found in the Stars and Stripes tunnel and which very closely resembles the Green Porphyry body found in Iowa gulch under the White Limestone. The Eclipse tunnel (M–7) runs in 170 feet through limestone and then strikes the contact of the overlying White Porphyry, which it follows. The porphyry is here unconformable to the limestone, cutting across its stratification. The dip of this limestone is 15° to the south. The lower tunnel (M–9), about thirty feet below this, is run on the contact of Blue Limestone and Parting Quartzite; both contacts show vein material. The small thickness of limestone included between Parting Quartzite and overlying White Porphyry is an additional evidence that the latter is here cutting across the Blue Limestone.

Head of California gulch.—At the head of California gulch, on the north, the Ohio Bonanza tunnel (not on map) runs in at the surface of a fragment of Blue Limestone which has been left above the White Porphyry; still higher up, the Snowbird shows a sandstone completely impregnated with pyrite and surrounded by Pyritiferous Porphyry, which is supposed to be a detached fragment of Weber Shales. On the south side the Tinker (E–43) shaft has penetrated the White Porphyry to the underlying limestone. The Belle Vernon shaft was sunk through 80 feet of Wash and 150 feet of White Porphyry without reaching it.

The occurrence of Wash here in California gulch is significant, as showing that the Iowa gulch glacier must at one time have filled the valley to the height of the saddle east of Printer Boy Hill and a part of its moraine material must have been pushed over into the head of California gulch, or else that a portion of the glacier actually extended over the ridge. In the lower part of the gulch there is no evidence of glacial action.

Pyritiferous Porphyry.—On the south side of Green Mountain, overlooking Iowa gulch, is the Alta tunnel, which runs 30 feet through Wash, 63 feet through White Porphyry, and 192 feet into the overlying body of Pyritiferous Porphyry, here dipping northeastward, while the North Star shaft (E–23), just above it, is sunk in Pyritiferous Porphyry. The rock here, though characteristic, does not contain much pyrite, except at the end of the Alta tunnel, where it is associated with stains of galena. Little Schuylkill shaft, in the south head of California gulch, has been sunk through Pyritiferous Porphyry into the underlying White Porphyry, while the Ella and adjoining (F–38) tunnels are run in Pyritiferous Porphyry. All these shafts are just below the Weston fault, and the Pyritiferous Porphyry belongs to the main sheet which covers the greater part of the slopes of Breece Hill, and which corresponds with the lowest sheet east of the fault, viz; that found just above Idaho Park.

In California gulch, as already stated, there is a still lower body of Pyritiferous Porphyry, whose rock, though not absolutely identical with the other, resembles it closely enough to form a part of the same body, and which comes at different points in contact now with the Blue Limestone and now with the White Limestone. It is therefore supposed to be cutting up across these beds. It is proved on the south side of the gulch in the Ben Franklin tunnel and shaft and in the Kid, Burt (M–13), Soda Card (M–20), and other shafts. The Wynan shaft (M–12) has sunk into it through the Parting Quartzite, while the Eclipse No. 2 shaft (M–8) is still in White Limestone.

North side of California gulch.—On the north side of Upper California gulch the Parting Quartzite outcrops at Pigtail gulch and can be traced in a number of prospect holes and in the slide. In the Iron Duke it shows iron ore which deflects the needle. The Frank shaft (L–26) has gone through the White Porphyry into underlying White Limestone. The Charlie P. (L–28) tunnel in Pigtail gulch and the P. I. R. (L–29) and Comstock tunnels run also in White Porphyry, which gradually thins out to the westward between the two bodies of Pyritiferous Porphyry. The Comstock runs in on the contact of this White Porphyry and a thin layer of dark, impure limestone, which dips 15° to the northeast and is considerably mineralized. From it has been obtained serpentine similar to that found in the Red amphitheater of Buckskin gulch. The lithological character of this limestone gives no definite indication of its horizon. The presence of the serpentine allies it to the White Limestone, but general stratigraphical considerations favor its reference to the horizon of the Blue Limestone.[1] In either case it is evident that the White Porphyry, as well as the lower body of Pyritiferous Porphyry, is here cutting up across the strata.

Printer Boy Porphyry.—Lower down the gulch the portion of Printer Boy Hill included between the Pilot and Mike faults, a wedge-shaped block of ground which seems to have been let down between them, shows at the surface only a body of quartz-porphyry, which is noticeable as being that in which the principal developments of gold ore have thus far been found, those of the Printer Boy and "5–20" mines. This porphyry is generally decomposed and does not correspond exactly to any other found in the region, though somewhat resembling the Gray Porphyry. It has a greenish-gray matrix, owing its color doubtless to the decomposition of bisilicates, with large white opaque feldspars often two to three inches long. Its eastern limits are defined by the Abe Lincoln (M–36), Nightingale (M–33), and

[1] On the map this limestone is outlined, but the blue color has been omitted.

Pilot tunnels, the latter of which is directly on the fault line. The workings of the various shafts of the Printer Boy mine follow a crack or fissure in the body of this porphyry and cut an apparently included body of Pyritiferous Porphyry. The Gray Eagle tunnel in Eureka gulch is on the western limits of the body, in contact with an underlying mass of Pyritiferous Porphyry. The Fitz-James (?) shaft (M–54), at the head of Eureka gulch and just west of the Mike fault, after penetrating the Wash, was sunk through a large mass of decomposed porphyry, apparently of two kinds, one supposed to be Pyritiferous Porphyry, and reached the White Porphyry, still below that. This body of Pyritiferous Porphyry is apparently part of the main sheet that covers Breece Hill, and seems to thin out to the south and west. It forms the bed of California gulch from Oro City up to the Pilot fault, while the underlying White Porphyry outcrops below Oro City. The shaft L–44, still on the east side of the Mike fault, is sunk in this same underlying White Porphyry.

Mike mine.—The Mike mine, just east of the head of Nugget gulch, is also sunk in the White Porphyry, a little west of the line of the fault. The porphyry here shows a very peculiar semi-columnar structure, which is evidently due to the pressure and movement caused by the fault. It separates out in long, flattened prisms, and the porphyritic structure of the material, which is reduced practically to a clay, is almost lost. The flat surfaces of the prisms are parallel to the fault plane, and not at right angles to it, as would be the case if it were the columnar structure of a dike.[1]

Breece Hill.—The whole surface of Breece Hill north of California gulch and east of the Mike fault shows nothing but Pyritiferous Porphyry. In the weathered rock, as has already been stated, pyrites are not generally found, having been dissolved out by surface waters; but wherever it is exposed by shafts or tunnels it is found to contain, at a distance from the surface, a most remarkable quantity of fine crystals, varying from almost microscopic size to one-eighth of an inch or more in diameter. These are frequently concentrated along natural joints in the rock, and in such cases

[1] Developments made in this mine since the completion of field-work have confirmed the assertions made in regard to the structure at this point, and shown on Atlas Sheet XVIII, Section FF. The contact was struck in the shaft at a depth of 426 feet, and the fault proved by a drift run east. The formation dips 20° to the southwest, showing that the amount of basining-up was under rather than over valued. The ore found is principally sulphurets and said to be exceptionally rich.

sometimes accompanied by a slight deposit of galena, as, for instance, in the Printer Girl, Lalla Rookh, and Lillie tunnel. Thus far no valuable deposits of ore have been found in this body, nor, except on its northern edge, has its thickness been determined. On its southern and western borders it is found to be underlaid by White Porphyry, and on the northeastern edge the main sheet of Gray Porphyry intervenes between the two. As already explained, it is evidently cutting up across the formations in California gulch, and on White's Hill it rests directly on the lower sheet of White Porphyry, probably cutting up across Blue Limestone and upper White Porphyry to the north, as shown in the north and south sections, K and L, Atlas Sheet XXI. The numerous prospect shafts which have been sunk in this body were mostly deserted at the time of this visit, so that definite data as to their depth could not always be obtained The Comstock (L–17) and Tribune (L–11) shafts had reached a depth of 300 feet and were still in it. The Cumberland shaft, at a depth of 450 feet, had struck the underlying Gray Porphyry, into which it had penetrated 25 feet. The Lady Jane shaft, a little to the west, had also reached the Gray Porphyry, but its depth was not ascertained. At the northwestern corner of the body, the Ishpeming shaft (L–42) and the Kent shaft (L–43) had also penetrated the Pyritiferous Porphyry, the former to a depth of 90, the latter of 100 feet, and reached the underlying White Porphyry, showing that the Pyritiferous Porphyry rapidly thins out in this direction.

Breece fault.—The northern limits of the body are sharply defined by the Breece cross-fault. This fault, which has porphyry on either side and at its western end identically the same rock, cannot be traced on the surface. It has a nearly east and west direction, extending across Adelaide Park, through the Silver Cloud (K–59) and Eureka shafts, north of the Kent, south of the Breece Iron, north again of the Glasgow and Comstock shafts, which are in the Pyritiferous Porphyry, and south of the Pennsylvania shaft (K–19), which is in the Gray Porphyry. The porphyry in the Silver Cloud shaft shows the same evidence of pressure as that already described in the Mike, while the Eureka shaft shows a breccia material made up of small fragments of what would appear, under the microscope, to be volcanic rock of the rhyolitic type. No satisfactory explanation of this peculiar occurrence has been found, nor can it be hoped for until work on the now abandoned shafts shall be resumed.

The upthrow of the Breece fault is to the north, and apparently reaches a maximum at its eastern end, where it is estimated at about 500 feet.

Breece Iron mine.—The Breece Iron mine, which is situated on the western slope of Breece Hill, overlooking Adelaide Park, has a remarkable deposit of red hematite, mixed with magnetite, which occurs at the contact of the main sheets of White and Gray Porphyries. Its ore is found at the surface in two bodies, having a maximum thickness of nearly thirty feet each, the lower of which is underlaid by White Porphyry, while, between it and the upper body, which is apparently an offshoot from the main body, is a sheet of decomposed porphyry which has certain resemblances both to the Pyritiferous and to the Gray Porphyry. This deposit is apparently due to the oxidation of a mass of iron pyrites, which were brought to their present position in solution in a similar manner to the other ore deposits of the region. Indications of iron are found along the contact line between the White and Gray Porphyries, to the eastward, but as yet no considerable bodies of iron have been developed.

West of the Breece mine, the Superior and Mountain Boy, on the ridge connecting Breece and Yankee Hills, have also struck a considerable body of iron between the Gray and White Porphyries, dipping north. This may be a continuation of the Breece Iron body, the intermediate portion having been removed by the erosion of the head of Stray Horse gulch, which has brought to the surface the White Porphyry underlying the Gray. On the other hand, while the Breece iron is an anhydrous red hematite, the material developed in these shafts consists of brown hematite and bluish-gray chert, the usual replacement material of Blue Limestone, for which reason the outcrop is indicated on the map by the color of that formation. The Theresa (K–57) shaft, to the northeast, finds shales impregnated with pyrites at the contact of the two porphyries, at a depth of 325 feet.

AREA NORTH OF BREECE FAULT.

The line of Mike fault, if continued northward, would pass through an anticlinal fold, whose crest reaches from the north slope of Yankee Hill to the southwest foot of Canterbury Hill, just below the forks of Little Evans gulch. To this line converges also the northern end of the Iron fault, whose throw becomes null at the crest of the fold. The simplest expression of the structure of the region between Fryer Hill and Weston fault north of Stray Horse gulch is that of a synclinal basin in Little Stray Horse Park, the eroded crest of an anticline at Yankee Hill, and a syncline farther eastward, whose rim is partially cut off by the Weston fault. The intrusive masses of porphyry here associated with the regular sedimentary series are a lower sheet of White Porphyry between the White Limestone and Parting Quartzite, an upper sheet of White Porphyry above the Blue Limestone, and the main sheet of Gray Porphyry above it. This comparatively simple structure, resulting from folding alone, which obtains along the line of Big Evans gulch, on the north slope of Yankee Hill, is complicated on the south, first, by the displacement of the Iron fault, which cuts diagonally into the crest of the fold after crossing Stray Horse gulch west of the Argentine tunnel and passing between the Double-Decker and Highland Mary shafts, the east and west shafts of the Hard Cash mine, and through the eastern end of the Chieftain tunnel; secondly, by the movement of the Adelaide cross-fault, which extends from the Iron fault opposite the mouth of the Argentine tunnel, just west of the Laura Lynn shaft, to the saddle between Adelaide Park and the head of Nugget gulch; and, thirdly, by the intrusion of several irregular masses of Gray Porphyry.

Syncline east of Yankee Hill.—The greater part of the surface between Yankee Hill on the west, the mouth of Lincoln gulch on the east, and the steep slopes of Prospect Mountain on the north is covered by the main sheet of Gray Porphyry, which directly overlies the upper sheet of White Porphyry. The White Porphyry only comes to the surface along the flanks of the Yankee Hill anticline and in the valley of Upper Stray Horse gulch and Adelaide Park. The contours of the map in the latter region would seem at first glance to negative the idea that the exposure of porphyry was simply due to a deeper erosion, since they show in the White Porphyry area not only a valley but also the summit of a ridge. It must be borne in mind, however, that these contours represent the actual surface of the ground and not the rock surface, whereas the geological outlines refer only to the latter; and the records of the depth of Wash in various shafts here show that this ridge was formed by the south moraine of the Evans glacier.

The Keystone (K–58), Uranus (K–53), Tiger bore-hole (K–47), White Check (K–48), Tootie Gaylord (K–46), Big Six, and the lower shaft of the Breece Iron have found White Porphyry immediately under the Wash, the latter shaft being sunk into it for a depth of 350 feet, while the Tiger bore-hole, at a depth of 500 feet, was, as well as could be ascertained, still in it.

On the upper northwest slope of Breece Hill are a number of shafts in the Gray Porphyry, most of which have not gone through it. The Fenian Queen, adjoining the road, passed through 150 feet, respectively, of Gray and White Porphyry into the underlying Weber Shale. The Nora, near the foot of the slope below it, reached the contact under the Gray Porphyry without finding any intervening White Porphyry.

A group of shafts in the neighborhood of the Great Hope and Across-the-Ocean find the Blue Limestone at a comparatively small depth, in general not more than seventy to eighty feet, and the White Porphyry between it and the Gray Porphyry is either very thin (fifteen to twenty feet in the shafts above mentioned) or entirely wanting, as in the Bosco (K–28). The Great Hope, after passing through these sheets of White and Gray Porphyry, found 60 feet of vein material, and reached the Parting Quartzite, here carrying gold, at a depth of 130 feet. On the other hand, directly west of these shafts, the Independent has been sunk 420 feet in the Gray Porphyry and the H. M. L. 160 feet without reaching the bottom, while the Onota, which is 150 feet lower than the Independent, found vein material at a depth of 400 feet, after passing through 300 feet of Gray Porphyry and 100 feet of White Porphyry. There is, therefore, evidently a synclinal basin between the Great Hope and the crest of Yankee Hill, and also some indication that the contact sinks to the eastward before rising up under the influence of South Evans anticline against Weston fault; in other words, that there is a slight ridge or secondary fold in the strata on the line through these shafts, as shown in Section D, Atlas Sheet XVIII.

The Little Prince, on this same line, but higher up on the slope of Breece Hill, reached the Blue Limestone horizon, which is here represented by a mass of silicious vein material containing pockets of carbonate, at a depth of 230 feet. Inasmuch as this shaft starts at an elevation of about two hundred and fifty feet above the Great Hope, the absolute level of the contact is here even higher than at the Great Hope, as shown in Section L, Atlas Sheet XXI.

A number of shafts near this — the Galesburg (K–33), the White Prince (K–36), and Nettie Morgan (K–38)—have also reached the contact after passing through Gray and White Porphyry. The Big Six, at a depth of 300 feet, and the Tiger bore-hole, at 500 feet, as already mentioned, were still in White Porphyry, showing that in a southwest direction it thickens very rapidly. Between Evans gulch and Little Evans the moraine ridge buries the rock surface to such a depth that except at its western end it has not been reached.

On the slope of Prospect Mountain, as will be shown later, the Gray Porphyry is overlaid by the Weber Shales. The underlying White Porphyry is thinning out to the northeast, while still farther north the Mount Zion Porphyry comes in between the Gray Porphyry and the Weber Shales.

Yankee Hill anticline.—Across the west slope of Yankee Hill, just below its crest, runs the axis of an anticlinal fold, which in Evans gulch probably bends to the southwest to connect with the anticline shown at the forks of Little Evans, at the south base of Canterbury Hill. The rock surface in the crest of the fold on Yankee Hill is formed of White Porphyry, belonging to the sheet which comes between the White and Blue Limestones, this region being northeast of the imaginary line already mentioned as running southeast from Fryer Hill, along which the main sheet of White Porphyry splits in two, one portion remaining above the Blue Limestone and the other being found below it.

North slope of Yankee Hill. — The regular succession of beds on either side of the axis of this anticlinal fold is best shown in the shafts on the north side of the hill. In Johnson gulch the Andy Johnson (P–1) shaft reaches the contact after passing through both the main sheet of Gray Porphyry and the underlying White Porphyry, the latter being here 84 feet thick. The Bevis No. 3 (P–5), Bevis Discovery (P–6), and the Boulder Nest (P–8) shafts have started in White Porphyry and reached the contact at depths below rock surface of 170 feet, 45 feet, and 50 feet, respectively, the latter having also 70 feet of Wash. The Hidden Treasure tunnel (P–7) is run in on the contact line. The William and Mary tunnel (P–12) runs on the contact of the Parting Quartzite and White Limestone, and the Sappho shaft develops the contact of White Limestone, dipping 10° east, with underlying White Porphyry. This White Porphyry is the lower sheet which occurs normally between the Blue and White Limestones, and the White Limestone developed in the two shafts is evidently a portion split off from the main formation by this porphyry sheet and left above it. The White Rabbit (P–17) and Little Stella are sunk in the lower sheet of White Porphyry, the latter having reached the main body of White Limestone below it. The Bismark (P–20) and Holden (P–24) are sunk in the lower portion of the White Limestone, near the crest of the fold, the latter having reached the Lower Quartzite beneath it.

On the west of the fold the J. B. Grant and the Dania (P–30) are sunk through the lower sheet of White Porphyry into the underlying Limestone, while the First Chance (P–37), Bobtail (P–40), and the Cordelia Edmonston find Blue Limestone, or the vein material which replaces it, immediately below the Wash. These outcrops form part of the eastern member of the Little Stray Horse syncline.

South slope of Yankee Hill.—On the south side of Yankee Hill, towards Stray Horse gulch, the simple anticlinal structure shown above is considerably complicated. The first disturbing element is the Iron fault, which may be regarded as the result of an anticlinal fold, since the beds dip away from it on either side. Hence, an eastern dip is found here in a position on the slope corresponding to the western dip shown in the last-mentioned shafts, and, by the movement of the fault, Lower Quartzite and Archean outcrops are exposed directly east of it. Besides this, there extends from the crest of the hill southward across Adelaide Park a large mass of porphyry resembling Gray Porphyry, which splits the Blue Limestone, and which, from the meager data obtainable, seems to be cutting up across the formation from below. For convenience of description this mass of porphyry will be called the Adelaide body. Near the crest of Yankee Hill a considerable body of iron-vein material has been developed, which passes into Blue

Limestone to the south and belongs to the eastern member of the Yankee Hill anticline, being a continuation of that found in the Andy Johnson and other mines.

The Little Champion (P–11) and Greenwood shafts were still in this body of vein material, the former at a depth of 200 feet, after having passed through 30 feet of Wash and 15 feet of White Porphyry. The Clara Dell shaft, close by, found Wash, 126 feet; vein material, 5 feet; White Porphyry, 95 feet; Adelaide Porphyry, 20 feet; and White Porphyry again, 121 feet. The Rothschild (P–9) was sunk 65 feet in Adelaide Porphyry, while the Leavenworth (P–4), a short distance east, reached the Blue Limestone after passing through 220 feet of White Porphyry without finding the Adelaide body, which must therefore go down very steeply on this line. The Louisville (O–13) on the north and the Laura Lynn (O–15) on the south side of Adelaide park are both in Adelaide Porphyry, while the Day bore-hole (O–14) in the middle furnishes the following important section, as derived from an examination of drill-cores: Adelaide Porphyry, 100 feet; White Limestone, 87 feet; Adelaide Porphyry, 39 feet; White Limestone, 37 feet; Lower Quartzite, 116 feet; Archean, 2 feet. It thus appears that the Adelaide Porphyry is here in part immediately above the White Limestone, whereas in the Clara Dell it was in the lower body of White Porphyry, which is wanting at this point. From the extremely short distance between the Rothschild and Leavenworth and from the great depth of the Blue Limestone in the latter, it is assumed that a probable angle of dip of the Blue Limestone would bring it to the surface near the former, were it not that it is here cut off by the Adelaide Porphyry, which must cross it nearly vertically. South and east of the Day bore-hole again, the Park (O–4) shaft, the shaft O–6, and the Lily (O–5) shaft find Blue Limestone beneath the Wash, the last having reached White Porphyry beneath it. In the two latter shafts and in the eastern Park (O–1) shaft the limestone has a cream-colored tint, resembling decomposed White Porphyry, while in the western Park shaft it has the characteristic blue-gray color. The underlying White Porphyry is cut in the adjoining shafts (O–10), (O–12), and Keno (O–11), while Keno (O–7) is near the probable line of the Adelaide fault. The Horseshoe shaft, just south of these, at the head of Nugget gulch, passed through over four hundred and eighty feet of the upper sheet of White Porphyry before reaching Blue Limestone.

Adelaide fault.—The Adelaide cross-fault follows nearly the bed of Stray Horse gulch from the Iron fault up as far as the Adelaide smelter, from which point it bends southward, passing to the south of the Laura Lynn shaft. In this portion, however, it is impossible to determine its location with any approach to accuracy, as but few shafts are sunk and at its eastern end White Porphyry occurs on either side of it. Its displacement is slight, its upthrow being on the northeast, and probably reaching a maximum at its eastern end. It might be considered as a branch of the Mike fault, that fault having split into two at its northern extremity.

It must be admitted that the triangular piece of ground in Adelaide Park between the Mike fault and the Adelaide cross-fault, in which the few deep shafts that have been sunk are mainly in different varieties of porphyry which the miners do not distinguish apart, shows a complication of structure of which the explanation afforded by the map and sections may not prove entirely accurate when more extended explorations are made. There seems little doubt, however, that the irregular body of Adelaide or Gray Porphyry has been forced up directly from below somewhere in this region; that it crosses the strata, and by thus interrupting the currents has been influential in determining the deposition of metallic minerals in this neighborhood, which are not only very abundant, but very irregularly distributed.

Southwest slope.—On the southwest slope of Yankee Hill the succession of outcrops indicated by the shafts is as follows: The Shenango (P–16) and Logan No. 2 shafts are in White Porphyry, below the Wash, while the Woodruff and Red-Headed Mary (P–22) have penetrated this body and reached the White Limestone beneath it. The shaft P–25 finds White Limestone below the Wash; the Hard Cash (P–31) and the Moonstone (P–32) shafts are in Lower Quartzite, and the Hard Cash (P–35), Logan No. 1 (P–27), and Silver Basin shafts have penetrated the Lower Quartzite to the underlying Archean. The Double-Decker shafts (P–47 and P–48) have been working on a body of gold ore in the Lower Quartzite, near the junction of the Adelaide and Iron faults.

Moraines.—The depth of Wash, where it could be obtained, affords data for locating the limits of the south branch of the Evans glacier. These nearly coincide with the bed of Stray Horse gulch, which has been eroded along the contact of its moraine with the rock surface to the south. South of this line there is practically no Wash, while the line of shafts just north of it show the following depths of moraine material: Leavenworth (P–4), 207 feet; Rothschild (P–9), 260 feet; Clara Dell, 126 feet; Woodruff, 148 feet; Logan, 100 feet; Silver Basin (P–33), 231 feet; Indiana (P–53), 180 feet; Raven, 200 feet; Right Angle (P–69), 200 feet; Hunkidori (in the gulch), 35 feet; Denver City shafts, 180 feet.

AREA BETWEEN MIKE AND IRON–DOME FAULTS.

The area west of the Mike fault is divided into three faulted blocks by the displacement of the Iron–Dome and Carbonate faults. North of the line of Stray Horse gulch these faults merge into folds, and the structure is that of a series of anticlines and synclines, of which the Yankee Hill anticline and syncline have just been described. In what follows, the areas included between the two faults will be first taken up; then the Little Stray Horse Park syncline and Fryer Hill double anticline; after that the Prospect Mountain region north of Evans gulch, in which the folds are merged into one broad anticlinal and synclinal fold, and finally the as yet unknown mesa region under Leadville itself.

Iron-Dome fault.—The Iron fault has been actually cut by underground workings and its plane explored to a greater extent than any other in the region, so that the line of its intersection with the rock surface is the most accurately determined, and perhaps for this very reason the most irregular. This irregularity has no doubt been exaggerated by the effect of erosion, and if the intersection of the fault plane with the rock surface were in a horizontal plane it would show less abrupt curves, but still present a marked contrast to the lines usually employed to represent fault outcrops.

At its north end, on the west slope of Yankee Hill, as already shown, it merges into an anticlinal fold. Its plane is first cut at the end of the Chieftain (P–43) tunnel, which runs 360 feet in an average direction S. 55° E. through Blue Limestone and vein material, much compressed and broken, and passes suddenly into granite; the plane of the fault is here nearly vertical. South of this point it passes between the (P–46) shaft of the Hard Cash mine in vein material on the west and the two (P–31 and P–35) which are in Lower Quartzite on the east. It crosses Stray Horse gulch between the Argentine tunnel and the Devlin shaft, then is lost sight of in an area of White Porphyry, in which it bends to the west, and is next seen in the Codfish Balls (O–37). Its course beyond this through the mines of Iron Hill will be described in detail in Part II, Chapter II.

Beyond California gulch it is again lost sight of in porphyry, but its line would carry it into the axis of a synclinal fold between California and Iowa gulches. The actually proved continuation of its movement is along the California fault up California gulch to the Dome fault, which runs south across Dome Hill and in Iowa gulch passes into a probable anticlinal fold. The displacement of this fault is an upthrow on the east, its maximum of about one thousand feet being reached opposite the Iron mine, and decreasing both to the north and south.

The area between Mike and Iron–Dome faults from the southern boundary of the map to the Adelaide cross-fault is practically a block of easterly-dipping beds, the surface being principally formed by the main sheet of White Porphyry, with a fringing outcrop on the west of the Blue Limestone, and, where erosion has cut deep enough before the Iron–Dome fault is reached, by those of the lower formations. These are actually exposed only on the south slope of Iron Hill, facing California gulch.

Long and Derry Ridge.—On Long and Derry Ridge, west of the Mike fault, the underlying rocks are buried beneath the moraines of Empire and Iowa gulches, and, as shown on the general map, by Lake beds, so that the indications afforded by shafts of the position of the outcrops of Blue Limestone are comparatively rare. As far as known, the Echo and Hoodoo, at the head of Thompson gulch, are the only ones that have proved it, the one at a depth of 160 feet, the other at a depth of about one hundred and ten feet.

Josephine Porphyry.—The Josephine, Pine Tree, Aurora, and other shafts have developed a body of porphyry which has been called after the first-named shaft, in which it has been best developed. It apparently forms a sheet between the White Porphyry and underlying Blue Limestone, the

Pine Tree having reached it after crossing 145 feet of White Porphyry. It is a coarse-grained, gray rock, containing white and rather glassy feldspars, quartz in smoky, rounded grains, and biotite in distinct crystals. Cavities filled with white opaque calcite are frequently found. The gray color of the groundmass is due to numerous black specks, many of which are ore grains and others minute biotites. The feldspars under the microscope are seen to be partly triclinic, although monoclinic feldspar predominates. Both quartz and feldspars contain inclusions of the groundmass and glass inclusions. In the quartz, in one case, fluid inclusions with a moving bubble are also observed. Calcite is present in considerable quantity, both in the groundmass and in the feldspars. In general, from the microscopical examination alone, Mr. Cross would have been inclined to class this rock among the Tertiary eruptive rocks. If it be so, it is probably not an intrusive sheet, as has been assumed, but an irregular dike. These indications do not, however, seem sufficiently decisive to outweigh those of its field habit and mode of occurrence, which ally it to the later intrusions of porphyry of pre-Tertiary age.

Lake beds.—Lake beds were found in a prospect hole near the shaft M–41, were passed through by the Pine Tree shaft, and penetrated to a depth of 175 feet in the Continental shaft (M–50), which was sunk in the Iowa south moraine. Several shafts and tunnels have been run in this moraine and have very probably penetrated the underlying Lake beds, but, as far as known, have not reached rock in place on the south of Iowa gulch.

Iowa gulch.—On the north bank a number of shafts and tunnels have proved the existence of outcrops of Blue Limestone in the vicinity of the Nisi Prius workings, one of whose tunnels has followed the contact for a distance of 700 feet, disclosing a considerable body of contact vein material. The Little Birdie (N–18) tunnel was driven 200 feet in the moraine without reaching rock in place.

Dome Ridge.—On Dome Ridge the principal developments have been made near the outcrops of the Blue Limestone, the few shafts in porphyry at considerable distance east of this not having been sunk to any great depth. No definite data are therefore obtainable as to the aggregate thickness of the White Porphyry sheet. The principal workings are those of the

Dome, Rock, and La Plata mines, the former of which is an incline following down the contact to the east, and the two latter tunnels running in at or near the contact, in a southerly direction. On the steep hillside, at the mouth of the Rock tunnel, stood once a huge outcrop of hard carbonate, from which was obtained the first ore of this character found in the region. A short distance above the contact, on Dome Hill, is an intrusive sheet of Gray Porphyry, which, on the western point of the outcrop, cuts up into the White Porphyry, but in California gulch comes actually in contact with the limestone, and at the La Plata mine cuts into it so that a small detached portion of the limestone is left above this intrusive sheet. It also extends up the south slope of Iron Hill, parallel to the contact, and only separated from it in places by a thin sheet of green *Lingula* shales, which belong to the Weber Shale formation. At the foot of the steep slope of Iron Hill, opposite the Rock mine, the Blue Limestone is laid bare in the quarry of the Montgomery claim.

South slope of Iron Hill.—The steep north slope of California gulch, from here down to the Iron fault, which crosses the gulch at the Garden City mine, presents actual outcrops of the lower Paleozoic formations, the Blue Limestone, Parting Quartzite, White Limestone, and Lower Quartzite, together with an intrusive sheet of Gray or Mottled Porphyry near the bottom of the Blue Limestone. In point of fact, these outcrops are covered by from six to ten feet of slide material, but are readily seen in the numerous prospect holes which dot the side of the hill. The dip of the limestone, as shown by the various inclines on Iron Hill, varies from 12° to 25°, while its strike is more nearly north and south than the average strike of the sedimentary beds throughout the region. In the Iron mine itself the dip shallows as it is followed into the hill, and becomes, beyond the Tucson shaft, nearly horizontal; while in the Horseshoe shaft, at the head of Nugget gulch, which has reached the contact at a depth of 482 feet, the limestone is said to have dipped 8° to 10° to the southwest, showing a tendency to a synclinal structure in this block of ground, which is still more marked in the block next west. The Colonel Sellers shaft and drill-hole, south of this, near the mouth of Nugget gulch, had not yet reached the contact.

North Iron Hill.—From the Codfish Balls shaft northward to Stray Horse gulch the line of the Iron fault is somewhat indefinite, the miners who sunk the few shafts not having found any valuable ore bodies at the contact and having confounded the limestone, which is here bleached quite white, with the overlying porphyry. In the angle between the Iron fault and the Adelaide cross-fault, as shown by the workings of the Argentine and Adelaide mines, the formation dips to the southeast, so that successive outcrops of White Limestone and Lower Quartzite are brought to the surface. The structure at this point, which will be explained in detail in Part II, Chapter II, is still further complicated by the intrusion of minor sheets of Gray and White Porphyry, which have split up the Silurian formation, and by the crossing of the main sheet of White Porphyry down to the horizon of the Parting Quartzite across the basset edges of the Blue Limestone. The principal mineralization has here taken place at the contact of this White Porphyry with the Parting Quartzite, instead of, as in other cases, on the surface of or in the Blue Limestone.

AREA BETWEEN IRON–DOME AND CARBONATE FAULTS.

Carbonate fault.—Carbonate fault has a general direction a little more to the east of north than Iron fault. Its upthrow is likewise to the eastward, and the displacement has a probable maximum in the bed of California gulch, where Silurian beds are proved by shaft developments to come in contact with White Porphyry. On the southern slope of Carbonate Hill its plane is actually proved in the shafts of the Ætna and Yankee Doodle mines. Here its movement is only about two hundred feet; but a second fault is found crossing the Glass–Pendery claim, the amount of whose movement, which is also an upthrow to the east, is not known, since the contact has not been reached on its west side. This fault apparently joins the Carbonate fault before reaching California gulch. Northward the movement of the Carbonate fault gradually decreases and is partially distributed among some smaller faults and folds. In this portion its actual plane has not been proved; and it is very possible that it does not extend as a continuous fault as far as indicated on the map. Indeed, in the

Waterloo claim its continuation shows a slight upthrow to the west, so that at some point south of that its movement must be null.

South of California gulch.—Of the actual rock surface of the southern portion of this area, which is deeply buried beneath thick deposits of Lake beds and the superincumbent moraines of the Iowa glacier, nothing is as yet definitely known. The outlines as given on the map must therefore be regarded as theoretical deductions from the structure of the adjoining regions developed by actual explorations. That a synclinal fold exists here is well proved, and the probable slope of the rock surface beneath the Lake beds would cut off the successive sedimentary formations approximately along the lines represented on the map.

In Iowa gulch the few prospect shafts were still in surface material. The Black Cat shaft, on the ridge north of the gulch, had been sunk 530 feet through moraine material and underlying Lake beds.

In Georgia gulch the developments of the Coon Valley shaft, where a drill was supposed to have reached contact at 575 feet, show a thickness of 200 feet of Wash, 375 feet of Lake beds, and 75 feet of White Porphyry, with the contact not yet reached at 650 feet. The Resumption shaft, near this, found the same thicknesses of Wash and Lake beds, but had not reached the porphyry. In the Zulu King (N–24) and Commercial Drummer (U–1), northwest of this, near the top of the ridge overlooking California gulch, White Porphyry was found at comparatively shallow depth immediately under the Wash, showing that beneath Georgia gulch a bay once existed in the original Arkansas lake.

Proof of synclinal fold.—The intrusive body of Gray Porphyry between White Porphyry and Blue Limestone comes to the surface on the banks of Iowa and California gulches, adjoining Dome fault on the west, thus proving a westward dip in the underlying formations; in other words, that they basin up to the eastward and that the Dome fault runs along or near the axis of a shallow anticlinal fold. It has been reached after passing through White Porphyry on the California gulch side by the Bank of France shaft, in the angle of the Dome and California faults; by the City Bank and Oro City shafts, higher up the slope; and by the Vining (N–19), near the fault on the crest of the ridge, which reached it after passing through the overlying White Porphyry.[1]

Emmet fault.—The Robert Emmet tunnel (O–45) starts in near the contact of Gray Porphyry and overlying White Porphyry. A winze was sunk in the tunnel, from which a drift to the west has cut the Emmet fault, a short cross-fault, by whose movement a little triangular block of ground is lifted up on the westward. Parallel with this fault is a slight anticlinal fold, along the axis of which the Columbia tunnel runs in on the contact and finds the formation dipping away to the right and left, but more steeply to the westward. The Blue Limestone is found in actual rock outcrop on the bank of the gulch below this. The Crescentia shaft, a little west of the Columbia, had reached the Gray Porphyry under the White Porphyry at a depth of 335 feet. It is probable that this body of Gray Porphyry thins out to the west of this.

As to the exact line of the continuation of the Iron fault on the south side of the gulch, if it extends so far, no data have yet been obtained, nor can it be definitely stated whether Crescentia shaft is to the east or to the west of this line. The dip of the formation west of the Columbia tunnel is steep enough to account for the contact not yet having been reached in this shaft at a depth of 335 feet.[2]

Graham Park.—On the steep west slope of Iron Hill toward Graham gulch the White Porphyry is probably at its thickest in this area. The Blind Tom shaft has been sunk in it to a very considerable depth, though the exact depth could not be ascertained. The City of Paris shaft and bore-hole are said to have passed through 200 feet of Lake beds and 600 feet of White Porphyry below them. Other shafts on the Carbonate Hill side have reached depths of 500 feet and are still in the porphyry. The Devlin shaft, however, on the northwest slope of Iron Hill, reached the contact at 200 feet and the Highland Mary (P–52) found it at 175 feet. These facts furnish a direct evidence of what might have been assumed by analogy, that the

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[1] Since the close of field-work contact has been reached in the Vining at 317 feet and in the Little Rosie at 375 feet, in the latter of which the formation is said to dip 30° to the southwest, thus confirming the deductions made from the relations of the two porphyry bodies.

[2] Since the close of field-work a westerly-dipping contact is said to have been reached by a drift east from the bottom of the Crescentia shaft, at a distance of 300 feet.

synclinal structure of Little Stray Horse Park, which is on the direct northern continuation of this block, continues in modified form to the southward. It is very probable, therefore, that the contact rises to the eastward before reaching the Iron fault along its entire extent, though it is impossible to say at what angle. In the Agassiz, Greenback (O-53), and adjoining shafts a sheet of vein material of relatively small thickness is found dipping to the northeast, with White Porphyry on either side. This represents a portion of the Blue Limestone which has been split off from the main body by the cutting down of the White Porphyry; that is, the lower sheet of White Porphyry here crosses the Blue Limestone formation at a low angle, leaving wedge-shaped portions of the latter above and below it overlapping each other. The folding of the Little Stray Horse syncline and subsequent erosion have produced a curved line of outcrop, approximately as given on the map. The thin streak of blue on the south side of Stray Horse gulch represents a thin sheet split off from the main body of Blue Limestone, which to the northward thickens so as to include the whole of this body on Fryer and Yankee Hills; while here the bulk of the Blue Limestone is separated from this thin sheet by a great thickness of White Porphyry, probably not less than 600 to 800 feet.

The Greenback shaft, after passing through Wash and Lake beds and 10 feet of White Porphyry, found vein material and limestone in a thickness of 55 feet. The Mahala (T-2) passed through 145 feet of overlying White Porphyry, 10 feet of vein material, and 105 feet of underlying White Porphyry. The Agassiz passed through 40 feet of overlying White Porphyry, 5 feet of shales, and 30 feet of vein material. The Gone-Abroad (T-4) also found vein material, after passing through White Porphyry, at a depth of about seventy-five feet. The Robert Emmet shaft (S-3), after passing through 210 feet of Wash and White Porphyry, cut 50 feet of vein material and passed again into White Porphyry, showing a considerable thickening in the body of vein material to the northward. An actual outcrop of this body of iron is found on the south side of Stray Horse gulch, near the Robert Emmet tunnel (S-13). The Wolfe Tone shaft (T-5), which is about five hundred feet west of the Agassiz, has been sunk to a depth of over five hundred feet in the White Porphyry, which is here underlying the Agassiz deposit, but without reaching the lower Blue Limestone.[1]

California gulch.—On the west side of the area under consideration rock in place has not been found south of California gulch, except in the Swamp Angel and Jordan (T–14) tunnels on its south bank, which have been run for some 400 feet southward on the contact. The Deadbroke (T–16) and Rosebud (T–18) have also developed the contact on the north side of the gulch, and the J. Harlan shaft has been sunk through Blue Limestone into an underlying sheet of Gray or Mottled Porphyry. Higher up the gulch the Last Rose of Summer and some adjoining shafts struck slates and sandstones belonging to the Weber Shale formation, which belong to a portion of the formation included in the White Porphyry. The Prospect incline, starting in at an angle of 23° in the White Porphyry, reached the contact, whose angle is somewhat shallower (averaging from 12° to 20°), and followed it in for a distance of over five hundred feet. At 375 feet from the mouth was a sharp fold, possibly accompanied by some displacement, in which the contact went down almost perpendicularly for about one hundred and twenty-five feet, and was found again in its normal position at a distance of 14 feet beyond in the regular course of the incline.

The White Limestone is opened in a quarry adjoining the road on the north side of California gulch, directly below the Prospect incline. This is the only point where the White Limestone is found actually visible on the surface in the immediate vicinity of Leadville. The O'Donovan Rossa shaft is also in White Limestone, while the Irish Giant, above it, is sunk through the same sheet of Mottled Porphyry shown in the J. Harlan, into the underlying half of the Blue Limestone. The shaft (T–46) is also in White Limestone, while the adjoining Blind Tom shaft is in White Porphyry on the west side of the fault. A second intrusive body of Gray or Mottled Porphyry in the White Limestone itself is proved by some small shafts in California gulch not indicated on the map, which also show the cropping of

[1] Since the close of field-work the Wolfe Tone shaft has reached vein material and limestone at a depth of 625 feet, and after passing through it struck another body of porphyry, whether belonging to the underlying intrusive sheet of Gray Porphyry or White Porphyry is not known. It is probably the former.

the upper portion of the Lower Quartzite adjoining the fault. A shaft still lower down, opposite the sampling works on the edge of the creek bed, is sunk several hundred feet in White Porphyry.

Carbonate Hill.—The area east of Carbonate fault, included in the Carbonate Hill map, will be treated in detail in Part II, Chapter III, and only the general features need here be mentioned. The strike of the Blue Limestone is nearly north and south, bending somewhat to the eastward toward the northern end of the hill. Its dip may be taken at an average of 21°, but is found locally to vary very considerably on account of a series of longitudinal waves or folds in the formation. The sheet of Gray or Mottled Porphyry within the Blue Limestone is very persistent, and is evidently a later intrusion. From data obtained from the few points at which it has been proved by underground workings, it is evident that it is not confined to any particular horizon, but locally cuts across the beds, sometimes at a considerable angle. It is best shown in the Evening Star mine, where it seems to be at the base of the Blue Limestone. What is apparently an offshoot from it is found at the contact in the Morning Star mine and extending up into the overlying White Porphyry, while west of the line of the fault in the Forsaken and Henriett mines the main sheet is found cutting across the Blue Limestone, and the principal mineralization has taken place between it and the portion of the Blue Limestone which underlies it.

Of the country underlying Stray Horse gulch, Stray Horse Ridge, and Little Stray Horse gulch the structural data obtained from explorations are somewhat unsatisfactory; but on Fryer Hill the continuation of Carbonate fault is found to be a gentle anticlinal fold whose axis runs in a northeasterly direction through the Dunkin ground.

Little Stray Horse syncline.—Between Yankee Hill and the crest of Fryer Hill, through which also runs a general anticlinal fold, is included a basin or synclinal fold in the formation, whose deepest portion underlies Little Stray Horse Park. The surface rock in the center of this basin is the main sheet of Gray Porphyry, which is separated from the underlying Blue Limestone by a comparatively thin sheet of White Porphyry. The angle of dip of the beds follows the general rule which prevails in the folds in this region and is steeper on the east side of this syncline than on the west.

Eastern rim.—The Blue Limestone, which is largely replaced by vein material, comes to the surface on the eastern rim of the basin along the foot of the steeper slope of Yankee Hill. It is found directly under the Wash in the Cordelia Edmonston and adjoining shafts. The Birdie Tribble (P–42), at the very edge of the basin, found five feet of porphyry above the vein material and limestone. In the shafts of the Kennebec (P–55) both Gray and White Porphyry are passed through before reaching the limestone, and a sheet of porphyry six feet thick was also cut in the body of the limestone. The Chieftain tunnel and incline run in a southeasterly direction 360 feet through vein material and limestone, finding the Iron fault with granite on its farther side at the end. The limestone here shows the effects of a movement against the fault plane, being compressed into short sharp folds and much metamorphosed. There is a general tendency, however, to dip to the northwest; and it is probable that the extremity of the incline is in the White Limestone, although lithological indications are here extremely deceptive, owing to the alteration to which the rocks have been subjected. The Scooper shaft (P–44), a little to the south of the Chieftain, passed through 20 feet of Gray Porphyry and 5 feet of White Porphyry before reaching the Blue Limestone. The contact here stands so nearly vertical that it was supposed by the superintendent to be a fault. This supposition was rendered more probable by the fact that the line of this contact runs in a southeasterly direction. It is probably, however, only an exceptionally steep dip on this side of the basin. South of this the Del Monte (P–45) shaft is in Gray Porphyry. The Hard Cash (P–46) shaft is in vein material. The Fairplay (P–34) is still in White Porphyry, below the Blue Limestone. The upper White Porphyry, so thin in the Scooper, disappears entirely a little farther south, being altogether wanting in the Rarus shaft (P–61); or, as it might be considered, it is found entirely below the upper sheet of Blue Limestone.

The fact that the Blue Limestone is split into two sheets by the White Porphyry is shown in the shafts east of the Rarus in Stray Horse gulch. The Indiana shaft (P–53) finds the limestone directly under the Wash. East of this the Young Caribou (P–59) finds White Porphyry under the

Wash; and the Highland Mary (P–52) and Snowstorm (P–50), after passing through White Porphyry, reach the lower sheet of Blue Limestone beneath it.

Center of basin.—Towards the center of the basin a number of shafts have been sunk to a considerable depth in the overlying Gray Porphyry, and generally find sandstones or black carbonaceous shales at its contact with the overlying White Porphyry, but none have as yet reached the Blue Limestone. The greatest depths obtained have been in the Little Miami (P–58), which went through 269 feet of Gray Porphyry and 30 feet of White Porphyry, having a total depth of 396 feet; the Indiana (P–64) shaft, 230 feet of Gray Porphyry in a total depth of 330 feet; the El Paso, 325 feet of Gray Porphyry, having a total depth of 470 feet, and the Lickscumdidrix bore-hole (P–68), which went through 400 feet of Gray Porphyry without reaching the White Porphyry. The deepest portion of the basin is probably somewhere near the latter.

Western rim.—On the western rim of the basin contact has been reached in the shafts of the Denver City, Tip top, and Little Sliver mines, in which a varying thickness of black shale and sandstone, belonging to the Weber Shale group, has been found at the contact of Gray and White Porphyry. The Bangkok (P–77) has penetrated the Gray Porphyry to the underlying White Porphyry, while the Forepaugh (P–76), Cora Bell (P–78), and Union Emma (P–79) are still in Gray Porphyry. The Hunkidori shaft, in Little Stray Horse gulch, at the southern end of the basin, has already reached White Porphyry under the Gray. The Denver City (P–82), Wright (P–74), and Shamus O'Brien (P–73) shafts found Gray Porphyry under 180, 157, and 165 feet of Wash, and reached the Blue Limestone horizon at 234, 320, and 362 feet, respectively, each disclosing about ten feet of sandstone and shale, which carried as high as 22 ounces of silver, between Gray and White Porphyries.

FRYER HILL.

As the structure of Fryer Hill will be given in detail in a later chapter, it is only necessary here to give a brief outline of its structure as bearing on that of the surrounding regions.

In this area the formations have a general dip to the northeast, while along an east and west line they partake of the anticlinal and synclinal structure, which is already under discussion. On such a line, as shown in sections C and D, it is seen that the formations developed on Fryer Hill constitute the western rim of the Little Stray Horse basin, being at the same time compressed into a shallow anticlinal and synclinal fold. The axis of the anticline runs through the crest of the hill in the ground of the Dunkin mine, on a line with the continuation of the Carbonate fault. West of this is a broad, shallow synclinal fold, which takes in the ground of the Little Chief, Little Pittsburgh, and Chrysolite mines, giving to the outcrop of the Blue Limestone, as shown on the map, the form of an **S**. In the western portion of the Chrysolite mine ground, successively lower sheets of the lower White Porphyry, White Limestone, and Lower Quartzite come to the surface along the crest of an anticlinal fold, on whose western side, so far as the meager data obtained show, these beds dip steeply under the Wash and Lake beds which form the mesa-like surface of North Leadville. The difficulty of reading the geological structure of this area, which in the above brief statement seems simple enough, is enhanced by a variety of causes. In the first place, here, as in Little Stray Horse Park, there are no outcrops of rock in place, the rock surface being buried beneath about 50 to 100 feet of Wash. The data have therefore to be entirely obtained from shafts, and cannot be intelligently considered until they have been thoroughly mapped. Secondly, the replacement action has proceeded so far that practically no limestone is left, its whole mass having been replaced by vein material. Thirdly, this mass has been split up locally into two or more distinct sheets by the intrusion of White Porphyry. Fourthly, the lower sheet of White Porphyry is cutting across the formation; and, southwest of a line drawn diagonally through the corners of the Fryer Hill map, a wedge-shaped portion of the Blue Limestone is left below this sheet. Fifthly, there are later intrusions of Gray Porphyry extremely difficult to trace, as in their decomposed state they are scarcely distinguishable from the White Porphyry. An interrupted dike of this rock runs through the middle of the area in an east and west direction; and an intrusive sheet cuts diagonally across the White Limestone up into the lower sheet of White Porphyry, and on the north slope of Carbonate Hill into the Blue Limestone. This Gray Porphyry is exposed in the Vulture No. 2 workings of the Chrysolite mine, in the No. 5 shaft and drifts connecting it with No. 1 of the New Discovery mine, and on Carbonate Hill in the lower workings of the Waterloo and Henriett claims. The porphyry dike is seen in the workings of the Chrysolite, Little Chief, Little Pittsburgh, Amie, Big Pittsburgh, Hibernia, and Lee mines. The White Limestone has been reached in the Amie No. 2 shaft, New Discovery No. 6, and found at the surface under the Wash in the shafts of the Fairview, All Right, and Kit Carson, and in the Chrysolite No. 6 (S–51), while the Lida shaft (S–52), near Cumming & Finn's smelter, and the Little Eva (S–53) reach the Lower Quartzite below the Wash, the former finding a small body of White Porphyry included in it.

PROSPECT MOUNTAIN.

North of Evans gulch the geological structure, although probably more simple, is more difficult to read, owing to the thickness of loose detrital material above the rock surface and the relatively small amount of underground exploration. The North Evans moraine covers an area, widening towards its lower end, which but few miners have been enterprising enough to penetrate to the rock surface beneath, while on Prospect Mountain itself the Weber formations and the various porphyry bodies, of which it is mainly composed, present but few definitely distinctive characters by which to guide the geologist. In this region faulting action has apparently entirely ceased, and the structure is that of a somewhat irregular system of anticlinal and synclinal folds, whose axes run in such varying directions that it is difficult to deduce from them a satisfactory system. Sections A and B, Atlas Sheets XV and XVI, which run east and west, and Sections M and N, Atlas Sheet XXII, which run north and south, give a graphic delineation of the system of folds at right angles to either.

Crest of the ridge.—To the north and east the White Porphyry gradually thins out and the Gray Porphyry comes in contact with the Blue Limestone, while above this a sheet of Mount Zion Porphyry rapidly thickens and reaches its maximum on the north side of the Prospect Mountain, facing the East Arkansas Valley. West of the summit of Prospect Mountain the structure is that of a broad anticlinal and synclinal fold. On this line, by a deeper erosion at the head of the north fork of Little Evans, the body of Mount Zion Porphyry has been exposed, to be covered again farther west by portions of the Weber Shales and Weber Grits which have escaped erosion on the top of Canterbury Hill, while at the foot of the steep slopes in the valley of the east fork of the Arkansas the Blue Limestone comes to the surface beneath the overlying Gray and White Porphyries. The Weber Shales, which are brought to the surface by erosion, on the east side of the Mount Zion Porphyry, are shown in the Esmeralda, Spotted Tail (I–2), Little Maud (I–3), and Peru (I–5). The Thin Space (I–6) shaft penetrated them to the underlying Mount Zion Porphyry, and the Texas Ranger and Texas Boy's Chance, together with the intervening shafts, are in the outcrop of Mount Zion Porphyry, which is traced as far west as the Liberator.

Southern slope.— Along the foot of the steep southern slope of the mountain runs an anticlinal fold with an east-and-west axis, whose culminating point, as shown in Section N, is at the forks of Little Evans gulch. Between this and the top of the ridge is a shallow syncline, along whose axis a portion of the Weber Grits is left above the Weber Shales. The Gray Porphyry underlying the Weber Shales on the west side of this syncline is developed by the Brick Top, Bosco, Moose, and neighboring shafts. Towards the north fork of Little Evans the Hecla and Mountain Lion shafts and the Boettcher (Q–20) and adjoining (Q–19) tunnels are in the Weber Shales; the Geneva Lake (Q–3), Mary Ella (Q–4), Katie Sullivan (Q–11), and Buncombe (Q–13) in the underlying Gray Porphyry.

On Canterbury Hill the Garland (Q–33), Little Willie (Q–49), and adjoining shafts are also in the Weber Shales, on the south side of the syncline; likewise the Maryland, which develops the commencement of the body of Mount Zion Porphyry, here only five feet in thickness. The Resumption (Q–60) shaft is in the Weber Grits, in the middle of the syncline. The Cardinal (Q–39) shaft finds a thin detached body of Weber Shales between Gray and White Porphyries

The Great Prince and Minneapolis, on the north side of the syncline, develop the Mount Zion Porphyry under the Weber Shales, of which in the latter shaft a bed 30 feet thick seems to be included within the body of Mount Zion Porphyry Between the Princeton (Q–52) and Little Blonde tunnels and the St. Louis shaft the data furnished by intervening shafts show the existence of a second minor syncline. The St. Louis reaches the limestone after passing through 45 feet of Gray Porphyry and 30 feet of White Porphyry. The Mary Ann shafts (Q–51 and Q–56) find White Porphyry at the surface on the crest of a minor anticline. The shafts Q–45 and Q–46 are in Gray Porphyry at the surface, while the Little Blonde and Princeton tunnels develop a considerable body of iron-stained chert, replacing the Blue Limestone and dipping to the north under the White Porphyry.

Little Evans anticline.—Immediately below these two tunnels is the apex of the Little Evans anticline, whose main axis runs east and west. It is also connected with the Yankee Hill anticline by a fold running southeasterly and with the Big Evans anticline by one running southwesterly, between which is included the northern extension of the Little Stray Horse syncline. The lowest formation exposed on the crest of the Little Evans anticline is the Lower Quartzite, which is found below the Wash in the Lucknow shaft (Q–54). The Norcom (Q–55) shaft, a little north, finds the White Limestone dipping northward, and the Little Clara (Q–63), south of this, penetrates the White Limestone to the underlying quartzite. A little northwest of this the Lac-la-Belle finds Blue Limestone beneath the Wash.

The axis of the east and west fold, which sinks to the eastward, can be traced in a line of shafts from the Lucknow to the Uncle Sam. The Catawba tunnel (Q–41) runs in on the Blue Limestone just above the Parting Quartzite. The Carbonate No. 2 (Q–37) shaft is sunk through a body of Gray Porphyry, which is included in the Blue Limestone, into the Blue Limestone below, at a depth of 140 feet. The Swing tunnel (Q–42) and the Copenhagen (Q–43) and Carbonate King (Q–36) shafts are in the Blue Limestone on the south side of the fold In the Hancock (Q–31) and Providence (Q–32) shafts, on the crest of the fold, Blue Limestone dips with it eastward. The Pacific shaft (Q–35) shows a southward dip in the Gray

Porphyry overlying the Blue Limestone. The Columbia shaft, between the forks of Little Evans, penetrates 30 feet of Gray Porphyry and 100 feet of Blue Limestone to the Parting Quartzite beneath. The Humboldt and other shafts between the last mentioned and the Uncle Sam are all in Gray Porphyry. At the Uncle Sam shaft the White Porphyry comes to the surface in the crest of the anticlinal fold, whose axis here rises so that for a short distance the porphyry has been eroded off it. The Uncle Sam shaft has been sunk for a depth of 420 feet, passing through 100 feet of White Porphyry, the underlying Blue Limestone, Parting Quartzite, and White Limestone, and extends 40 feet into the Lower Quartzite, while the Uncle Sam tunnel has been run 250 feet into the overlying Gray Porphyry, and the Powhattan (Q–7) shaft adjoining was sunk through White Porphyry into the Blue Limestone. The Powhattan (Q–9), Rome (Q–6), Eaton (Q–10), and others on the hill above are in Gray Porphyry.

Yankee Hill anticline.—Of the anticlinal ridge connecting the Little Evans with the Yankee Hill anticline, few data have been obtained. The Little Hoosier, Abe Lincoln, and shafts P–29 and P–38 have penetrated the Wash to the underlying Gray Porphyry, in which the first named has been sunk 170 feet, the moraine material at this point being 120 feet deep. The shaft P–39 has reached the Blue Limestone beneath the Wash, and the Chicago Boy (P–67) passes through the Parting Quartzite into the lower sheet of White Porphyry. This lower sheet of White Porphyry has not been found north of this point, and is supposed to wedge out.

Little Stray Horse syncline.—In the northern continuation of the Little Stray Horse syncline the Buffalo shaft and drill-hole, on the Evans moraine ridge, is said to have reached a depth of 450 feet and is still in Gray Porphyry; and the shaft S–10 is also in Gray Porphyry. No other data could be obtained as to the depth of this basin, so that it can only be said that in its center the contact is probably 500 feet deep at least.

Big Evans anticline.—Of the Big Evans anticline, which is a continuation to the northward of that shown on the west edge of Fryer Hill, data are still more meager. The Argo (R–5) shaft finds White Porphyry beneath the Wash and is sunk into the underlying Blue Limestone. Adjoining this on the east is the Douglas (R–4*a*) shaft, and on the north the R–4 shaft, each in White Porphyry on either side of what is supposed to be the ridge of Blue Limestone connecting this anticline with South Evans anticline. The Third Term (S–44) bore-hole, just across Evans gulch from the Cumming & Finn smelter, passed through 170 feet of Wash into the Lower Quartzite, in which it found a small body of White Porphyry, supposed to be the same as that already mentioned as found in the Lida (S–52) shaft, on the other side of the anticline. The outcrop of Archean indicated on the map has not been proved by any shaft, but is simply a theoretical deduction from the dip of the beds, the rock surface being buried beneath one to two hundred feet of Wash. On the southwest slope of this anticline the Mystic and Silver Pilot (R–8) have been sunk a short distance in the overlying Gray Porphyry. The Oölite (S–57) shaft passed through 100 feet of Gray Porphyry and 15 feet of White Porphyry, reaching a considerable body of vein material and chert, in which were found fossils characteristic of the Blue Limestone horizon. The Sequa shaft (S–58), about eleven hundred feet west of this, reached a depth of 280 feet, still in Gray Porphyry, showing that the actual contact must be at a still greater depth, and thus proving the southwestern dip on this side of the anticline and a synclinal fold to the west.

AREA WEST OF CARBONATE AND FRYER HILLS.

General structure.—From the foot of Carbonate and Fryer Hills extends a broad, flat, mesa-like ridge, sloping at a regular angle of about two and a half degrees to the Arkansas Valley. This even surface is doubtless conformable with the surface of the stratified Lake beds which underlie it, over which rearranged moraine material or Wash has been spread out with comparative uniformity by the action of water. The relics of the moraines which were left by the Big Evans glacier are found in the ridge which extends from the west end of Fryer Hill to Capitol Hill; also, in James Ridge, adjoining the mouth of Big Evans gulch, and in a smaller ridge between the two, below North Leadville. No shaft has yet reached the rock surface beneath these recent accumulations of detrital material. The outcrops indicated on the map, and the basin character of the area, as shown in cross-sections, are therefore, in one sense, purely theoretical. As they have been determined, however, after a careful consideration of all the known facts and probabilities, it is well to state somewhat in detail the grounds on which the existence of a synclinal basin is rendered probable. The first argument in its favor is that of analogy, drawn from the existence of a synclinal basin adjoining it on the east, in Little Stray Horse Park, which evidently continues southward through the block of ground between the Carbonate and Iron–Dome faults. The facts to support this argument, viz, the proof of an actual dip towards the center of the basin from either side, are as follows:

Eastern rim of basin.—First, a western dip in the overlying beds on the west side of the Big Evans anticline is shown by the developments of the Oölite and Sequa shafts. Secondly, the Bob Ingersoll shaft and drill-hole, on the moraine ridge west of Fryer Hill, in East Ninth street, after passing through moraine material and Lake beds, are said to have penetrated nearly three hundred feet of White Porphyry. This shaft is southwest of the line where the White Porphyry cuts down below the horizon of the Blue Limestone. It is probable, therefore, that the porphyry cut in this shaft belongs to the upper sheet above the Blue Limestone, and the fact that so great a depth as 300 feet has been reached without finding contact indicates a very steep dip to the westward. The owners of the American Eagle shaft, at the west base of Fairview Hill, state that the limestone in their workings, which the dump shows to be White Limestone, dips both eastward and westward, which would show that there is an anticlinal fold here.[1] Third, along the west base of Carbonate Hill, the Pocahontas (T–40), Weldon (T–41), Rough and Ready, and other shafts have been sunk to a considerable depth in the White Porphyry beneath the Wash, and the California tunnel is also in White Porphyry until it reaches the Blue Limestone beyond the fault. This White Porphyry can be no other than that which overlies the Blue Limestone, since in this region no considerable body of White Porphyry is known to exist below this horizon; moreover, in the Niles-Augusta, Wild Cat, Washburne, and other mines, as will be explained in the detailed chapter on Carbonate Hill, there are indications of a prevailing western dip to the formations west of Carbonate fault. This summarizes the evidence of westerly dipping beds on the east side of the synclinal basin.

[1] Since the close of field-work, Mr. R. N. Clark, superintendent of the Chrysolite mine, states that the extreme west workings of that mine show the Lower Quartzite and White Limestone to be dipping to the westward.

Western rim.—On the western side, in the little cañon at the mouth of the east fork of the Arkansas, adjoining the west end of James Ridge, the Lower Quartzite is exposed in considerable thickness at the surface, dipping at an angle of 8° to 10° to the southeast, and some workings to the east of this, along the northern edge of James Ridge, are said to have disclosed the overlying White Limestone. The Peoria shaft, on James Ridge (not indicated on the map), may be expected to afford further data as to the actual line of outcrops of the formations and what portion of them have escaped erosion, when it reaches the rock surface. At the time of writing this shaft had a depth of 375 feet and was still in the marl of the Lake beds.

From these meager data and from the probable thickness of Lake beds and the angle of dip of the underlying formations the line of outcrops of the western rim of this basin have been constructed. While, therefore, the fact that a synclinal basin exists beneath this area seems fairly well established by the evidence just given, there is only a possibility that the line of outcrops given on the map will be found by future exploration to be strictly correct. They are dependent on two as yet unknown quantities: first, the angle of dip of the formations on either side of the basin, and, secondly, the amount of erosion which had taken place before the Lake beds had been deposited, or, what amounts practically to the same thing, the thickness of the Lake bed deposits which now underlie Leadville.

EXPLANATION OF TRANSVERSE SECTIONS.

The detailed description given above of the geology of the Leadville area can perhaps best be summarized in a consideration of the various sections which accompany the map, and in which this structure is graphically delineated. For its better comprehension the reader is requested to place these sections one above the other in the order indicated by their letters, commencing at the top. The first nine sections (A to I) are on east and west lines, approximately parallel with each other. These sections, being in general across the strike and more or less at right angles to the fault planes, show not only the amount of displacement occasioned by these faults, but the longitudinal folds into which strata have been compressed, and which are more or less intimately connected with the faults. The other seven sections (J to P) run north and south and give the effects of lateral pressure. As these are more or less parallel to the fault planes, they intersect the latter generally at an acute angle, and the angle of intersection is often much lower than the actual slope of the fault plane.

In representing the slope of the fault planes, in all cases where there were no data from actual developments it has been given as inclining toward the hanging-wall side at an average angle of 75°, and when cut diagonally by the plane of the section the angle of intersection was calculated from these premises. As all these sections are carefully constructed to scale and have a common base line, which is taken at 9,000 feet above sea-level, they represent with a high degree of accuracy the surface of the country and the relative thickness of the different sedimentary bodies, and in less degree that of the porphyry bodies, as far as can be deduced from their surface outcrops. In order to show as far as possible the data from which these sections have been constructed, the various shafts on or in close proximity to the plane of each have been indicated on the sections by lines running below the surface to show the depth to which their explorations have reached, full lines indicating those on the section plane, dotted lines those near it. The relative frequency of these shafts is therefore an indication of the comparative accuracy of the different portions of the section. It must, however, be borne in mind that the underground structure has been arrived at not solely by consideration of the shafts on the actual line of the section, but also by the consideration of the data obtained from the exploration of shafts over a comparatively large area, which afford grounds from which the theoretical structure may be deduced.

Section A.— Section A runs along Prospect Mountain ridge a little south of its crest and crosses diagonally the valley of the east fork of the Arkansas near its mouth. Its line lies entirely north of the extreme limits to which the movements of the faults have been traced. Its structure lines contrast strongly with those of the other sections on account of the broad and regular curves. This contrast is probably greater than that existing in nature from the fact that actual data from beneath the surface along this line are almost entirely wanting, and the underground outlines are simply theoretical prolongations of observed dips. The depth of the Blue Limestone horizon at the east end of the section is probably a maximum. Analogy renders it probable that the eastward dip shallows, and it is possible even that the beds rise somewhat towards the Mosquito fault. This remark applies equally to the corresponding points in the next four sections. The sheet of Sacramento Porphyry is represented here between the Weber Shales and Weber Grits, the horizon at which it occurs on the crest of the range east of the Mosquito fault, since it is fair to suppose that the sheet extended as far west as indicated on the sections. The thickness of the Mount Zion Porphyry on the west slope of Prospect Mountain can only be a matter of conjecture; it is fair to infer that it reaches at least 700 feet in its maximum development. The extension of Lake beds as far north as the line of this section in the Arkansas Valley is proved by excavations on the north bank of the stream. At the western end of the section the shore line against the Archean is shown in the abrupt termination of the Lower Quartzite. This would have been more striking had the section line been placed a little farther north, when the White Limestone would have been found to come in actual contact with the Archean.

Section B.—Section B follows in its western course the bed of Evans gulch; then, cutting across the southern spur of Prospect Mountain below the Prospect amphitheater, follows approximately the line of Little Evans gulch, and, crossing the two gulches diagonally just above their junction,[1] runs out on to the mesa at the intersection of the railroad line with Evans gulch. It thus shows portions of the Evans north moraine and, at its crossing of Evans gulch, the supposed shore-line of Arkansas lake. The eastern half of the section shows practically the same structure as Section A, except that the Weston fault comes in in the axis of the broad anticline. In its western half it cuts across the northern extension of the Yankee Hill and the Big Evans anticlines, and of the included Little Stray Horse syncline; and west of this shows the probable slope of the beds in the syncline beneath the mesa, as proved by the explorations of the Oölite and Sequa shafts; also, the White Porphyry, cutting across the Blue Lime-

[1] On the section its intersection with Little Evans gulch is wrongly marked "ditch."

stone where the northwest and southeast zone through Fryer Hill would intersect the section-plane.

Section C.—Section C runs through the crest of Little Ellen Hill in a direction a little north of west, crossing the South Evans anticline opposite the western point of the hill; thence following the south bank of Big Evans gulch across the north slope of Fryer Hill, it passes through the mesa just north of the railroad station in North Leadville. It thus shows at its east end the movement of the Mosquito fault; and, between this and the mouth of South Evans gulch, the same regular easterly dipping beds seen on the previous sections, slightly displaced by the movement of Ball Mountain fault. On either side of its intersection with South Evans gulch the considerable accumulation of recent material (*r*) represents the moraine left by the Evans glacier. The White Porphyry above the Blue Limestone, which in the preceding sections had thinned out near the crest of the fold, is now supposed to extend back to the Mosquito fault, but in a comparatively thin sheet; while in the crest of the South Evans anticline the dike cut by the Silver Tooth bore-hole is represented as the source of the White Porphyry sheet immediately overlying the granite. The plane of the section intersects that of the Weston fault at its junction with the Colorado Prince fault, and, on the theory of an inverted dip to the latter (assumed from the fact that granite overlies White Porphyry in the Boulder incline), would also intersect the plane of the latter at the angle given in the section. Beyond Weston fault the upward roll in the beds at the Great Hope mine is graphically shown, and the syncline included between this ridge and the crest of Yankee Hill. The section line passes north of the summit of this hill, and beyond this point shows the increasing thickness of the Wash or moraine material left by the Evans glacier. Its intersection with the Iron fault is at the northern extremity of that fault, whose movement is deduced from data furnished by the Little Stella and J. B. Grant shafts, on either side. Beyond this it passes through the Little Stray Horse syncline, the anticline in the Dunkin ground, and the syncline on the north side of Fryer Hill. The relative thinning out of the Blue Limestone on Fryer Hill, where it is entirely replaced by vein material, is to be remarked. This replacement, which is shown by a cross-marking, is not indicated in the Blue Limestone in the basin of Little Stray Horse Park, not because there is any reason to suppose that it does not exist there, but simply because explorations have not proved its existence and in drawing sections the practice has been established of only indicating replacement where it has been actually proved. The steep slope given to the beds west of Fryer Hill, as they pass under the western syncline, is deduced from data obtained on the line of the next following section. It will be observed that the intersection of the line along which the White Porphyry cuts across the Blue Limestone is here farther east than in the preceding section, and that the eastern extent of the lower White Porphyry body is considerably greater is proved by actual development.

Section D.— Section D starts from the same point on the eastern edge of the map as the preceding, but follows a line slightly divergent from it, running due west. The planes of the two sections are so close together that it will be only necessary to mention the points in which the structure of the latter differs. In the South Evans anticline it shows the irregular intrusive sheet of porphyry at the base of the Blue Limestone, developed in the Last Chance shaft, and the lower sheet of White Porphyry, cutting up into the Lower Quartzite and splitting off a portion of it, as shown in the Hoosier Girl (G–44). The intersection with the Colorado Prince fault at an acute angle renders the representation of the western slope of the South Evans anticline somewhat less simple. Its line passes through the crest of Yankee Hill, showing the replacement of the Blue Limestone in the Greenwood and Little Champion shafts, and, on the eastern rim of the Little Stray Horse syncline, the steep dip of the contact which is developed in the Scooper shaft. At Fryer Hill it passes along the bed of Little Stray Horse gulch, showing that the Blue Limestone horizon has there been eroded off. It likewise passes through the Bob Ingersoll shaft, and shows the steep dip theoretically required on the western slope of the anticline by the development of this shaft.

Section E.— Section E runs due east and west along the parallel of latitude 39° 15′, which forms the middle of the map, and is but a comparatively short distance south of the line of the two previous sections. On the eastern end it shows the Mosquito fault and a patch of Lower Quartzite left to the east of it, on the slope of West Dyer Mountain. In the block between Mosquito and Ball Mountain faults the easterly dip prevails; but in the neighborhood of the latter fault the influence of the anticline at the north foot of Ball Mountain is seen in a slight curvature of the beds. Between Ball Mountain and Weston faults the Colorado Prince fault cuts through the southern extension of the South Evans anticline; and the section shows a minor anticlinal and synclinal structure between this and the Weston fault, which is shown by the developments of the Highland Chief and Lowland Chief shafts and the Chemung tunnel. Replacement in the Highland Chief mine is supposed to have extended through the entire thickness of the Blue Limestone horizon and to have been influenced by the dike of Gray Porphyry which is shown in that mine. The recent formation (*r*) east of the Highland Chief mine is a portion of the moraine left by the South Evans glacier on the shoulder now called Idaho Park.

In the block west of Weston fault the shallow anticlinal and synclinal structure developed in the two previous sections is supposed to extend into the plane of this section, the underground data confirming this idea as far as they go. The plane of the section is very nearly coincident with the line of the Breece cross-fault, which, however, in its curves crosses it at an extremely acute angle. The projection of the intersection of these two planes, as shown on the section, is a line cutting the surface between the Breece Iron and Louisville shafts, which has a certain parallelism with the formation lines, with which it might be confounded. The plane of the section passes just north of the extremity of the Mike fault, whose movement is therefore not shown. The body of Adelaide Porphyry is represented as coming up across the Lower Quartzite and White Limestone, and then spreading out, sending an offshoot between the beds of the latter. At this point the plane of the section crosses the moraine ridge, north of Adelaide Park, forming a portion of the Evans south moraine. In the block between Iron and Carbonate faults the line of section illustrates plainly the synclinal structure and the splitting of the Blue Limestone into two sheets, as proved in the Cyclops, Gone-Abroad, and adjoining shafts. On the west slope of Carbonate Hill the section passes through the upper Henriett workings and the lower workings of the Waterloo claim, and shows the anticlinal axis, which very nearly corresponds with the Carbonate fault, in the latter. This axis, as already stated, is found to coincide with the line of the fault farther north; and it is possible that on the line of the section the fault movement may have already died out, since its actual plane has not been proved.[1] Of the synclinal basin under Leadville in the line of this section the depth and angle of the formations on its eastern rim are deduced from actual data, which are not, it is true, as complete as could be wished. The location of the western rim, however, is more theoretical.

Section F.— Section F, on a slightly broken line, passes through the crest of East Ball and Ball Mountains, from the latter across the slope of Breece Hill to the head of Nugget gulch, through the middle of Iron Hill, and along the bed of California gulch, into the mesa country. East of the Mosquito fault it shows a patch of Lower Quartzite left on the crest of East Ball Mountain. Between Mosquito fault and Ball Mountain fault it shows the development of White Porphyry in the lower horizons and its comparative absence above the Blue Limestone; between the converging Ball Mountain and Weston faults, the great development of Pyritiferous Porphyry and the probable continuation of the numerous sheets of White Porphyry in the lower horizons. The anticlinal structure shown in the eastern portion of this block represents the supposed influence of the anticline observed at the north base of Ball Mountain, which, owing to the curvature of the line of Ball Mountain fault, is the proper continuation of this portion of the area. The distribution and thickness of the numerous bodies of porphyry in the latter block are deduced mainly from the data obtained in the adjoining regions, since along the actual plane of the section, as will be evident from its examination, there are few data obtained from underground workings. In the next block, between Weston and Pilot faults, a body of Pyritiferous Porphyry is shown in section, whose thickness is largely a matter of conjecture, the only direct evidence being that of the Cumberland shaft, near its northern edge, where it is 450 feet. As the plane of the section probably cuts through the thickest portion of the body, the thickness of

[1] Later developments render it probable that the sheet of Gray Porphyry is in the Blue Limestone, above the line of Carbonate fault, instead of at its base, as shown in the section.

600 feet given must be considered a conservative estimate. The underlying White Porphyry is shown as disappearing in the middle of this body, since the latter is supposed to connect with the lower body in California, as shown in Section L. A slight anticlinal structure is shown in the sedimentary beds beneath the porphyry, as a probable connection between the Great Hope anticline on the north and that under Printer Boy Hill on the south. The block between Pilot and Mike faults, it is seen, is practically a wedge-shaped mass which has slipped down between the two faults. In this area is the intersection of the line of cross-cutting White Porphyry, which is therefore indicated here as spreading out under the Blue Limestone. On Iron Hill the line of section passes through the workings of the Iron mine; and the data down to the horizon of the Blue Limestone are derived from actual exploration. The transverse body of Gray Porphyry developed in these workings is supposed to be an offshoot from the intrusive sheet at the base of the Blue Limestone; it should not have been represented as actually projecting into the White Porphyry.

West of the Iron fault the section crosses what is probably the greatest thickness of White Porphyry left above the Blue Limestone, but the depth of the latter immediately adjoining the fault is, as already stated, purely theoretical and given as a probable maximum.

Section G.—Section G follows also a slightly broken line along the south slope of Ball Mountain, through Green Mountain and the head of California gulch, and then along the northern edge of Dome Ridge. At its eastern end it crosses diagonally the South Dyer fault. Between Mosquito and Ball Mountain faults the development of White Porphyry in the lower horizons is even more striking than in the preceding section. Between Ball Mountain and Weston fault the distribution of the porphyry bodies is similar to that in the preceding section, but the Pyritiferous Porphyry is supposed to be thinning out to the southward.

Between Weston and Pilot faults the section shows a probable vent of the lower body of Pyritiferous Porphyry, which is known to cut across the strata, and probably comes through the Archean in this vicinity. In the wedge-shaped mass between Pilot and Mike faults a sheet of Pyritiferous Porphyry is supposed to extend between the White and Blue Limestones, as a continuation of the lower sheet of Pyritiferous Porphyry which forms the bed of California gulch above the Pilot fault. West of Mike fault the contact has been carried back at the angle shown in the developments of the Oro La Plata mine, and the intrusive body of Gray Porphyry, which cuts across it at the mouth of the Oro La Plata tunnel, is represented as probably thinning out to the eastward. It is possible, however, that the contact basins up toward the Mike fault, as it does on Iron Hill and the Gray Porphyry sheet may have an underground connection with the Printer Boy Porphyry, which it somewhat resembles, and both come up through the same channel or vent. West of the Dome fault the westward slope of the beds in the lifted-up block of ground between the Robert Emmet and Iron faults is shown. Beyond the Iron fault the only data obtained from shafts are the relative positions of the Wash, Lake beds, and underlying porphyry.

Section H.—Section H is taken along a straight line running from the bed of Iowa gulch, on the eastern border of the map, through Printer Boy Hill and down the bed of Georgia gulch. The three eastern blocks do not differ sensibly from those of the preceding section, except that, as proved by actual developments on Printer Boy Hill, the White Porphyry above the Blue Limestone is exceedingly thick, for which reason its thickness in the adjoining block to the eastward is proportionally increased over that of Section G. The cross-cutting of the White Porphyry comes just west of the Weston fault, and, though entirely below the surface, is not wholly theoretical here, but proved by developments of adjoining mines. The anticlinal structure of Printer Boy Hill, the intrusive sheets of porphyry, and the three vertical dikes are also proved by actual observation. The convergence of the planes of the Mike and Pilot faults is a theoretical deduction founded on the theory of fault planes by observers in other parts of the world. The existence of Lake beds at this height is proved by the data afforded by the explorations of the Printer Boy mine. The depth shown for the Blue Limestone here may possibly be too great, since it is obtained by carrying back the angle of dip at the surface near the Dome fault, and it is very possible that the beds turn upwards towards the Mike and Pilot faults, under the influence of the Printer Boy anticline. The thickness of

Lake beds below Dome fault and the depth of the contact are derived from actual data as far west as the Coon Valley; beyond that they are theoretical deductions.

Section I.— Section I is a broken line following, as near as may be, the crest of Long and Derry Ridge from West Sheridan Mountain westward. It shows the beds left on the crest of West Sheridan; the anticlinal structure developed on Long and Derry Hill, between Mosquito and Weston faults; the uplifted block of ground between Weston and Union faults; the outcrop of Blue Limestone and general character of its replacement in the Long and Derry mines and the great thickness of the White Porphyry above it (the cross-cutting of the lower sheet of White Porphyry must have occurred in the part eroded off); the transverse dikes of Gray Porphyry, and the intrusive sheets of Green Porphyry between the White Limestone and Lower Quartzite; and, west of Mike fault, the outcrops of the Blue Limestone shown in the Hoodoo and Echo shafts, and the supposed form of the body of Josephine Porphyry, between it and the overlying White Porphyry. The depth assigned the contact adjoining the Mike fault may be too great, as in the previous section, since it is possible that the beds rise toward an anticlinal fold. In the actual plane of the section the Lake beds are not shown to reach as high up as they do on Section H; but their extent on a line immediately north and south of this plane would be equal to that of the former. West of the Hoodoo outcrop is indicated the anticline which forms the southern continuation of the Dome fault, beyond which a syncline must exist, as an extension of the synclinal basin proved, to the north; but what portion of the synclinal beds involved in these folds has escaped erosion is a matter of pure speculation.

Perhaps the most suggestive teaching afforded by the north-and-south sections is the graphic representation they give of the relative character and amount of Glacial and Post-Glacial erosion. They afford successive cross-sections of the various spurs represented on the map from the summit down to the mesa below. Where Lake beds still exist, the rock surface below them is the result of erosion in the earlier portion of the Glacial period. The rock surface beneath the moraine material (*r*), whether in its original ridges or rearranged, is probably practically the same as it was at the close of the Glacial epoch, while the sky-line of each section represents the final form which water has given to the surface left at the close of the Glacial epoch, whether it be rock or detritus.

Section J. —In Section J, which crosses Prospect Mountain ridge, the lower portion of Little Ellen Hill, Ball Mountain, and upper Long and Derry Ridge, are seen the main depressions made by the Evans, South Evans, and Iowa glaciers, the outlines of their beds somewhat rounded off by Post-Glacial erosion. The formations are seen to have three broad undulations rather than folds, the two southern of which are broken by faults.

Section K. —In Section K, which passes through Prospect Mountain, Breece Hill, the head of California gulch, and Long and Derry Hill, the two Evans glaciers had come together in one broad sheet of ice a mile in width and not less than six hundred feet in thickness. Of the moraine material still remaining here, a portion evidently belongs to the lateral moraines, and in the middle is left a relic of the medial moraine formed by the junction of the two glaciers. In Iowa gulch at this point, as evidenced by the moraine material remaining on Printer Boy Hill, the Iowa glacier was also about six hundred feet thick and possibly sent a small branch some distance into the head of California gulch. The folds have the same character as in the previous section, but their crests are farther north.

Section L. —In Section L, which passes through the lower portion of Breece Hill and the west slope of Printer Boy Hill, the bed of the Evans glacier retains about the same size as in the preceding section, although its outlines are somewhat more regular. The Iowa glacier, confined on the north by Printer Boy Hill, had spread out somewhat to the south, leaving its moraine material well on the crest of Long and Derry Ridge. California gulch has been cut in the crest of one of the folds mentioned above, and in it the lower sheet of Pyritiferous Porphyry is seen to be cutting across the formations.

Section M. —Section M, passing through the crest of Yankee Hill and just east of Iron Hill, shows the Evans glacier split again into two streams, having a total width of over eight thousand feet, but whose thickness is probably somewhat diminished. The Iowa glacier, on the other hand, seems to be contracting as it descends, and in the plane of this section the distance between the crests of its bounding moraine ridges is only a little over one thousand feet. Here the outline of the Lake beds shows a bay in the ancient lake Arkansas and that the older Iowa glacier occupied a wider bed than the later one. Except at the foot of the Prospect Mountain, the beds lie in an almost horizontal position.

Section N.—In Section N the teaching of the Lake beds is still more suggestive. The moraine material of the Evans glacier, which was probably again united into one sheet, is spread out over a still wider surface; while the reconstructed outline of the Arkansas lake shows that from Graham Park across to Georgia gulch a ridge then extended, through which the present bed of California gulch has been carved out since the Glacial epoch.

Section O.—In Section O, which runs through Fryer and Carbonate Hills, only the top of the latter and a portion of what is now California gulch probably remained above water during the Glacial epoch.

Section P.—In Section P, which runs across the mesa country, Lake beds and Wash cover the whole surface as far as the ridge north of the mouth of the Arkansas. The underlying beds are represented as lying in a single broad syncline, since, while there may probably be minor undulations, as in the sections above, there naturally can be no data for determining their position.

As regards underground structure the transverse sections are mainly useful as showing probable depths at which the ore-bearing horizon may be found. They are too nearly parallel to the direction of major strike, which is that of the majority of the folds, to give a correct idea of these folds; and their intersection with fault planes, being also at an acute angle, presents a somewhat distorted angle of dip. Still it may be observed that on these north and south lines the beds have a tendency to form anticlinal and synclinal folds. Bearing in mind that the prevailing direction of strike is in a northwest direction, the continuation of the folds will be found a little farther to the north in each successive section; for instance, in Section J the fold under Ball Mountain finds its normal continuation in Section K at the mouth of South Evans gulch, and in Section L joins the slight fold at the south face of Prospect Mountain. The form of the east-and-west folds, as shown in Sections L, M, and N, along the base of Prospect Mountain, suggests that the mass of Prospect Mountain afforded more resistance to compression than the adjoining country to the south, so that the folds are compressed sharply up against it. The reason of this may be found perhaps in the unusual thickness of the porphyry bodies on Prospect Mountain, which are probably much less plastic than the sedimentary beds.

CHAPTER VI.

DISCUSSION OF GEOLOGICAL PHENOMENA.

In the last two chapters the observations gathered have been presented in the form which it was supposed would be most useful to the geologist or miner who wished to study the region itself. For those who have no occasion to examine the actual ground, it may be well to present concisely and in a generalized form some of the more suggestive facts observed, in a geological rather than topographical order, which will be the object of the following pages.

SEDIMENTARY ROCKS.

Archean.—That Archean land masses must have existed during the deposition of the Paleozoic and Mesozoic beds found in this region is abundantly proved, aside from all structural evidences, by the occurrence at various horizons, in beds evidently of littoral formation, of rolled grains and pebbles of Archean rocks. Among these grains and pebbles that which would best resist abrasion, quartz, forms naturally the larger proportion, but granite and even gneiss are found, and, among the finer materials, feldspar and mica often form a large proportion of the sandstones. It is further noteworthy that these pebbles do not differ in character from the present Archean rocks; in other words, afford no evidence that the latter have been changed by metamorphism since the Cambrian epoch. The fact that only at one point, and this close to a supposed shore line, is any but the characteristically lowest bed of the Cambrian found in contact with the Archean, shows that the upper surface of the latter, or the bed of the Cambrian ocean, must have been comparatively smooth and have presented no abrupt cliffs or slopes which were too steep for a uniform deposition of sediment over them.

Bedding planes were frequently observed in the Archean in proximity to its upper surface, perfectly parallel with and corresponding to the bedding planes of the Cambrian quartzite immediately above it. As this distinctness of bedding planes occurs in granite as well as in gneiss and as in general the bedding planes of the Archean, as seen on a large scale, are almost invariably discordant with those of the overlying beds, it seems that they must have been produced by the pressure of the superincumbent mass of beds.

The eruptive granite of this region is, in all cases, pre-Cambrian in age, no instance having been observed of its intrusion into the rocks of any formation later than the Archean.

As regards the relative age of the rocks which form the Archean, the little study that could be devoted to this subject goes to show that the amphibolites, gneisses, granite-gneisses, and, probably, part of the granites proper constituted the older or original formation; that these were succeeded by the distinctly eruptive granites, which cut through and include fragments of the above; and that the vein-like masses of pegmatite are the most recent formations of all the Archean rock masses.

While the structure lines which give evidence of original bedding or stratification in these rocks are less distinctly marked than in other parts of the Archean of the Rocky Mountains and were often so obscure that no attempts were made to trace out any structural system in the Archean as a whole, they are nevertheless sufficiently well marked to suggest an original horizontality in the different layers, and that they have been subjected to an infinitely greater compression and folding than the later formations, while the parallelism of certain upper planes with the lower ones of the Cambrian, which has been remarked above, and the varying angle at which both are found, show that the Archean has partaken of the folding to which the Cambrian and later beds have been subjected.

Paleozoic.—The lower 600 feet of the Paleozoic system in this region, comprising the Cambrian, Silurian, and Lower Carboniferous formations, which are remarkably persistent as a whole, though varying from point to point in the relative proportions of calcareous and silicious material entering into their composition, give evidence, in their even and thin beds and in their fineness of grain, of a slow and uniform deposition in quiet and rather deep waters. Even in the conglomerate, which is invariably found at the base of the series, only very small pebbles of the very hardest and most tenacious forms of quartz are found. Neither fragments of Archean rocks nor even feldspar fragments occur in them. The lower calcareous beds also, in spite of their dolomitic character, are usually compact and fine grained.

In the middle member of the Carboniferous, however, a decided change in the character of the sediments takes place: they become, as a rule, very coarse-grained, carry feldspar and mica and rolled pebbles of granite and schist; they often contain carbonaceous matter, which is sometimes concentrated into actual beds of coal along the borders of the original land mass, and remains of plants peculiar to the Carboniferous period are found in them at a considerable distance from the supposed shore line. It is evident, therefore, that in the middle Carboniferous epoch the seas became shallower, that the abrasion of the land masses was more rapid than theretofore, and that on the land vegetation flourished luxuriantly in this mountain region, as it did at the same period in other parts of the world.

During the succeeding Upper Carboniferous epoch and also in the Mesozoic era the same coarser character of sediments prevails, although carbonaceous deposits are wanting until towards the close of the Cretaceous. Both in the Weber Grits and the Upper Coal Measure formations the calcareous deposits are not only very subordinate in quantity but very variable; at one point in a given thickness of rocks only a single thin bed of dolomitic limestone will be found, whereas within the same horizon, at another point not very far removed, several may occur.

Dolomitic sediments.—One of the most noteworthy facts developed by the study of the sediments of this region is the prevalence of dolomites among the calcareous deposits. All the calcareous beds below the Robinson limestone, which was taken as the base of the Upper Coal Measures, are, with the unimportant exception of a locally developed silicious limestone in the Cambrian, true dolomites of varying purity. In the hand specimen they have generally the granular structure characteristic of dolomites, and under the microscope it is seen that there is little or none of the twin structure peculiar to calcite, and that they are therefore composed, not of a mixture of calcite and carbonate of magnesia, but of true dolomite or double carbonate of lime and magnesia. The upper bed of the Robinson limestone, on the other hand, and also the few limestones of the Upper Coal Measure formation that were examined are true limestones and have a characteristically different appearance from the dolomites in the hand specimen. They are fine grained and compact, instead of granular, generally of light color, and often have the conchoidal fracture and fine texture of a lithographic stone. The lime and magnesia contents of twenty different specimens of limestones from different horizons and localities are given in Table VI, Appendix B.

It is also noteworthy that all of these limestones, as far as tested, were found to contain chlorine in appreciable amount. Microscopical examination of the Blue Limestone collected at Leadville, whose contents in chlorine amounted to one-tenth of one per cent., showed that it probably occurs in the form of a solution of chloride of sodium, in extremely minute fluid inclusions within the grains.

These investigations were made in the hope that they might throw some light upon the cause and manner of formation of dolomites in general. It can only be said that it seems evident that the magnesia is an original constituent of the rocks, and not introduced later by metamorphic action. It were difficult to conceive of such an action, for instance, in the case of the Robinson Limestone, the upper fifteen to twenty feet of which are almost chemically pure carbonate of lime, while the lower ten feet contain less than 88 per cent. of carbonate of lime, the rest being carbonate of magnesia and insoluble material; or how such metamorphic action should be so widespread and uniform over this great area and yet stop at a given bed or horizon.

T. Sterry Hunt,[1] who, with others, has advocated the theory that dolomites are formed by the actual precipitation of the carbonate of magnesia, maintains that its separation requires the absence of chloride of calcium

[1] Chemical and Geological Essays, Boston, 1875, p. 92.

from the waters in which it is deposited and that isolated or evaporating basins are indispensable conditions of the formation of dolomite. In this particular region these conditions might have been fulfilled, since the Archean land masses certainly inclosed the sea on two sides. His theory requires, however, that all the lime contained in the sea waters should have first been precipitated by the carbonate of soda, which would then act on the chloride of magnesium and throw it down as carbonate. It would seem, however, from the character of the rocks, which are formed of crystalline grains of the double carbonate, that the two salts were probably precipitated at the same time and that a certain amount of chloride in solution was inclosed in the grains as they crystallized.

As regards the question whether carbonate of lime is more readily dissolved out of a dolomite than carbonate of magnesia, the evidence goes to show that percolating waters act upon the double salt, and not upon its more soluble member alone, since the veins and cavities, such as are shown in the lower specimen on Plate VI (p. 64), which have been refilled by white crystalline material deposited by these waters, are found to have the same composition as the original dolomite. Moreover, where the entire rock has been apparently changed by the action of waters, as in the so-called "lime sand" found in the mines, which is Blue Limestone from which the cementing material of the grains has been removed, or in the case of a given bed in the White Limestone of Dyer Mountain, which in one part has, by this action, from a compact light-blue rock, become clayey in structure and pink in color, analysis shows that the proportions of carbonate of lime and magnesia remain essentially unchanged, whatever variation there may have been in the other constituents.[1]

In both the above cases the metamorphism, or change in the character of the limestone, must have taken place about the time of the deposition of the ore bodies in these regions, and would therefore not have been produced by surface waters. The action of surface waters, using this term in its ordinary, restricted sense of waters which come from the surface under essentially the same conditions that exist at the present day, is apparently different from the above, judging from the following observation.

[1] See Analyses 5, 6, 9, and 10. Table VI, Appendix B.

The conglomerates which form the Lake-bed deposits are often found to have a calcareous cement, that can be readily separated from the pebbles which it incloses. This conglomerate is of so recent date that at the time of its formation the structural conditions of the range must have been essentially those which prevail at the present day, and the waters from which the cementing material was derived were surface waters, which may be supposed to have drawn their calcareous constituents from the outcrops of the various dolomitic beds of the lower Paleozoic series. Chemical tests show that the cement is made up almost entirely of carbonate of lime, with little or no carbonate of magnesia. It would seem, therefore, that when exposed to the action of surface waters the dolomites of this region have yielded up their carbonate of lime more readily than their carbonate of magnesia. This may be due to a previous disintegration under the action of atmospheric agents which rendered them more attackable or to a superior solvent power of surface waters over underground waters in their action upon the carbonate of lime.

Serpentine.—The development of serpentine in the Silurian beds of this region is, it is believed, the first observed instance of its occurrence in the Rocky Mountain region, and therefore deserves some detailed mention. Its principal point of development is in the Red amphitheater in Buckskin gulch, on the south face of Mount Bross, where it is found mainly in the transition beds at the base of the Silurian formation, though extending to a limited extent up as far as the base of the Carboniferous. It was also observed in limited development on the cliffs at the south base of Mount Lincoln, and specimens were obtained in the Leadville district from the Comstock tunnel in California gulch, where its exact horizon could not be definitely determined. No actual serpentine was found at any other point, but a greenish-colored bed was observed frequently at about the same horizon, which by a microscopical examination of certain specimens was proved to contain amphibole or pyroxene.

As developed in the Red amphitheater, it occurs generally in limestone, forming a greenish, veined, and clouded rock, like verd-antique, the veins or streaks of serpentine generally running parallel with the stratification, but sometimes crossing it at right angles. It also occurs in a yellow, homogeneous-looking rock, resembling yellow beeswax, which proves by analysis to be an intimate mixture of calcite and serpentine. A complete analysis of the soft green material from a specimen of the darker-colored rock is given in Analysis I, Table VII, Appendix B, which proves it to be an almost normal serpentine, the oxygen ratio being 3 : 3.95 : 2.11, instead of 3 : 4 : 2, which is the theoretical proportion. Analysis II, in the same table, is that of the whole mass of yellow rock, which is found to contain 57.57 per cent. of carbonate of lime. If this be deducted, the composition of the residue is essentially the same as that of I. The microscope confirms the conclusion that the rock is a simple mixture of serpentine and calcite, as no other mineral can be distinguished by it. It also shows that the major part of the rock is in grains which show the cleavage distinctly, whereas the small grains of calcite which are sometimes found in the dolomites show no such cleavage lines; hence it is evident that the calcite has been recrystallized.

Origin of the serpentine.—It is evident, from the manner of its occurrence in and intimate admixture with the sedimentary rocks, that the serpentine is not of eruptive origin. It seems equally improbable, from its extremely local development, that it could have been formed at the time of the precipitation and deposition of the original sediments. It is noteworthy, further, that the localities where it was found have been near centers of eruptive action and of consequent intense metamorphism. The dolomites of this horizon, which are all more or less silicious, contain all the constituent elements of serpentine, except water. If by the addition of this element a reaction between it and the silica and magnesia could be brought about, serpentine might have been formed directly from the dolomites. As, however, it is difficult to conceive of such a direct reaction, it seems better to seek some intermediate step. Among the specimens of serpentinous rock from the Red amphitheater, one has gray portions, comparatively free from serpentine, in which fibrous silky crystals can be observed. The microscope showed that these are amphibole crystals, and, further, that pyroxene was present. Analysis III, Table VII, shows the composition of these silky crystals after they had been separated from the rest of the mass, which is practically that of actinolite. The part supposed to be pyroxene, which is distinguishable as being less lustrous, was not analyzed. Now, the formation of serpentine as an alteration product of amphibole and pyroxene has been not unfrequently observed and actual pseudomorphs have been found.[1] It thus appears evident that a part at least of the serpentine in these rocks is an alteration product of amphibole and pyroxene, and in further confirmation of this hypothesis the microscope shows, in specimens of a green silicious rock from the lower part of the Red amphitheater and of a similar rock from the south base of Mount Lincoln, among fresh and unmistakable amphibole crystals, some in process of decomposition, whose end product is serpentine, the remaining components of the rock being quartz grains and calcite in alternate layers.

J. D. Dana,[2] in treating of similar occurrences of serpentine in the dolomitic limestones of Southern New York, supposes that the process of change was that by a first metamorphism the uncrystallized dolomite became penetrated with tremolite, actinolite, and other magnesian silicates, and that "these beds underwent a later transformation, converting the tremolite and other magnesian silicates and part of the remaining dolomite into hydrous magnesian silicates and mostly into serpentine." At first glance the Mosquito Range phenomena seem to present a further analogy with those of Southern New York in that there are presented two periods of possible metamorphism (or activity of metamorphic action), viz, that following the intrusion of the porphyries and diorites and that following the folding and faulting which accompanied the uplift of the range. There is, however, no evidence that the dynamic movement was either accompanied or directly followed by any widespread metamorphic action. The decomposition of metallic minerals, which was a metamorphic action, preceded this movement and followed the eruption of porphyries.

As to whether the serpentine has been derived entirely from amphibole and pyroxene, or whether a part may have been derived directly from dolomite, as suggested by Dana in regard to the New York occurrence, no definitely conclusive evidence has been obtained. No opportunity was offered for tracing the yellow rock, which would seem probably to have

[1] J. Roth: Allgem. u. chem. Geologie, pp. 123, 127, 131. Berlin, 1879. A. Lagorio: Mic. Anal. Ostbaltischer Gebirgsarten, p. 43. R. B. Hare: "Die Serpentin-Masse von Reichenstein" (Neues Jahrbuch, II. Bd., p. 346. 1880.)

[2] American Journal of Science, Vol. XX, p. 32. July, 1880.

been derived from a limestone bed relatively free from quartz, to a less completely altered condition, where it might have been seen whether there had been a previous formation of amphibole. In the dark-green rock, however, there seems little doubt that the serpentines are derived from silicates.

With regard to the formation of amphibole and pyroxene, their distribution seems wider and more even, and the question presents itself whether they have been formed in situ by a slow process of metamorphism preceding the appearance of the eruptive rocks, or after this period and immediately preceding that of the serpentine, or, again, whether they are simply derived from the Archean rocks mechanically. In favor of the last supposition is the fact, observed by Mr. Cross in one specimen, that the amphibole penetrates the quartz grains and is sometimes entirely encircled in them, and that these latter contain fluid inclusions with moving bubble.

STRUCTURAL FEATURES.

The most striking features in the geological structure of this region are the forms of the folds and the close relation between them and the great faults which traverse it from north to south.

Folds and faults.—The typical form of the former is what has been called the **S**-fold, in which the anticline has a steep and almost vertical face to the west, or towards the original land mass of the Sawatch, and a gentle slope to the east, while in the adjoining syncline the conditions are reversed, and the gently rising slope is to the west. This is the most natural form of fold which would result from the supposed cause of uplift of the range, namely, a horizontal thrust of the beds against the Archean mass of the Sawatch. In a fold produced in this way the line of greatest tension, and where the tendency to fracturing and displacement would be greatest, is, as shown by Daubrée's well-known experiments,[1] along this steep side of the fold, and in point of fact it was found that along this line occur the great strike-faults of the range.

By reference to the sheets of sections (Atlas Sheets VIII and IX) it will be seen that the great Mosquito fault, which extends for an unknown distance beyond the northern limits of the map, and its two southern branches, the London and Weston faults, fulfill in the main these theoretical conditions.

[1] A. Daubrée: Géologie Expérimentale, p. 321. Paris, 1879.

It is rarely possible to trace upon the surface the actual line of a fault or the structure lines of the immediately adjoining beds, for the reason that the rocks are generally metamorphosed and disintegrated to such an extent as to render them obscure. The theoretical studies of fault structure have, moreover, been mainly made in underground workings, especially in coal mines, where it is often the case that the movement of displacement is so slight and the thickness of beds involved so small that it is questionable whether they should not more properly be considered as joints, rather than as fulfilling the same conditions as these great faults many miles in length and with displacements involving thicknesses of beds of as many thousand feet. Even in this region, where the opportunities for observation are exceptionally favorable, the actual fault planes and the structure lines of the adjoining beds can but rarely be distinguished. Either only Archean rocks, in which no structure lines are visible, are to be found on one side of the fault, or the surface conditions are such that the structure lines are entirely obscured in its vicinity. In drawing the sections, moreover, the endeavor was to represent the facts as far as observed, without reference to any structural theory, and they were already engraved before any theoretical study of the structure as a whole was undertaken. If, then, in any case they misrepresent facts, the error is as likely to be against the above theory as in its favor.

At the northern edge of the map a syncline is plainly traceable in close contact with the fault line on the west of the Mosquito fault, and the remains of the corresponding anticline on its east side are found in the fragment of Cambrian quartzite resting on the Archean just beyond the limits of the map. From here southward to Empire gulch either the Archean alone adjoins the fault line or the stratification lines of the sedimentary beds in its immediate vicinity are entirely obscured; those given in the sections are only the theoretical prolongation of dips observed at such a distance that there is room for a very marked flexing to have occurred before they reached the fault plane. On Empire Hill is what might be classed as a monocline to the west of the fault, were it not that its continuation farther south at Weston's pass shows that it is part of a deep syncline, cut off by the fault, and a portion of the crest of the corresponding anticline on the east side still caps Weston's Peak. It is in the London fault, however, that the relations of the fold and the fault are most clearly seen, because the sedimentary beds still remain on either side to show the structure lines and erosion has cut down into the rock mass so deeply as to afford to the observer actual sections of the earth's crust several miles in length and one to two thousand feet in thickness. These have been described in detail on pages 143–165 and illustrated by sketches in Plates XV, XVI, and XVII, so that it will be hardly worth while to redescribe all the conditions here.

It is probable that the steepness of the angle of dip of the beds on either side of the fault plane in these cases may be due to a continuation of the movement of contraction, or the lateral thrust, since the original faulting and folding, for it is now generally conceded by geologists that the elevation of mountains is continued in a somewhat modified form long after the original dynamic movement, and may very probably be going on at the present day. In the case of the fold at Weston's pass a lateral movement along the fault plane seems also necessary to explain the observed conditions.

This dipping downward of the beds on either side of the fault would seem at first sight to be an exception to what is given in text-books as the rule for the plication of beds adjoining a fault plane, namely, that they bend in opposite directions down toward the fault on one side and up toward it on the other. It is not really so, however, as mature reflection will show. In the case presented by the text-books of strata dipping in opposite directions on either side of the fault, if the beds were brought back to the position they occupied before the displacement, they would be found to have a simple monoclinal fold, such as is described as common in the Colorado Plateau region by the geologists who have written upon it, and which, according to them, is often associated with a fault. These folds and faults differ from those in the greater intensity of the plication and in the different position of the fault plane in regard to the flexure. If one of the **S**-folds described here could be drawn back to its incipient state of flexure and the strata adjoining it brought to an approximately horizontal position, it would gradually become the monoclinal flexure described by them; or one might imagine the monoclinal flexure under conditions of greater pressure, and with a general uptilting of the whole sedimentary series involved, developing into one of these **S**-folds. As regards the position of the fault plane, in the supposed case of the monocline it actually cuts the steep side; but here it cuts generally through the syncline on one side of it. It can readily be seen by reference to the section that a comparatively slight lateral displacement of the fault planes to one side or the other would produce the above-quoted conditions of an opposite dip on either side of the fault, or, to be more accurate, opposite as regards the fault plane, since the actual dip is the same on both sides of the fault in the case of the monoclinal fault and reversed in the case described here.

In connection with the shorter and less important faults which traverse the region of the Leadville map, the folds are much more gentle and less strongly marked than in the case of these larger faults; but in almost every case where it is possible to obtain data it is found that the same interdependence of folding and faulting exists.

Hade of faults.—In the few instances where it was possible to obtain actual measurements of the hade of the fault planes, or their inclination from the vertical, it was found to be towards the downthrow side, or that the plane of the fault slopes away from the side which has risen; this is the condition which generally prevails, and it is explained on the theory that the uplifted side has thus a broader base than the downthrow side. In only a few isolated cases was evidence found, and only indirect evidence at that, of the opposite conditions, or of a reversed fault. The angle of hade in the observed cases was almost equal to the angle of dip of the strata; in other words, the fracture was directly across the beds. In drawing the faults where the angle could not be observed, as was the case in the majority of instances, they were constructed to accord with this condition. The objection has been made to the assumption that the normal hade of faults should be in the direction of downthrow, that it is opposed to the theory that faulting, like folding, is the result of contraction, inasmuch as hading in this direction tends to lengthen the linear space occupied by a series of beds on a given cross-section, rather than to contract it. This may be graphically seen in the sections on Atlas Sheet VIII. In Section A, for instance, where only one fault crosses the section, the linear contraction of a given bed, as there drawn, is about three thousand feet in the length of the section, or $3\frac{1}{2}$ per cent. On Section D the apparent amount of contraction is the same, although the beds are much more sharply flexed; but it is found that, by reason of the angle of hade given to the faults, there has been 1,500 feet of apparent expansion of the beds; or, if the fault planes had been made vertical, the same amount of flexing would have given 1,500 feet more length to the beds and the contraction would have been 4,500 feet, or $5\frac{1}{3}$ per cent. The sections present probably an exaggerated statement of what actually exists, for it is possible and even probable that the planes of the great faults stand more nearly in a vertical position; still, observation renders it probable that the average hade in the faults of this range is with the downthrow, and for this reason the displacement of the faults has not tended to contract the linear distance occupied by a given series of formations on a transverse line, but rather to expand it slightly. It seems probable that the plication of the beds has been a gradual and uniform movement, though relatively accelerated at the period assigned to the dynamic movements; but that the actual fracturing of the beds along the present fault planes was primarily produced by some violent shock, similar to the earthquake shocks of the present day; that the direction of a fracture plane across the beds, as thus primarily determined, would not necessarily be dependent on the force of contraction, although its position would naturally be on lines of greatest tension or weakness.

It may also be conceived in a region like the one under consideration that, while the folding is evidently a result of tangential contraction, the faulting may be, in part at least, the result of radial contraction. It is probable that tangential pressure acts only on a comparatively thin shell of the upper crust of the earth, for very sharp folds, where observation in depth is possible, are found to become gradually more rounded and gentle as the distance from the surface increases; also, that the force which has been exerted in an intensely plicated region is the expression of the accumulated energy of contraction over a wide area. Thus, in the case of the Mosquito range, tangential pressure may be conceived to have pushed up a roll of the earth's crust into a ridge, which would have been much higher than the restoration of the eroded beds in their present position would give, if it had not been for the counteracting effect of faulting; and faulting might, in this sense, be considered a result of subsidence or of radial contraction. It is easily seen, for instance, by studying any one of the given cross-sections of the Mosquito range, that were the movements of the faults reversed, so as to bring the beds on either side of each back into their original position, and thus leave them as they would have been if influenced by plication alone, the range would have been about four thousand feet higher than at present, supposing erosion to have acted under those conditions with the same energy that it has under the present. This view of the elevation of the range involves, it is true, a subsidence of the region adjoining the Sawatch shore line and probably of the whole Sawatch mass. Subsidence and elevation in cases like this, which refer to a far distant period of the earth's history and where limited areas are involved, are more or less interchangeable terms, since the only fixed point to which they can be related is the center of the earth, whose distance cannot be determined with a possible error less than the amount of movement involved, and we have to content ourselves with the assumption that there must be a tendency in all movements of the earth's crust to preserve a certain equilibrium, and that, where one portion of the crust has been elevated in relation to an adjoining one, the apparent movement is probably the sum of an actual elevatory movement on the one side and of a subsiding movement on the other, each of which is necessarily less in amount than the apparent movement.

The same may be said of areas large enough to assume an almost continental importance. Thus the Plateau region of the Colorado River has evidently subsided relatively to the adjoining mountain areas of the Wasatch and of the Rocky Mountains, as shown by the great average difference of level of corresponding formations in these areas; but the Plateau region must always have been relatively lower than these, since it was from the abrasion of their land masses that its sediments were in large measure derived. It may, however, be considered in general to represent an area of subsidence, and the others to be areas of elevation; and the type structure which prevails there, namely, that of broad level blocks descending abruptly along given lines by monoclinal flexures and faults to lower levels, to be more frequently the result of subsidence, while the movements in the adjoining mountain masses were probably more often true movements of elevation.

The one-sided or S-shaped fold.—In the above remarks considerable stress has been laid upon the one-sided or **S**-fold and its frequently associated faulting, because it seems to be the extreme development of the most common form of plication throughout the Rocky Mountains and the region of the Great Basin. In the latter region it often happens that only one side of the fold protrudes above the Quaternary deposits, which cover the greater portion of its surface, so that the narrow mountain ridges present only a monoclinal slope. For this reason the structure of what is called the Basin province has been characterized as a region of faulted blocks uptilted in different directions and practically without plication.

I dissent from this reading of the geological structure, first, because my own observations in the region mentioned have shown many unmistakable instances of the above-mentioned structure, in which it is true the flexing is often gentle, but nevertheless a true plication, and which have led me to believe by analogy that in other cases, could the structure beneath the valleys be seen, the missing faulted-down members of the fold would be found; secondly, because the diversely tilted blocks which are given in the sections involve what seems to me to be a geological impossibility, or at least one which is not yet found possible by observation, namely, the actual annihilation of considerable wedge-shaped segments of stratified beds by the simple action of faulting. Even in the Uinta Range, which differs from the Rocky Mountain ranges in that it is the truncation of a complete arch of sedimentary strata, with no evident pre-existing elevation beneath it, the anticlinal fold has the one-sided structure. The axis of this range is along the northern edge of the uplift; to the south of the axis the beds descend in gentle slopes; to the north they dip steeply at angles of 40° or 50°, and are partly faulted along this steep side. On a line with this steep side, at the eastern end of the range, is a submerged ridge of Archean, whose resistance, as I have already suggested,[1] probably caused the sharper and more

[1] Exploration of the Fortieth Parallel, Vol. II, Descr. Geol., p. 201. Washington, 1877.

complete plication of the formations at that end of the range. This ridge may extend westward at a greater depth along the whole length of the range, and be the unyielding mass whose resistance caused the sharper flexure along its northern edge.

I also differ from the views advanced by some geologists with regard to the structure of the Rocky Mountain region, or the Park province, as they designate it. One considers the type structure of this region, as represented by the Colorado and Park Ranges, to be the same as that of the Uinta, viz, that the sedimentary strata formerly arched over them, and that the uplift was that of a broad platform raised by vertical movement, having a fault or monoclinal fold along either edge. Another, in speaking of the whole Cordilleran system east of the Sierra Nevada, says it has no plication properly speaking, as expressed by the folds of the Appalachian, although he admits that some regions show a certain amount of flexure, including in them probably the Basin and Park provinces. In regard to these provinces he says that these flexures are not, so far as can be discerned, associated with the building of the existing mountains in such a manner as to justify the inference that the flexing and the rearing of the ranges are correlatively associated; that the flexures were in the main older than the mountains, and that the mountains were blocked out by faults from a platform which had been plicated long before, and after the irregularities due to such pre-existing flexures had been nearly obliterated by erosion. He says further that the amount of bending caused by the uplifting of the ranges is just enough to give the range its general profile and seldom anything more.

I have already shown, in Chapter II, my reasons for considering that the main Archean masses of the Rocky Mountains, as represented by the Colorado and Park Ranges, were never submerged, and that therefore the sedimentary strata could not have arched over them as they did over the Uinta Range; also, that the Mosquito Range, which might be considered at first sight an exception, is not geologically part of the Park Range, but an uplift of later formation, contemporaneous with and of analogous formation to the so-called "Hog-back" ridges on the east flanks of the Rocky Mountains, though of more complicated structure, owing partly to its eruptive masses and partly to a more intense movement of compression. On the eastern flanks of the mountains the anticline, east of the first monoclinal slope which rests directly on the Archean, is rarely seen, being concealed beneath later deposits. Its slopes are probably relatively gentle, as it is not compressed between two Archean masses like those of the Mosquito Range, but has a broad mountainless area at its back. Could this fold be seen it would probably be found to have the **S** character; that is, a steeper slope to the west. The fact that the monoclinal slopes on the eastern flanks are sometimes very steep I judge to be due to a later movement of contraction since the dynamic movement, by which the upper beds have been pushed against the Archean and the beds which rest directly on it, and thus brought into a vertical or even an inverted position.

As regards the correlation of folding and faulting, the geological evidence, as I read it, is entirely opposed to the idea that the uplift of the ranges was independent of and later than the flexing, and produced mainly by faulting. The evidence of the Mosquito Range, which may be fairly taken as a type, though perhaps an extreme one, of Rocky Mountain structure, certainly shows a close interdependence between folding and faulting. That the rocks forming the Archean land masses were plicated and eroded long before is quite evident, but that they were blocked out by faults and lifted into a platform is purely hypothetical and incapable of proof. Again, while the closely appressed folds of the Appalachians are rarely found in the Rocky Mountains, I consider the folding that does exist there none the less a true plication. The peculiarly regular, narrow folds of the Jura Mountains and of the Appalachian system are simply the extreme type of closely folded strata, due to peculiarly favorable conditions which it is not now worth while to discuss at length, and differ from those of the Rocky Mountains in amount rather than in kind.

ERUPTIVE ROCKS.

The eruptive rocks of this region fall naturally into two groups or series, whether considered from the point of view of their age, of their manner of eruption, or of their internal structure and composition.

Here, as in all attempts at establishing geological classification, there are found to be occurrences which form intermediate or transition members between the two groups, but yet do not invalidate the legitimacy or advisability of establishing such a division or classification. Geologists have hitherto been divided in opinion as to the nature of the relation between the age of an eruptive rock and its internal structure and composition, the extremists on one side maintaining that this relation is an absolute and fixed one, and that where, as is so often the case, its geological and external structural relations furnish no evidence as to the age of a rock, a careful study of its internal structure is sufficient to determine within certain limits its period of eruption; those of the opposite school maintain that no such relation exists, that the correspondences observed are merely accidental coincidences not dependent on age, and that the many subdivisions established by the former school are not legitimate, and, inasmuch as there are an infinity of intermediate members, could with advantage be reduced to a few general divisions. The manner of eruption, whether as an intrusion or as a surface flow, has not in general been considered an essential function of classification. In this region it would seem that the characteristic differences of internal structure of the above two classes depend rather upon the conditions under which they have consolidated than upon the absolute geological age of either class, although their relative ages, which are distinctly marked, correspond, as it happens, with the differing conditions of consolidation.

Age.—As regards their period of eruption, the rocks of this region may be divided into an older and a younger series, the former of which were erupted before the dynamic movement which caused the uplift of the range and were involved with the inclosing sedimentary strata in the consequent folding and faulting, while the latter are of later date than that dynamic movement.

An exact definition of the age of either group is unfortunately not yet possible. In the first place, the time of the dynamic movement is assumed as at the close of the Cretaceous period, this assumption having been adopted by the consensus of the geologists who have studied the Rocky Mountain region, for the reason that the Tertiary beds, where found in contact, are seen to have been deposited unconformably upon the Cretaceous. But in the district included in this examination no Tertiary beds are found. Moreover, it is not impossible that later and more detailed studies may lead to a modification of this view. Secondly, although the older eruptives are only found in Paleozoic formations within the limits of the map, rocks almost identical were observed in Triassic and even in Cretaceous strata, not far beyond those limits. Moreover, the same class of rock, as will be shown below, is found in other parts of Colorado to cut through the latest Cretaceous beds. It seems probable, therefore, that though the eruption of this type of rock may have commenced much earlier, it lasted in this region till near the close of the Cretaceous. As regards the age of the younger series, the entire absence of Tertiary beds in the region renders it impossible to assign their eruption to any particular division of this era. The time that elapsed between the eruption of the last of the older series and the first of the younger must, however, have been much longer than the above statement would seem at first glance to warrant, since in it not only were the inclosing beds elevated above the ocean, and by plication and faulting brought practically into their present position, but erosion must have removed their upper portions down to a general level, which could not have been much higher than that of the average peaks and ridges of the present day.

But little direct evidence was obtained as to the relative age of the varieties composing either group, but what was found, as well as the indirect evidence and a certain indefinable habitus of the rocks, goes to confirm Clarence King's theory[1] that in each series of rocks composing a local eruption, and which may be considered in general to have a common source, the acidic rocks were the earlier, and the more basic followed in the order of their relative basicity. Thus, among the older series of rocks the more basic porphyrite is younger than the acid quartz-porphyries. Direct evidence of this is confined to the single instance observed of actual contact of the two varieties of rock on the extremity of the east spur of Mount Lincoln; and here, owing to the character of the exposure, the apparent cutting of Lincoln Porphyry by porphyrite cannot be considered entirely unquestionable. The external habit and internal structure of the rocks, however, both con-

[1] Exploration of the Fortieth Parallel, Vol. I, Systematic Geology, p. 715. Washington 1878.

firm the above conclusions. In the hand specimen some of the porphyrites might readily be taken for Tertiary eruptives. Among quartz-porphyries the White Porphyry, which is the most acid of the group, not only has the characteristics of an older rock in its internal structure, but is actually cut by transverse bodies or dikes of the Gray or Lincoln Porphyry, and a small sheet of it, together with inclosing sandstones, is included in the great mass of Sacramento Porphyry. An apparent exception to this evidence of the earlier age of its principal mass is found in the existence of two dikes of White Porphyry cutting Lincoln Porphyry, on the north wall of Cameron amphitheater, but their mass is relatively very small and the occurrence altogether an exceptional one.

Among the Tertiary eruptives Nevadite seems to be older than the andesites, judged by its internal structure and its geological surroundings, but the rocks are so widely separated that no direct evidence was obtainable.

Manner of occurrence.—The two groups are further distinguished by the fact that the older rocks are entirely intrusive and the younger extrusive; in other words, that the former never reached the surface, but were consolidated within the sedimentary strata and under the pressure of a considerable mass of overlying rocks, while the latter were, as far as can be determined at the present day, actually extruded upon the surface before final consolidation. This is an important distinction in its bearings upon the internal and petrographical structure of the rocks, and one upon which it seems geologists have hitherto not laid sufficient stress.

Intrusive sheets.—The greater mass of the older rocks occurs as sheets between the strata of sedimentary rocks, generally following a given horizon over great distances. That they were not poured out upon the surface and the overlying sedimentary beds deposited upon them—that is, that they are not interbedded sheets—is abundantly proved by the facts that they frequently cross the strata from one bedding plane to another and that they also occur as dikes cutting across the strata transversely, whose actual connection with the intrusive sheet it was sometimes possible to observe; large fragments of the overlying beds are, moreover, often found entirely included in them. The great number and extent of these intrusive sheets are very remarkable. They vary in thickness from a foot or two up to over a thousand feet. In Mosquito gulch sheets of porphyrite averaging 20 feet in thickness can be traced continuously on the cañon walls for several miles without showing any vent, and the sheet of White Porphyry which covers the Blue Limestone is shown by its outcrops to have been practically continuous over the area of the southern half of the Mosquito map. The only direct evidence of a channel or vent leading to this sheet of porphyry from below is at White Ridge, the point where it occurs in maximum thickness, whence it might be assumed to have spread out from this point as a center of eruption. In this case it would have spread ten miles from its center, gradually thinning out from 1,500 feet over the vent and 500 feet within a mile or two of it to 20 feet at the farthest point observed. The reconstructed form of this body, as shown in Section F, corresponds to that of the dome-shaped bodies in the Henry Mountains, described by G. K. Gilbert[1] under the name of laccolites. Indeed, it is evident that the manner of eruption of all the older igneous rocks of this region was analogous to that of the Henry Mountain rocks, although the amount of plication, dislocation, and subsequent erosion to which these have been subjected renders it more difficult to reconstruct accurately their original form, and it is probable that if they were restored they would be found to want the regular, symmetrical shapes he describes. The large dome-shaped bodies are rare, but relatively thick sheets, one above another, are often very numerous; for instance, in the Ten-Mile district, just beyond the northern limits of the map, the outcrops of seventeen were observed in a single transverse section across an estimated thickness of less than 15,000 feet of sedimentary strata.

DIKES.—Normal dikes in the sedimentary strata were rarely observed, and wherever the sheets cross the strata transversely it is usually at a very low angle. In the Archean formations, on the other hand, the older rocks were almost invariably found in the form of narrow and rather irregular dikes, as a rule not over fifty feet in thickness, the principal eruptions being two large bodies of diorite, whose outlines were not very accurately determined.

[1] Geology of the Henry Mountains Washington, 1877.

The Archean exposures studied in this region were once covered by portions of the same sedimentary series in which these intrusive sheets are now found. It may, therefore, be assumed that the form of the channels through which the fused masses were forced up into the overlying beds is fairly represented by the average outline of these dikes. According to this reasoning it is evident that the channels in the Archean were extremely small as compared with the extent of the sheets themselves, and were rather in the form of the narrow fissure, which has been supposed to be the source of so-called massive eruptions, than of the rounded "necks," which have sometimes been observed as the actual vents of volcanic eruptions.

Relation of form to composition.—In comparing the relative form of the intrusive bodies with the composition and structure of the rocks which compose them, it is found that the more basic the rock the thinner is the sheet and the greater its relative extent in a horizontal direction. It is true the range of relative acidity in this region is not the very widest, the White Porphyry, whose beds are relatively the thickest, having about 70 per cent. of silica, while the hornblende-porphyrite, which occurs in the thinnest sheets and at the same time with relatively great horizontal extension, has a little over 56 per cent. of silica. Basalts range from 45 to 50 per cent. of silica. The great sheet of White Porphyry has an estimated thickness of 1,500 feet at the point of its supposed intrusion from below, and the least thickness observed is 20 feet. The Sacramento Porphyry, which is slightly less acid (having 65 per cent. of silica) and whose greatest thickness is found immediately adjoining the White Porphyry laccolite, is evidently somewhat thinner, being probably less than 1,000 feet at its maximum, while the hornblende-porphyrite sheet of Mosquito and Buckskin gulches is found in a maximum thickness of 25 feet, and frequently thins to 6 feet, or even less; yet its practical continuity over considerable areas is even more readily evident than in the case of the larger masses of quartz-porphyry. A more remarkable instance of the great relative area of a basic intrusive sheet is that of the Whin Sill, in Northumberland, England, which, according to Messrs. Topley and Lebour,[1] is a basaltic intrusive sheet, that has been traced with unimportant breaks for a distance of 75 to 80 miles in a thickness of

[1] Quarterly Journal of the Geological Society, XXXIII, pp. 406–421, 1877.

about seventy feet. It occurs in the Carboniferous formation, and, like the porphyrite of Mosquito gulch, while apparently following a given bedding plane, actually changes from one horizon to another within a vertical range of about seventeen hundred feet.

It is apparent from the above facts that in underground flows of igneous rocks, as in lavas flowing on the surface, the coefficient of extent in relation to thickness of flow is a function of the relative basicity and consequent fluidity of the fused mass.

Amount of intrusive force.—In studying these intrusive sheets one is forcibly impressed with the magnitude of the force exerted during the intrusion of the lava, which here seems almost capable of actual measurement. Assuming as a type of these sheets the great body of White Porphyry above the Blue Limestone, it is seen that at its thickest point under White Ridge it has pried open the strata a distance of about fifteen hundred feet vertically, since that estimated thickness of White Porphyry is now found between the Blue Limestone and the overlying Weber Grits. The fused rock-mass at the time of its eruption must have been nearly fluid enough to obey the laws of hydrostatic pressure, in accordance with which the force applied to it at any point would be equally distributed throughout its mass and equally transmitted in every direction against its boundary walls. As long, therefore, as it retained the fluid condition, this force would be expended, not only in raising the beds immediately over the vent, but in spreading open the strata at as great a distance from this vent as the fluid mass could penetrate. The fluid condition was not, however, retained indefinitely, but the mass cooled gradually, and, in cooling, became solid and no longer capable of transmitting the hydrostatic pressure; therefore, the force available for prying open the strata became gradually less as the distance from the vent increased, and the distance by which the strata were forced apart at the vent may be assumed as the measurement of the maximum force exerted. It has been seen that the thickness of beds above this horizon to the top of the Cretaceous, which is the series assumed to have accumulated before the igneous rocks were injected or intruded, is estimated at 10,000 feet. It is possible that at the time of intrusion these beds were still under water, in which case the weight of the water should also be added. But this is too uncertain a matter to enter into even so crude a calculation as the present, and may therefore be neglected. The average specific gravity of these beds may be assumed at 2.50, as the upper beds were probably somewhat lighter than the average of those observed in this region. A cubic foot would therefore weigh 155.8875 pounds, and 10,000 cubic feet 1,558,875 pounds, which is the theoretical pressure exerted by gravity on each square foot of surface, and to raise this 1,500 feet would require a force of 2,338,312,500 foot-pounds exerted on each square foot of surface.

The above figures are to be considered rather as an indication of the magnitude of the subterranean forces involved than an actual value of any particular force, since the assumptions on which they are founded cannot be mathematically proved. For instance, on the contraction theory of the folding of the beds, the tangential strain to which they were already subjected may have been sufficient to produce a tendency in the beds themselves to split apart, and thus in part have counteracted the theoretical pressure exerted by gravity.

Mathematical demonstrations, as applied to geological phenomena, are at best of very doubtful value, owing to the impossibility of obtaining data or measurements of an exactness that may be considered of mathematical accuracy, and it often occurs that such demonstrations, which undoubtedly display a high order of mathematical ability on the part of their author, are comparatively worthless, or even misleading, owing to his assumption of a premise which cannot be proved to be true.

Source of intrusive force.—What may have been the impelling force which brought the fused material to its present position is evidently a purely speculative question, and therefore hardly appropriate to be discussed here. Whatever it may have been, it was undoubtedly of the same nature as that which has caused flows upon the surface. Much ingenuity has been displayed by theoretical geologists in discussing the source of volcanic energy, but in the present stage of experimental or synthetic geology it is impossible to find direct proofs for or against their views. The theory advanced by Clarence King (op. cit.) is among the latest, and is deserving of consideration because of his long and varied field experience. It may be stated in a crude, brief way as follows: Starting with the assumption of a solid interior, he shows that the increment of heat and the increment of pressure from the surface toward the interior of the earth are not the same, but may be expressed by two curves which would cross each other at a given depth. Under normal conditions, by the time the temperature in depth has increased to the ordinary fusion point of rock masses, the pressure has also increased to such a degree as to raise the fusion point of these rock masses, so that it is no longer possible for them to fuse. This he considers the permanent condition of the earth below the point of junction of the curves of temperature and pressure. Now, if for any reason the pressure is suddenly decreased, as it would be by the removal of a considerable weight of rock from the surface over a given area, and if this removal is more rapid than the change of temperature, which owing to the low conductivity of rocks must be very slow, fusion would set in and a subterranean lake of molten rock be formed. He conceives that for mountain areas the removal of large amounts of rock material by erosion would be relatively rapid enough for this purpose. Upon the thus melted mass there would be exerted the pressure of the rocks above it, and probably also an additional pressure due to expansion of its own mass by fusion, which would force the liquid magma toward the surface.

Why intrusive and not surface flows?—The next question that suggests itself is, why did the fused masses which formed the older rocks stop in their upward course at a given horizon and spread out there, instead of continuing on upwards to the surface, as did the more recent flows? Was it owing to a difference in the chemical composition of the magmas from which either series were formed or to a difference in the quality and amount of the impelling force, or, again, to a difference in the resistance offered by the rock masses through which they passed? The first of the three alternatives may, it would seem, be at once answered in the negative, since the same range in ultimate chemical composition is found in intrusive rocks as in recent lavas. The distinction that petrographers have claimed to find between the older or intrusive rocks, as a class, and the recent lavas, depends on internal structure and the arrangement of the mineral constituents, while they acknowledge that the chemical composition of the two classes may be practically identical. In this region White Porphyry and Nevadite among the acid types of the two classes, and hornblende-porphyrite and hypersthene-andesite among the more basic, are almost identical in chemical composition.[1] The loci of eruption in either case are not more than ten miles apart, and yet in one instance the molten material congealed at a depth of over ten thousand feet and in the other at the very surface; and the resulting rocks are distinct varieties, differing more in the case of the basic ones, where composition is more closely alike, than in the acid.

In a discussion of the origin of a certain group of laccolites, an argument has been made in favor of the theory that their laccolitic or intrusive character is dependent on the density of the eruptive magma (which is necessarily a function of its chemical composition); that the molten mass would stop in its upward progress through the sedimentary strata, when it had reached a point at which the average density of the rocks below it was greater than, and that of the rocks above it less than, its own average density. This argument is, however, materially weakened by the instability of some of the premises. First, it is assumed that the density of laccolitic or intrusive rocks is less than that of erupted lavas. Even should this prove to be true of that group, it would not be a sufficiently wide basis on which to found a generalization for laccolitic or intrusive bodies as a whole. Secondly, the data used in support of a necessary condition of this argument, namely, that "the acidic rock of the laccolites must have been heavier in its *molten* condition than the more basic rock of the neighboring volcanos," are, as the author acknowledges, insufficient, even if trustworthy. Aside from the value of this argument as such, however, the facts observed in this region, as mentioned above, afford a direct proof of observation against it. Moreover, as no chemical analyses of the rocks of this group of laccolites were made, it is by no means impossible that they are, as a class, much less acid than the author supposed.

Whether or not there was a difference in the impelling force in the case of intrusive sheets and of surface flows is a purely speculative question, for which no direct evidence can be obtained. It might perhaps be argued that, if the magma from which each of these series was formed originated at essentially the same position within the earth's crust, it would

[1] See analyses 1 and 9 and 5 and 10, Table I, Appendix B.

have required about the same amount of force to bring the earlier intrusions to their place of consolidation, 10,000 feet below the surface, that it did to bring the later flows to the surface after the 10,000 feet of superincumbent strata had been removed by erosion.

In regard to the third alternative, it seems that a part at least of the reason for the stoppage of the intrusive magma at its present position may be found in the resistance to its passage offered by the sedimentary strata. If it were a question only of the porphyry sheets above the Blue Limestone, it might be assumed that the Weber Grits offered some special conditions of impenetrability; but, in point of fact, although intrusive sheets are almost always found at this horizon in the Mosquito region, they also occur at many other horizons, both above and below. While it cannot be maintained, therefore, that any particular bed offered special resistance to the passage of the fused mass, it is not only evident a priori, but supported by observations of many of the transverse sheets and dike-like bodies, that a continuous and unbroken horizontal rock stratum would offer more resistance than one that was inclined, broken, or fissured. The molten rock-mass would naturally seek joints or fault planes, or, in default of these, follow the lines of least resistance along bedding planes. That the intrusive bodies are not found following the planes of the great faults of this region would in itself be a sufficient proof, were none other available, that these faults are subsequent to the intrusion of the older igneous rocks. Taken as a whole, it seems evident that the upward passage of a molten stream would be much more impeded in a series of horizontal and comparatively unbroken strata, such as are supposed to have existed here at the time of the intrusion of the older rocks, than it would be after they were uptilted, flexed, and dislocated, as they were at the time of the eruption of the younger series. In the case of each of the three larger masses of true eruptive rocks of the region, viz, those of Chalk Mountain, of Black Hill, and of Buffalo Peaks, wherever the sedimentary strata are visible in close connection with the eruptive mass they are seen to be standing at a very steep angle and the eruptive mass has apparently flowed over their basset edges.

Internal structure.—From this point of view the division of the igneous rocks of the region is also well marked, although it is in the nature of things more difficult to draw a sharp and definite line of separation than in the case of the two characteristics already discussed. It is also to be remarked that, whereas these structural distinctions have hitherto been considered to be essentially a function of the age of the rocks, the studies conducted during the present investigation tend rather to the conclusion that these distinctions are primarily dependent on the manner of occurrence of the bodies, or, in other words, the conditions under which they consolidated, and only secondarily on their age; hence that the age of a rock can only be relatively and not absolutely determined by its internal structure and petrographical constitution. The details of the microscopical structure of the various rock species are so fully described and discussed by Mr. Cross in Appendix A that only a few of the more prominent characteristics of the two types, such as will serve to correlate them with those of other regions, need to be given here. The older series are either entirely granular, or, where porphyritic, are characterized by the holocrystalline structure of the groundmass and an absence of isotropic or amorphous material, when examined under the microscope. Many of the orthoclastic varieties have extremely large crystals of that feldspar, which give a striking and easily recognizable appearance to the rock masses; although very prominent in Colorado, this peculiarity can hardly be regarded as an essential characteristic of the type. They are not vesicular or scoriaceous; in other words, they present the external characteristics of a rock cooled under pressure. The younger type, however, while in exceptional instances almost holocrystalline, generally contains isotropic material or actual glass substance. Its orthoclastic feldspars are essentially sanidine, it may be vesicular and scoriaceous, and in general carries abundant glass inclusions and bears evidence, either in its structure or in the constitution of its mineral constituents, of having cooled at or near the surface, and consequently more rapidly than the older type. In the Mosquito region there is apparently a definite relation between age and relatively granular character of the different varieties of either type; thus White Porphyry is the most thoroughly granular rock among the older series, and Nevadite among the younger. Although the relation of pressure and conditions of cooling to internal structure are so marked and important in the two great series, or, so to speak, generically, the difference of internal structure in a given species, due to difference of pressure, is, if it exists at all, so slight as to escape observation. Thus, between the lowest body of White Porphyry, which occurs in the Archean, and the highest, which is near the top of the Weber Grits (a vertical range of about three thousand feet), no essential difference in internal structure was detected. It would appear, therefore, that, while very wide differences in the conditions of cooling may produce a generic difference between two series of rock varieties, the internal structure of a given variety is not dependent on those conditions alone, but that the species possesses certain essential characteristics of its own which are dependent on other factors.

While the petrographical studies made in the course of this investigation, forming only an accessory and not an essential part of it and being confined to a limited area, are not sufficiently complete to form the basis of an essential change in the classifications hitherto adopted, they point decidedly to the fast approaching necessity of some essential modification in them. Thus, the White and Lincoln Porphyries would a few years ago have been unhesitatingly classed by petrographers, from a study of their specimens and aside from any field observations on their geological relations, as granite-porphyry or mica-granite, and probably of Paleozoic or early Mesozoic age, from their resemblance to well-known rocks of that age in other parts of the world. The hornblende-porphyrites, on the other hand, might from the same standpoint have been classed as Tertiary andesites.

Orthoclastic and plagioclastic rocks. — The now universally adopted chemico-mineralogical classification (based on Tschermak's classical studies) of orthoclastic and plagioclastic rocks is one which presents ever-increasing difficulties of application with the progress of microscopical and chemical investigation. In the present instance the older rock series contain relative proportions of orthoclase and plagioclase feldspar, often so evenly balanced that the slight variations in their proportions, which may be found in different parts of what is apparently the same mass, would be sufficient to justify the placing of the same rock now in the orthoclastic division now in the plagioclastic. Again, in those porphyries in which the orthoclastic feldspars have developed in large individuals, it is evident that so much orthoclastic material has thus been abstracted from the groundmass that, were the latter taken as the type of the rock, it would be classed as plagioclastic, while in the rock as a whole, or in those varieties in which the large orthoclases have not been developed, orthoclase predominates. It is apparent, moreover, that, owing to the increased facilities which the microscope now affords for the detection of plagioclase among the microscopical constituents of a rock, an ever-increasing number of rocks hitherto supposed to be orthoclastic will be found to have a predominance of plagioclase feldspars, and that, if this distinction remains without modification as a basis of classification, the extent of rock species of the orthoclastic type will become more and more restricted and eventually rather rare.[1]

Distribution of intrusive rocks in the Rocky Mountains.—The older and intrusive series of rocks, represented in this region by the porphyries, porphyrites, and diorites, form undoubtedly a very large proportion of the igneous rocks of Colorado and adjoining regions which have hitherto been classed as Tertiary eruptives or as eruptive granites. To how great an extent they should be substituted for the latter on the existing geological maps it is not yet possible to determine with accuracy, owing to the incompleteness or absence of characteristic specimens. An opportunity was, however, offered in the case of the Henry Mountains, so ably described by Mr. Gilbert, who kindly loaned a considerable number of the actual rock specimens and sections, upon which the determinations for his work were founded. These were submitted to Mr. Cross for microscopical examination, several new thin sections being made by him for this purpose. The results of his investigation, although (owing to the incompleteness of the series and the altered condition of many of the specimens) not adequate to afford a complete characterization of all the rock masses found there, show conclusively that they belong to the same structural type as the older intrusive rocks of this region. Out of 19 varieties represented by specimens or thin sections, 14 were found to correspond very closely in composition and structure to the

[1]A remarkable instance of this tendency is found in the recent review of rock determinations of the fortieth parallel by Messrs. Hague and Iddings (American Journal of Science, xxvii, 453, 1884), which shows that in the vast area covered by that survey only a single true trachyte, and that not of the most characteristic type, was observed, although in the original determinations, made in the light of the best petrographical science as it existed twelve years ago, these rocks were supposed to form a large and important class there.

hornblende-porphyrites of the Mosquito Range and 3 differed from the Mosquito rocks in containing a peculiar development of augite in the place of hornblende.[1]

Mr. Gilbert enumerates various isolated groups of mountains in the plateau region—the Sierra La Sal, Sierra Abajo, Sierra El Late, and Sierra Carriso—which, from the description of geologists who have visited them, he infers to be true laccolites. He also infers that their rocks are analogous to those of the Henry Mountains, which is very likely to prove true in so far that what he describes as porphyritic trachyte may correspond to the porphyries with large crystals above described. His further generalization that the two types of mountain structure, the laccolitic and the volcanic, necessarily involve two chemical types of rock, the one acidic, the other basic, is, as shown above, not authorized by the observed facts. It might fairly be reasoned that the more acidic lavas, when intrusive, owing to their greater viscosity, would tend to form thick, dome-shaped masses like his laccolites, rather than basic lavas; but even this tendency is not without its exceptions.

It is the intrusive quality, not the relative acidity or basicity of the magma, to which the characteristic structure of this rock type is due.

Dr. Peale[2] has further extended the probable development of intrusive bodies, more or less analogous to the laccolites in form, but furnishes no decisive determination of their petrographical structure or composition From specimens seen or actually collected by the writer, it may be stated, however, as a fact about which there can be little question, that the type of intrusive rock represented by the older series is extensively developed between the North and Middle Parks, in the Middle Park, and between the Middle and South Parks, that it forms the mass of Spanish Peaks, and occurs in enormous developments in the Gunnison region, where the varieties characterized by large feldspars cut across Cretaceous strata. Similar bodies also exist beneath the more recent lavas of the San Juan region, which lends probability to the supposed similarity of the rocks forming the isolated mountains of the Sierra El Late, Sierra Carriso, and others.

[1] Mr. Cross's detailed description of these rocks will be found at the end of Appendix A.

[2] "On a peculiar type of eruptive rocks in Colorado." Bulletins United States Geological and Geographical Survey, Vol. III, pp. 551–564.

Contact metamorphism.—There is a notable absence of caustic phenomena in this region, either on the inclosing or the included sedimentary rocks at their contact with the intrusive masses, such as are generally supposed to accompany the eruption of igneous rocks.

In the case of such numerous and large bodies they might naturally be expected to be exceptionally frequent and well marked, since the eruptive masses must have retained great heat for an unusually long time on account of the depth at which they were consolidated. Perhaps the absence of any evidence of fusion in these rocks might be explained on this very ground, that at that depth the pressure was so great that the fusion point was considerably raised, and hence a temperature sufficient to hold in a molten condition the mixed material already fused would be insufficient to melt homogeneous and by themselves comparatively refractory rocks, like sandstones and dolomites. However this may be, nowhere was any evidence of fusion observed in the sedimentary rocks, even in the case of very small fragments entirely included in the eruptive rock. Even in the dikes of porphyrite cutting through the Archean, in which inclosed fragments of country rock, generally of small size, are particularly abundant, neither quartz, granite, nor gneiss, of which these fragments generally consist, shows any alteration at the contact, though the porphyrite material often fills small cracks in them, showing that it was in a thoroughly fluid condition at the time they were caught up. Such alteration as was found could more readily be ascribed to the combined action of heat and water than to heat alone.

On the other hand, the reflex action of the colder sedimentary rocks on the eruptive mass is generally noticeable, and is such as is ordinarily found, showing itself in a fine-grained or even compact structure for a few inches or more from the contact, and in a somewhat different arrangement of the mineral constituents of the rock. It is much more prominent in the narrow dikes than in the large intrusive sheets, but occurs at both upper and lower contacts of the latter, and may also be detected around the included fragments. Even in these cases, however, there was no appearance of vitrification

Instances of regional metamorphism are not wanting. Sandstones are changed to quartzites, dolomites frequently into marbles and less often more or less serpentinized; but these changes cannot be assigned to the direct action of heat, since they are in no sense contact phenomena. Their development is local and irregular, extending over considerable areas, where there is no actual contact of the altered beds with intrusive rocks, and, on the other hand, being more generally absent from the actual contact with these rocks.

Non-absorption of sedimentary rocks by eruptive masses.—Another important observation in regard to these intrusive bodies, and in one sense a corollary of the above statements, is the fact that, although they have split apart and pried open the sedimentary strata and caught up or entirely surrounded both large and small fragments of sedimentary rocks, there is no evidence of their having absorbed or assimilated within themselves by actual fusion any portion of these sedimentary rocks; certainly not any considerable masses thereof. Not only are there no relics of fusion at the present contact, as there necessarily would have been if a portion had already been fused, but in reconstructing the sections on actually measured profiles there is no portion of the sedimentary strata missing, which cannot be accounted for by erosion. Along the contact surface the fused mass has cracked off fragments, often quite small, which have consolidated again into a sort of breccia; again, the thinner sheets have sometimes bent back and contorted a stratum of limestone or quartzite at the end of the flow or as it crossed from one bed to another; but of fusion, as already stated, there is no sign.

I have insisted on this point because the question of the capability of an igneous mass to absorb, or eat up as it were, the sedimentary or even already consolidated igneous rock through which it passes, is one which has always interested me, and for which, in a field experience of over fifteen years, largely among eruptive rocks, I have vainly sought for demonstrable proof. It is customary among geologists to draw their ideal underground sections of igneous masses as if this capability were unlimited, and geological text-books seem to tacitly assume that it is so, without offering an explanation of how it is possible or the grounds on which the assumption is made.

So far as I know, the English geologists are the only ones who have met the question distinctly and have brought forward instances in nature to prove that igneous eruptions have eaten up practically unlimited amounts of sedimentary rocks. These instances are the so-called granite bosses in Ireland (Mourne Mountains), Scotland, and England (Devon and Cornwall), cutting through upturned Cambrian and Silurian rocks, which are comparatively undisturbed by the eruption and maintain their normal strike up to these granite masses on either side.[1]

Professor Geikie goes so far (op. cit., p. 550) as to ascribe the variability in composition and structure of intrusive masses to involved and melted-down portions of sedimentary rocks. It would be presumptuous to doubt the correctness of the field observations on which these generalizations are founded, and yet it is not only possible, but has sometimes come under my observation that a granite boss has been found protruding through a given rock or series of rocks, and therefore been judged by the geologist who examined it to be younger than the latter, whereas, in fact, the reverse was the case, and the latter rock had been deposited, or had flowed, around an already-existing granite protrusion. In many cases it is difficult to obtain direct proof whether the protruding or the inclosing rock is the older, and in such a case the probability one way or the other may be dependent on this very question of the capability of igneous rocks to assimilate large masses of sedimentary rocks.

A case in point is the granite body of Little Cottonwood cañon, in the Wasatch Mountains, of which a section some seven miles long has been exposed by the erosion of the cañon. The present outcrops of the body occupy an area whose dimensions may be roughly stated as 7 by 15 miles; and a thickness of some 5 miles of sedimentary rocks abuts against its northern side, the upper members sweeping round and in part covering its eastern portion, and continuing southward in an almost horizontal position. There is no special disturbance of these beds in contact with the granite; so far as observed, they follow the normal dip and strike induced by the dynamic movement of the region. Neither are there any masses or fragments of sedimentary rocks included in the granite. Regional metamorphism exists

[1] A. Geikie: Text Book of Geology, pp. 541 et seq. London, 1882.

in the changing of sandstone to quartzite and of limestones to marble, but these are by no means contact phenomena, and occur as often, if not oftener, at considerable distances from the granite as in direct contact with it. Porphyry dikes also cross the sedimentary strata in the vicinity, but these have no more necessary connection with the granite than have the neighboring bodies of volcanic rocks. They are not direct offshoots from it, and, so far as their manner of occurrence and structure go, may bear the same relation to it that the porphyries of the Mosquito Range do to the Archean eruptive granite. When I examined this region on the Exploration of the Fortieth Parallel, my first impulse, guided by my teachings as a student of geology, was to consider the granite an intrusive mass cutting Carboniferous strata; it was, however, difficult to conceive that it should have eaten up over five hundred cubic miles of sedimentary rocks without leaving some more definite evidence of this action than it has. This, together with other considerations, led me, after a careful weighing of the evidence, to the view that the granite must have been erupted in Archean time, and that in the ocean of the Cambrian and subsequent periods it formed a submerged reef around which the sedimentary beds were deposited. Professor A. Geikie, the English geologist, whose eminent ability none can recognize more fully and heartily than I do, after a visit to the region, occupying only a few days, decided promptly that my view was wrong, and, evidently basing his opinion on the granite bosses of his own country, has published it in his text-book[1] as an instance of Post-Carboniferous granite. While, owing to the necessarily hasty character of reconnaissance work like that of the fortieth parallel, it is very possible that a more detailed study might lead us to modify our own views, especially in regard to so complicated a district as that in question, I should still be unwilling to admit, even at the instance of so experienced a geologist as Professor Geikie, that the Cottonwood granite can be Post-Carboniferous, even if my only reason were that I do not admit the possibility that the granite had eaten up or assimilated this enormous mass of sedimentary rocks without leaving any trace of fusion on the adjoining rocks, any incompletely assimilated portions within its own mass, or without showing in its own structure and composition any marked variation from that of the normal rock.

[1] Op. cit., p. 646.

It seems to me that there is a marked distinction between the metamorphism that is found in regions where igneous rocks abound (and which is generally admitted to be the result of the combined action of heat, pressure, and water) and that which involves the entire absorption and assimilation of foreign rock masses into the substance of the igneous mass itself. The former in its extreme phase supposes a simple rearrangement of the materials of a rock, a change in their form without any essential change in their chemical composition, and involves at most the bringing of them to a viscous state, not to that of fusion. The latter must be a dry process and involves a fusion of the foreign materials as complete as that of the original magma in the deep-seated source from which it came. For fusing the 500 cubic miles of sedimentary beds supposed to have been assimilated by the Cottonwood granite body an enormous amount of heat must have been abstracted from that body. Now, to have this amount of heat to yield up, and yet to be able to maintain itself in a state of fusion long enough to crystallize in the same way that it would without this addition of foreign material, supposes an amount of original heat stored up within its mass that ought to have vitrified some of the rocks through which it passed. It is not difficult to conceive of such heat in the deep-seated source from which the igneous rocks came, but that it should still exist in these rocks when they have reached the point where they are ready to solidify, and which may be assumed to be near the limit that this heat would carry them, seems highly improbable. The only cases of actual vitrification of inclosed fragments in igneous rocks that I have read of have been in recent volcanic rocks, where the fragments were extremely small.

As suggested above, the pressure under which the intrusive rocks of the Mosquito Range were consolidated would necessitate a higher temperature to produce fusion. In the case of the Cottonwood granite the pressure under which consolidation took place and the consequent temperature of the fusion point must have been greater still. But the Mosquito porphyries retained a very fluid condition, and therefore a temperature higher, as compared with the fusion point, than the Cottonwood granite, for a very long time, since they were spread out in thin sheets and ramifying bodies in every direction at considerable distance from the central mass, while the

Cottonwood granite, as far as can be seen, formed only a single massive body without ramifications. The porphyries must therefore have had more superfluous heat than the granite to devote to the work of melting up the included masses of sedimentary rocks, and one can see here, as one cannot in the granite, that such masses were actually caught up and included in the fused rock. It would be fair to assume, therefore, that in this case relatively larger amounts of sedimentary rocks would have been fused and that the evidence of such fusion would be more apparent.

In the present condition of microscopical investigation we may trace the development of one mineral from another and detect its most minute alteration, either by fusion or by chemical interchange; and, had any of these sedimentary rocks been assimilated into the igneous mass, it would seem hardly possible that every trace of the process should have escaped our observation in the thousands of rock sections that have been examined. In point of fact, however, although in the case of the porphyrite dikes the eruptive material is found to fill minute cracks in the inclosed fragments of Archean rocks, there could be detected no evidence of fusion on either adjoining or inclosed sedimentary rocks. In the eruptive rocks themselves, moreover, the alterations of mineral constituents are all the result of secondary processes after the mass had fully cooled and crystallized.

The testimony of the chemical composition of these rocks is, so far as it goes, equally opposed to the supposition that foreign matter has been assimilated by any of these intrusive bodies. Of White Porphyry too few specimens were analyzed to afford a decisive test; but it is to be remarked that the two specimens (see Table II, Appendix B) which show an abnormally high percentage of silica are from the London and New York mines and are extremely decomposed and altered, a secondary action which has decreased the proportion of more soluble basic constituents and correspondingly increased the percentage of silica. Of the Lincoln or Gray Porphyry six specimens from different bodies show an average of 68.08 per cent. of silica, with an extreme variation from this average of 2.63. For the combined alkalies, three specimens show an average of 6.14 and an extreme variation of 0.86; and for lime and magnesia combined, three specimens show an average of 4.03, with an extreme variation of 0.19.

The Cottonwood granite, which, on the supposition advanced by Professor Geikie, must have taken up an enormous amount of silica, lime, and magnesia, shows, however, no abnormal amount of these constituents in its composition, which is that of a normal granite rather rich in plagioclase.[1]

[1] The composition of this granite, as given in Exploration of the Fortieth Parallel, Vol. II, p. 357, is as follows:

SiO_2	71.78
Al_2O_3	14.75
FeO	1.94
MnO	0.09
CaO	2.36
MgO	0.71
Na_2O	3.12
K_2O	4.89
Ignition	0.52
	100.16

APPENDIX A

PETROGRAPHY

BY

WHITMAN CROSS

CONTENTS.

PETROGRAPHY.

BY WHITMAN CROSS.

INTRODUCTION.

The eruptive rocks of the district embraced by this report are naturally divisible into two groups, according to age. Although the age of neither group can be exactly defined in geological time, the larger and more important one is unquestionably older than the period of disturbance which produced the great faults and folds described in other parts of this volume, while the other group is younger. In this district, rocks of the former group penetrate the Upper Coal Measure strata; in adjoining regions they occur in similar manner in the Trias; and masses of nearly identical character are found in the Cretaceous of districts not far removed from the Mosquito Range. The conclusion that the rocks of the older group are of late Mesozoic age seems warranted by all that is known concerning their occurrence. In regard to the period of dynamic disturbance, it has already been stated in Chapter II that the known evidence places it at the beginning of Tertiary time.

It is plain, then, that the rock groups mentioned might be considered the direct equivalents of the Tertiary and Pre-Tertiary divisions of many writers, but it is thought best to refer to them simply as the *older* and the *younger* groups, and by this division it is intended to express merely the actual relationship as to age which is shown by the observed occurrences. The question concerning the possible influence of age upon the structure of these groups cannot be fully discussed at the present time, because the rocks of other districts in Colorado, the study of which has been undertaken, form with those of the Mosquito Range a connected series, requiring a correlation of observations upon all of them before justifiable conclusions can be drawn.

All of the older eruptives and some of the younger series are fully crystalline, although few of them are typical granular rocks, and the structural forms presented are such as render advisable some statement as to the sense in which the terms "granular" and "porphyritic" are used in the descriptions that follow. When these terms are applied with the old and natural meaning, to designate certain universally recognized rock structures, it is probable that the groups formed by the application will be practically the same, whether the attempt is made to accurately define the boundary line or not. All consider granite as a typical granular rock; and that rock which would be cited by any one as typical of the porphyritic structure could scarcely be placed elsewhere under any existing definition. This latter assertion is at least true now that Rosenbusch has withdrawn his earlier definition,[1] by which the presence of some amorphous matter in the groundmass was made essential to a porphyry. The new ground taken by Rosenbusch[2] in regard to the essential difference between the granular and porphyritic modifications of eruptive rocks seems to the writer open to some serious objections, although the great value of many of the points so clearly presented must be gratefully acknowledged by all. While a full discussion of the question cannot be entered upon in this place, the chief objections to the new definition may be briefly stated.

If the writer correctly understands the position taken by Rosenbusch in his essay upon the essence of the granular and porphyritic rock structures, the latter wishes so to redefine the terms "granular" and "porphyritic" that they shall henceforth indicate genetic and not structural relations. It is claimed that the typical structures hitherto designated by these terms have their origin in the history of each individual rock mass; the granular rocks having come to complete solidification in the course of what may be termed a single *phase;* the porphyritic types, on the other hand, having passed through two phases, in the second of which the groundmass was formed—the matrix for the crystals of the earlier phase. The genetic groups thus outlined are to replace the structural ones, while the terminology is to remain the same.

The first objection to be raised is that a new division of eruptive rocks according to a genetic principle does not in any way destroy the purely structural groups already existing, even if the divisions produced by the two principles are exactly coincident in extent. It will still be desirable and necessary to refer to rock structures independently of genetic connections, and the terminology of the science is not simplified but rather complicated by the application of a given term in two distinct senses. Granular cannot be logically used with a genetic meaning while, at the same time, it is desirable to apply it in accordance with existing usage as a purely structural term. In the second place, it seems a matter for debate as to whether the groups formed on the new principle *are* coincident with the structural ones. If not, we surely cannot cover them by a single definition, nor use the same terms in their description.

That the new definitions, when logically applied, do produce divisions widely different from the corresponding structural groups is well illustrated in the case brought up by Rosenbusch himself, in a passage of which the following is a free translation :

> If we follow in thought the process of granite formation, we reach at length a point, after the separation of ore-grains, apatite, zircon, biotite, hornblende, or augite, and a part of the feldspars, where, between the ready-formed mineral particles which are to make up the mass of the rock, a very fluid, acid residue remains, out of which some feldspar and quartz are yet to be formed. If now, through any cause, the solidification of the rock be suddenly interrupted at this point, the residue will solidify as amorphous substance (it might under certain conditions be spherulitic or even granophyritic) and we have thus a granular mixture of the granite minerals (with the exception of quartz) and irregular

[1] Physiographie der massigen Gesteine, pp. 86, 87.

[2] "Ueber das Wesen der körnigen und porphyrischen Structur bei Massengesteinen." Neues Jahrbuch für Mineralogie, etc., II, 1, 1882.

patches or particles of a very acid glass—a case described by G. vom Rath in a so-called trachyte from Monte Amiata, in Tuscany. Such a rock can only be designated as a granular rock which is not entirely holocrystalline. On the other hand, if the rock contains quartz among its crystalline particles, then it may no longer be regarded as granular, but rather as a porphyritic rock.[1]

According, therefore, to the new rule, strictly applied, we may have a granular rock containing glass. In the case cited the glass is described as in isolated particles; but the classification could not have been different had it appeared as a base holding and cementing together the mineral grains, neither can the amount of this glass be restricted under the considerations which gave rise to the definition. A rock of the orthoclastic series, containing crystals of ore, biotite, apatite, plagioclase, and some orthoclase, imbedded in glass or microfelsite, which might compose more than half of the mass, would still be a *granular* rock, while, had the crystallization proceeded further and some quartz been added to the other minerals, the product would have been a *porphyry*. Again, in referring to the observed difference between diabase and gabbro resulting from the formal development of the feldspars, Rosenbusch remarks that this difference is only an apparent one, if the essence of the diabase *structure* be considered as lying in the *relative age* of the feldspars and not in their *form*.[2] Yet this formal difference still exists and must be described; but, if Rosenbusch's definitions be adopted, it cannot be described as structure.

These instances have been considered somewhat in detail, to show clearly the correctness of the statement that Rosenbusch desires to *replace* the structural groups by purely genetic ones, and also to show that the two divisions are not coincident in extent. In regard to the latter point it seems to the writer that it may fairly be questioned whether all granular rocks are the result of one phase and whether all porphyritic rocks have required two phases of consolidation.

Finally, the great precision aimed at by Professor Rosenbusch in his new definitions seems to be unnatural. Rock groups blend insensibly in all directions; therefore sharp boundary lines are arbitrary and undesirable.

In the following rock descriptions the terms "granular" and "porphyritic" are used in the purely structural sense. Were the genetic principle applied the grouping would be the same.

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[1] "Verfolgen wir in Gedanken den Act der Granitbildung in seinem Verlaufe, so wird nach Ausscheidung der Erze, Apatite, Zirkone, Biotite, resp. Amphibole oder Pyroxene, und eines Theils der Feldspathe ein Stadium eintreten, wo zwischen den ausgeschiedenen, die fertige Hauptmasse des Gesteins bildenden Gemengtheilen in unregelmässigen Partien eingeklemmt ein sehr acides Magma vorhanden ist, aus welchem sich der letzte Rest der Feldspathe und der Quarz auszuscheiden hätten. Denken wir uns nun durch irgend welche Ursache an dieser Stelle den Bildungsprocess des Gesteins plötzlich unterbrochen, so wird der Rest von Mutterlauge amorph erstarren (er könnte unter Umständen auch sphärolithisch, ja granophyrisch erstarren) und wir erhalten so ein körniges Gemenge der Granitmineralien (mit Ausnahme des Quarzes) und unregelmässige Brocken und Partien eines sehr sauren Glases—bekanntlich ein Fall der nach G. vom Rath's Beschreibung bei einem sogenannten Trachyt vom Monte Amiata in Toscana vorliegt. Ein solches Gestein kann nur als ein körniges Gestein mit nicht ganz holokrystalliner Ausbildung bezeichnet werden.—Enthielte dagegen das Gestein unter den krystallinen Ausscheidungen auch den Quarz, so wäre es dann nicht mehr als ein körniges, sondern als ein porphyrisches zu betrachten." Op. cit., p. 15.

[2] "Wenn man das Wesen der Diabasstructur nicht in der Form, sondern in dem relativen Alter der Feldspathe sieht." Op. cit., p. 8.

Classification of Mosquito Range eruptives.—The eruptive rocks of the Mosquito Range are classified as belonging to the following groups:

Older . . { Quartz porphyry. Diorite. Porphyrite.

Younger { Rhyolite. Andesite.

For the reasons given in the chapter on rock formations, the possible eruptive granites of the Archean areas are not included in this discussion. It is at once noticed that basic eruptives, such as diabase or basalt, do not occur in this region, and even the andesites above mentioned are only found outside the area mapped.

Nearly all the important rocks of the district are described as quartz-porphyry or as porphyrite. Of these two classes there are several marked types, and they are so connected by intermediate or transition forms as to build an almost complete series, uniting the dissimilar extremes. The treatment of these rocks in the present chapter, which has been revised in the light of experience gained in adjoining districts, is somewhat different from that at first adopted; hence a few minor discrepancies may be noted between the classification here given and that indicated by the coloring of the map and the text of the main work. The map was engraved and colored before this information from other districts was obtained, and could not, therefore, be changed; the general text is, however, consistent with the divisions of the map. The inconsistencies alluded to are really of but little moment, as they relate to certain more or less questionable forms near the line between quartz-porphyry and porphyrite, which, taken by themselves, might readily be differently classed by different persons. The changes are introduced here for the sake of preserving, as far as possible, a uniform system in this and in forthcoming reports on adjoining districts.

OLDER ERUPTIVES.

QUARTZ-PORPHYRY.

MOUNT ZION PORPHYRY.

This rock occurs in the masses of Mount Zion and Prospect Mountain and is designated by a special coloring upon the detailed Leadville map, while it is united with the White Porphyry on the map of the Mosquito Range.

In structure it resembles a fine-grained granite at first glance, there being but few biotite leaves, with occasional feldspar and quartz crystals, which by reaching a diameter of three or four millimeters become conspicuous in the mass of the rock. When the rock is fresh the naked eye easily distinguishes many quite uniformly small quartz grains imbedded in the feldspar, which is the chief constituent. Biotite is uniformly but sparingly present in small, irregular leaves.

Microscopical.—By the aid of the microscope the following constituents are found, named in order of their formation: Zircon,[1] magnetite, apatite, biotite, plagioclase, orthoclase, and quartz.

With a low power of the microscope the chief part of the rock is found to consist of an irregular granular mixture of orthoclase and quartz, the latter occurring in roughly rounded grains 0.3^{mm} to 0.7^{mm} in size, which often seem inclosed in the more irregular and frequently larger grains of orthoclase. The presence, in almost every grain of these two minerals, of plagioclase microlites having a prismatic habit with apparently somewhat rounded terminations, and averaging 0.1^{mm} in length by 0.01^{mm} to 0.03^{mm} in width, shows their coincident formation. These microlites, which consist of from two to five laminæ, are very numerous and form the most characteristic constituent of the rock. Plagioclase grains occur, corresponding in size to those of orthoclase and quartz, but they usually show some crystal outlines, and through their freedom from the microlites the correspondence of these grains to the larger, stout crystals, which are sometimes 4 millimeters in diameter, seems clearly established. The total absence of the microlites, the difference in form, and the larger angle of extinction, reaching in some observed cases 20° either side of the twinning plane, show plainly that these crystals represent an earlier and doubtless more basic variety of plagioclase than the microlites. The larger crystals are not abundant, and are seldom prominent in the hand specimen. Biotite is never developed in crystal

[1] In nearly all the rocks of this district a mineral, presumably zircon, has been found. Its identity has been proven in a rock from the Ten-Mile district, chemically and crystallographically.

form, and is usually much altered. The three accessory minerals are sparingly present, apatite especially so. In none of the sections examined is there any finer-grained interstitial matter.

Alteration.—The decomposing agencies acting upon the Mount Zion Porphyry seem to have been particularly favorable to the formation of *muscovite*, which is the end product of the alteration of the biotite, as well as the immediate one of that of orthoclase and plagioclase. In the latter two minerals the process takes place in the usual way, and in the extreme decomposed state each grain and microlite not wholly inclosed in quartz is replaced by a brilliantly polarizing aggregate of minute, colorless, but lustrous leaves. In the case of the biotite there are visible transition stages. Ore particles and yellow needles (rutile ?) are first formed, and the biotite passes into a yellowish-brown, faintly-polarizing, unknown substance, which soon gives way to a mica indistinguishable from the product of the adjoining feldspars. Occasionally pure leaves of muscovite are found in quite fresh rock, but, as they always increase in quantity in more decomposed specimens, their secondary origin is probable. No other secondary product of importance remains, in the advanced stages of decomposition. Specimens of Mount Zion Porphyry which are bleached through the disappearance of the biotite become indistinguishable from White Porphyry. (See p. 76.)

WHITE OR LEADVILLE PORPHYRY.

On account of its relation to the ore bodies, its peculiar mode of occurrence, the large area in which it is found, and its petrographical interest, the White Porphyry must be regarded as the most important eruptive of the district, and it will be described in considerable detail.

Macroscopical.—In its most typical form it is a nearly white, compact or finely granular rock, which at first glance seems to be homogeneous, but under close examination usually discloses a number of small feldspar crystals, and, scattered irregularly through the mass, not unfrequently, double pyramids of quartz. Hexagonal crystals of dark brilliant muscovite may occasionally be seen, but this is probably secondary, as are, very certainly, the clusters of pearly leaves of the same mineral, which are characteristic of the rock in some places, as in California gulch, on Lamb Mountain, and in the intermediate region. The total absence of biotite and bisilicates makes the rock seem dull white, except when stained by secondary infiltration products, and decomposition in the ordinary way only makes the rock seem more homogeneous and compact than before. Upon the contact with the wall-rock or in some of the more narrow dikes the White Porpyhry is found to contain more numerous crystals of quartz and feldspar, imbedded in a very compact groundmass [235].[1]

Through decomposition the rock assumes in some places a granular appearance, as if composed of small, worn grains,[2] but no corresponding microscopical structure can be seen.

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[1] The collection numbers of particular specimens will be inclosed in brackets.

[2] The structure referred to is illustrated by specimens from the Shamus O'Brien [33], Robert Emmet [33*a*], Little Pittsburgh [32*a*], and Katie [33*c*] claims.

Microscopical.—The essential constituents of the White Porphyry are plagioclase, orthoclase, and quartz, developed in a remarkably uniform-grained mass, in which lie occasional crystals of one or more of the same minerals. Orthoclase seems to predominate, but never very greatly, and the chemical analysis confirms this view. Compared with the Mount Zion Porphyry, it is found that plagioclase occurs also in microlitic forms, but less abundantly, and in some of the more compact modifications may be wanting. Biotite, which was present in the Mount Zion rock, has never been seen in any of the numerous specimens of White Porphyry collected, nor was it ever noticed in the field, notwithstanding the fact that much of the rock seems quite fresh, judging from the condition of the feldspars. As the White Porphyry seems in all other respects to be very closely allied to the variety mentioned, it is to be particularly noted that many of the muscovite leaves are found to contain yellowish needles (rutile ?) or stout crystals (anatase ?) directly comparable to those resulting from the decomposition of biotite in the Mount Zion and other porphyries. It is therefore probable, in spite of the singular absence of intermediate alteration products, that a part of the muscovite in the White Porphyry came from biotite. Magnetite is found very rarely, and apatite scarcely more frequently, while zircon in minute, brilliant crystals is quite abundant.

The size of the grains is sometimes but little below the power of vision of the naked eye, and they might frequently be distinguished were it not for the decomposition of the feldspars. In numerous instances, however, usually in dikes or contact specimens, but sometimes in large masses, the texture becomes so fine that it is beyond the power of the microscope to identify separate granules as quartz or feldspar, and the mass thus becomes cryptocrystalline. In all such cases the structure remains evenly granular, there being no tendency towards a development of indistinct fibrous matter, nor does any portion appear amorphous, or, more correctly, isotropic. A few minute, irregular inclusions are usually visible in the larger quartz grains, some of them being undoubtedly fluid, while the others are not recognizable. No glass is determinable, and the minute, dark interpositions in the feldspar are probably secondary—forerunners of the coming decomposition.

Alteration.—Here, as in the Mount Zion rock, the conditions have favored the production of muscovite from all changeable constituents. Only in comparatively rare cases do calcite and kaolin appear. Many of the specimens collected are very much altered and show when examined in polarized light under the microscope a number of irregular quartz grains, imbedded in a brilliant, variegated mass of minute muscovite leaves. Little aggregates representing the original microlites of plagioclase penetrate the quartz grains in every direction. It is owing to this decomposition that the quartz is ordinarily invisible in hand specimens, as the muscovite leaves envelope each grain so closely that fracture does not separate them. The leaves of muscovite are so very small that the characteristic luster is seldom detected without close examination.

Chemical composition of Mount Zion and White Porphyries.—Analysis I, below, was made by L. G. Eakins, upon a fresh specimen of Mount Zion Porphyry from the Little Harry shaft, Prospect Mountain [24*a*]. Analysis II by W. F. Hillebrand, upon a typical specimen of White Porphyry from the quarry in California gulch at the southwest base of Iron Hill [27*p*]. The specimen is no longer fresh, but it is not in an advanced stage of decomposition. It was taken as a representative of the main sheet near Leadville.

	I.	II.
SiO_2	73.50	70.74
Al_2O_3	14.87	14.68
Fe_2O_3	.95	.69
FeO	.42	.58
MnO	.03	.06
CaO	2.14	4.12
BaO	....	.03
SrO	Trace	Trace
MgO	.29	.28
K_2O	3.56	2.59
Na_2O	3.46	2.29
H_2O	.90	2.09
CO_2	....	2.14
Cl	....	Trace
P_2O_5	None	....
Total	100.12	100.29
Specific gravity	....	2.680

The specific gravity of II was taken at 16° C. By special test in the White Porphyry a very small amount of lead was found, = 0.003 per cent. of PbO (Part II, Chap. VI). No CO_2 was found in I; that in II, taken together with the increased percentage of CaO, indicates the presence of calcite, which is probably an infiltration product, as there are dolomite bodies in the neighborhood. The close agreement of these analyses is such as might have been expected from the preceding descriptions and confirms the views expressed as to the close relationship of the two rocks.

PYRITIFEROUS PORPHYRY.

This porphyry, so called on account of the remarkable amount of pyrite invariably found disseminated through its mass, owes its importance principally to its supposed connection with the ore deposits of Leadville.

Its geographical extent is limited to the district shown upon the map of Leadville and vicinity, where it seems to occupy a stratigraphical position, which to the north is filled by the Gray and to the east by the Sacramento Porphyry. From the latter it is distinguished in field appearance by its almost universally decomposed condition, and in its constituents by a relatively small proportion of plagioclase; from the former, in addition, by the absence of large crystals of orthoclase, and from both by the want of hornblende.

As a type, will be taken the unusually fresh rock occurring in White's gulch between the Printer Girl and Golden Edge claims [87]. It has a distinct porphyritic structure, showing numerous white feldspar crystals, with quartz, biotite, and pyrite as other recognizable constituents. Altered feldspars are nearly indistinguishable from the white groundmass, and plagioclase is but seldom identifiable with the naked eye. There are no large feldspar crystals, as in the Gray Porphyry. Quartz occurs most frequently in irregular fragments and rarely contains bays of the groundmass. Biotite appears in distinct leaves, usually altered to a green chloritic substance. Through a nearly parallel arrangement of its leaves a stratified appearance is produced in some cases. Before disintegration of the rock, the place of the biotite is often occupied by ocher derived from the decomposition of pyrite. The latter mineral is scattered through the whole rock, but concentrated upon fissure planes by secondary processes. Galena appears locally in small quantity, but only on fissure planes. Some specimens contain irregular fragments of other rocks, chiefly quartzites of the Weber Grits formation.

Microscopical.—No additional original constituent is shown by the microscope, with the exception of minute crystals of zircon. Apatite, so seldom wanting in rocks of this class, has not been identified in the Pyritiferous Porphyry. Pyrite takes the place of magnetite and seems to be an original constituent. Its particles are included in quartz and appear in arms of the groundmass, which penetrate or separate quartz grains. It is also seen imbedded in biotite and is scattered through the groundmass in the manner characteristic of the original ore minerals in similar rocks. Few of the feldspars are entirely fresh and most of them are replaced by very fine aggregates of muscovite or kaolin. Plagioclase is identifiable in rare cases and was undoubtedly much subordinate to orthoclase in the fresh rock. In the freshest specimen obtained, chemical analysis showed 4.62 per cent. of potash and 2.91 per cent. of soda. Quartz appears in angular grains which are sometimes fractured and show parts of but slightly different optical orientation, separated by thin arms of the groundmass. Fluid inclusions are abundant in many grains, usually with but little fluid, while empty pores are also numerous; but none of glass was seen. Biotite is altered to chlorite or allied products, with a separation of yellow needles and tabular crystals, presumably rutile and anatase, respectively.

The groundmass never reaches the coarseness of grain common in other porphyries of the region. It is always very finely and evenly granular, never allowing a distinction of quartz and feldspar.

MOSQUITO PORPHYRY.

This type of quartz-porphyry, found in several distinct bodies and exhibiting in all a marked uniformity in structure and composition, has been named from its principal observed occurrence in the North Mosquito amphitheater [98]. All the bodies are dikes in the Archean, and besides the locality mentioned the rock was seen upon the north wall of Mount Lincoln [97] and in Cameron amphitheater [96], in the latter case penetrating sedimentary beds.

It is a light gray rock of fine grain, whose most prominent constituent is quartz in clear, irregular grains, which seldom exceed 0.5^{cm} in diameter. Other recognizable elements are biotite in small leaves, not abundant, and minute feldspars, which can scarcely be distinguished from the light groundmass. A brilliant, black ore in small specks is abundant. Glistening hexagonal prisms of what the microscope proves to be apatite are often seen, upon close examination.

Microscopical.—Zircon, ilmenite, pyrite, specular hematite, and probably magnetite are present in small quantity, a diversity in such constituents seldom seen in rocks of this region. Apatite, noticeable even macroscopically, is developed in stout prisms, with many minute inclusions, producing the dusty appearance often described. No other rock of the range exhibits a similar development of this mineral.

Biotite is shown in various stages of decomposition, chlorite being the first product, which sometimes gives way to epidote, or, as is clear in many cases, to a micaceous mineral apparently identical with the muscovite which is formed from adjacent orthoclase. Accompaniments of this change are yellow needles, presumably rutile, while the iron of the chlorite either is carried away or separates out in glistening black ore particles, thought to be specular hematite.

Of the feldspars, orthoclase seems to predominate slightly. Plagioclase is present both in crystals and in the groundmass, where its small microlites are much more prominent than usual. Quartz is regularly but rather sparingly present in large grains, seldom showing crystal outline and containing numerous small fluid inclusions, while none of glass was observed. A microcrystalline, granular mixture of quartz and two feldspars, with but very little primary mica, makes up the groundmass.

Chemical analysis shows 68.01 per cent. of silica, 4.36 per cent. of potash, and 4.26 per cent. of soda. The alkalies are rather more nearly balanced than one would suppose them to be from the microscopical examination.

LINCOLN PORPHYRY.

This rock is the most important of the varieties belonging to the second division of the quartz-porphyries of the district, namely, those in which the porphyritic structure is macroscopically very plain. It has been called the Lincoln Porphyry from the fact that it is best developed in and about the mass of Mount Lincoln, forming the extreme summit of that peak, and in this once important mining district bearing approximately the same relation to the ore deposits which near Leadville is assumed by the White Porphyry. As will be shown later, it is very closely allied to the Leadville Gray Porphyry and has intimate connection with the Eagle River Porphyry and other rocks of the adjoining district upon the north. In the following description will be condensed the observations upon twenty specimens collected at different places. Deviations from the type rock of Mount Lincoln will be specially noted.

Macroscopical.—The essential constituents are quartz, orthoclase, plagioclase, and biotite, all occurring in distinct crystals and imbedded in a compact groundmass of varying importance. A part of the orthoclase appears in large, stout crystals, frequently two inches in length, usually pinkish in color, and so fresh and glassy as to resemble markedly the sanidine of younger rocks. They are often Carlsbad twins and contain noticeable inclusions of biotite leaves. For most occurrences of the porphyry these large orthoclase crystals are eminently characteristic, though their development has been hindered in some cases, particularly in dikes and small masses. In some of these instances small crystals of pinkish color are plainly more numerous than in the type rock, but in others they cannot be well distinguished from the triclinic feldspar. Plagioclase is always very abundant in white individuals, seemingly less fresh than the orthoclase, although a striation can often be seen on the basal cleavage surfaces. Biotite occurs in small hexagonal leaves, which are sparingly but uniformly scattered through the whole. They are seldom fresh and usually appear to be changed into a green chloritic mineral. The quartz appears as a prominent macroscopical constituent, showing, as a rule, a development of pyramidal planes, to which the prism is occasionally added.[1] The groundmass is dense and homogeneous in appearance, usually grayish in color in fresh rocks, and very distinct. Only occasionally does it become subordinate. Ore particles are plainly distinguishable in it.

Specimens of the rock obtained from exposed surfaces of high mountains are usually bleached and light-gray in color, slightly stained by hydrous oxide of iron, while in tunnels and mine workings the rock is generally greenish through the chloritic decomposition products of the biotite.

Microscopical.—The microscopical examination reveals the following as original constituents, named in order of formation, viz: Allanite, zircon, magnetite, titanite, apatite, biotite, plagioclase, orthoclase, and quartz. All the minerals named occur in more or less perfect crystal form and are imbedded in a granular groundmass, consisting of plagioclase, orthoclase, and quartz. The amount of plagioclase in the groundmass is doubtless small, for it is so abundant in the form of imbedded crystals that but little substance could have remained for the second generation. The size of the grains in the groundmass is so small that one cannot well distinguish between quartz and orthoclase, but the holocrystalline nature is evident. No microfelsitic or glassy matter has been found in any rock of this type.

Of the accessory constituents the most noteworthy is *allanite*, which appears very sparingly but constantly in this and other rocks of the Mosquito Range and adjoining regions. It is apparently the first mineral formed, or is perhaps contemporaneous with zircon, these two minerals penetrating even magnetite and apatite. During the first study of these rocks the nature of this mineral was not determined, but, through the subsequent detailed investigation of a similar porphyry of the Ten-Mile mining district, enough was isolated by means of the Thoulet solution to allow of chemical analysis. The analysis, made by W. F. Hillebrand, was not completed, owing to accident, but it established the presence of Ce and La with the absence of Di, while Fe_2O_3 and SiO_2 were the remaining constituents of note. At about the same time Mr. Joseph P. Iddings, of the U. S. Geological Survey, determined the same mineral crystallographically in various rocks of the Great Basin in Nevada. As a rule the allanite is seldom macroscopically visible in the rocks of the Mosquito Range, while it is quite noticeable in those of the Ten-Mile region. It appears in small prisms of maximum length of about 5^{mm}, has a brilliant dark resinous luster, and when decomposed stains the surrounding zone in reddish-brown shades. The chance sections show a transparent, yellowish-brown mineral, with no distinct cleavage. The faces developed seem probably referable to ∞P, $\infty P\bar{\infty}$, $0 P$, and $+ P\bar{\infty}$. It is often twinned, possibly parallel $\infty P\bar{\infty}$, as by epidote, and in several sections which

[1] On the ridge east of Hoosier pass the outcrop of a porphyry sheet is marked by quartz crystals which have weathered out of the underlying rock and which show both pyramid and prism.

seemed to lie approximately parallel to $\infty P \grave{\infty}$ extinction took place at 35° to 38° from the vertical axis. Pleochroism distinct, the color varying from light to dark shades of yellowish brown.

Zircon is abundant in minute clear crystals. Fig. 3, Plate XXI, shows two zircon crystals of characteristic form included in a quartz grain of a Lincoln Porphyry. Titanite was seen in but one or two specimens, and then very sparingly. Magnetite and apatite occur as usual in such rocks. Biotite frequently includes apatite and zircon and may be penetrated by allanite. It is otherwise interesting from its alteration products, which will be discussed below.

The plagioclase, which is so prominently developed in crystals, is probably an oligoclase, judging from the extinction in the zone perpendicular to the laminæ, the direction being always within the limits of oligoclase. Orthoclase is seldom met with among the crystals of medium size, being present in larger individuals or in the irregular grains of the groundmass, where it presents nothing noteworthy. The significance of this development is pointed out later.

The large quartz grains and crystals contain a few fluid inclusions of irregular shape, and bays of granular groundmass penetrate them without any very marked change in texture of the mass. Glass inclusions are very rare in any specimens of the Lincoln Porphyry and never have been noticed in the type rock of Mount Lincoln. Quartz crystals have frequently exerted an influence upon grains of the same mineral in the adjoining groundmass, which have within a narrow zone the same optical orientation as the crystal. There is no regular relation of the quartz to the orthoclase within this zone.

Alteration.—Biotite is usually more or less altered and presents different products under different circumstances. In a specimen from the head of Clinton gulch, Summit County, the chief product is a micaceous mineral, seemingly muscovite, which contains numerous needles of rutile. In other cases chlorite is first formed, and this is also accompanied by yellowish needles, or by irregular paler grains of undeterminable nature, which resemble titanite or at times anatase. Epidote seems to replace the chlorite, or in other cases to come directly from the biotite without any intermediate stage. The feldspars give place to an aggregate of muscovite leaves in most cases, but calcite is frequently seen as a product from plagioclase and epidote, also, may be often found resulting from the alteration of the triclinic feldspar. As in some of the other types to be described epidote is very commonly a result of alteration of pure feldspar, there appears no good reason for regarding it as induced by the presence of assumed inclusions in the case of the Lincoln Porphyry. Secondary chlorite is sometimes deposited throughout the groundmass, giving a green color to the rock.

GRAY PORPHYRY.

This rock, which occurs in the vicinity of Leadville, is the nearest relative of the Lincoln type. It is, however, directly connected with a porphyry which has its chief vent of eruption and largest masses in the adjoining region to the north, at the headwaters of the Eagle River. This latter type will be fully treated in the report upon the geology of the Ten-Mile district, and, as other allied rocks can there be drawn into the discussion, the present description will not go deeply into a comparison of types.

The Gray Porphyry is seldom fresh, as it occurs in the region adjacent to the ore deposits, where agencies of alteration have been active, and presents usually a greenish-gray rock, showing numerous crystals imbedded in a prominent groundmass. The minerals are the same as those of the Lincoln Porphyry, viz, large orthoclase, small and numerous plagioclase, and biotite crystals. In the mines the rock is so bleached that even with its original large crystals, it is not easily distinguished from the White Porphyry. The quartz contains large bays or penetrating arms of the groundmass.

Microscopical.—One never-failing and striking peculiarity of this, in distinction to the Lincoln type, is the presence of outlines of a former constituent of the rock, which would seem to belong to hornblende, although no trace of that mineral in fresh condition could be found. These outlines are usually marked by dark grains, and inclose a fine-grained, grayish decomposition product, which acts very feebly in polarized light. They are not wanting in any slide examined, and are always of the same appearance, even when other minerals are entirely fresh.

The feldspars of the Gray Porphyry, unlike those of the Lincoln Porphyry, contain numerous fluid inclusions, which are generally arranged parallel to the chief cleavage planes. Besides these, there are many irregular interpositions, either devitrified glass inclusions or portions of the groundmass in a less crystalline state than it now presents in the main mass of the rock. They are light reddish-brown in color, and plentiful in most of the small crystals. Distinct glass inclusions, although not noticed in any feldspars, are very characteristic of the quartz grains. They are often sharply negative crystalline in form, and sometimes show devitrification; others are spherical, and in these it can often be seen that from opposite poles, which probably lie in the vertical axis of the quartz grains, cracks penetrate the sphere in three planes, cutting each other at about 60°. If the sphere be cut by the section at right angles to the axis uniting these poles and near one of them, there results a delicate six-armed figure, which appears as if contained in the quartz itself. The groundmass, though holocrystalline, is much finer-grained than that of the Lincoln Porphyry, and shows a tendency to an irregular intergrowth of quartz and feldspar.

Occurrence.—Gray Porphyry is quite limited in distribution, being confined to the immediate vicinity of Leadville, and to the region northwest of that point. As has been described in detail (p. 80), it occurs chiefly in one large sheet, with numerous offshoots, and the large sheet has been directly traced to a connection with an immense body at the headwaters of the Eagle River. The hornblende of the Gray Porphyry is considered analogous to the crystals of that mineral observed in small dikes which are offshoots from the Eagle River mass.

Chemical composition of the Lincoln and Gray Porphyries.—The following rock analyses were made by W. F. Hillebrand.

I is of Lincoln Porphyry, summit of Mount Lincoln [75]. It is quite fresh in appearance, although showing some muscovite, calcite, and chlorite, when examined microscopically.

II is of Gray Porphyry, Onota shaft, Johnson gulch, near Leadville [59a], fresh appearing, but somewhat altered, with the same products as in the former rock.

	I.	II.
SiO_2	66.45	68.10
TiO_2	0.10	0.07
Al_2O_3	15.84	14.97
Fe_2O_3	2.59	2.78
FeO	1.43	1.10
MnO	0.09	0.09
CaO	2.90	3.04
SrO	0.07	0.08
MgO	1.21	1.10
K_2O	2.89	2.93
Na_2O	3.92	3.46
Li_2O	Trace	....
H_2O	0.84	1.28
CO_2	1.35	0.92
P_2O_5	0.36	0.16
Cl	0.05	0.03
Total	100.09	100.11
Specific gravity, 16° C	2.670	2.636

The relative amounts of soda and potash indicate an abundant soda-lime feldspar. The titanic oxide found corresponds to the suggestion that the yellow needles in the decomposed biotite are rutile, for the magnetite does not give signs of an intermixture of titanic iron through its alteration products. The presence of strontia in determinable quantities is unusual and worthy of note; it doubtless comes from the plagioclase. Instances of its determination in rocks are rare,[1] though it would probably be found in many cases if sought for.

Although the large pink or white orthoclase crystals are characteristic of most of the occurrences referred to the Lincoln and Gray Porphyries, still a number of cases were found where the rock seemed identical with these types in every respect, excepting that the large crystals were wanting. In some bodies of rock, moreover, the large crystals were by no means equally distributed. It seemed therefore desirable to ascertain more definitely the source of the alkalies in the rocks analyzed. In each case enough of the large orthoclase crystals had been included in the material used for analysis to give average results.

In the mass of Mount Lincoln a dike of rock was found which was considered as a representative of the Lincoln Porphyry [78], although it was darker, more compact, and contained none of the large pink orthoclase crystals. Alkali determinations gave 2.42 per cent. of potash and 3.15 per cent. of soda, very nearly the same ratio as in the type rock. There was also found 64.16 per cent. of silica. The reduced amounts of all these are doubtless due to the increased quantity of biotite and of ore in this dike rock.

In the next place the Gray Porphyry, of which the complete analysis had been made, was subjected to further investigation. Alkali determinations were made in the

[1] Streng, Neues Jahrbuch für Mineralogie, etc., p. 537, 1867.

mass of the rock, carefully avoiding the large pink crystals, with the result of 2.95 per cent. of potash and 2.61 per cent. of soda. As small flakes were used for this purpose, it is probable that the groundmass was present in abnormal quantity, thus causing a relative increase in potash, even while excluding the large orthoclase crystals. Plagioclase was found to be much subordinate in the groundmass, as stated above.

The large pink orthoclase crystals themselves were then analyzed, with the result:

SiO_2	62.22
Al_2O_3	20.33
CaO	2.95
K_2O	8.31
Na_2O	3.45
Li_2O	Trace
Ign	1.90
Loss	.84
	100.00

Careful examination of the material used showed only a few specks of biotite, but some soda-lime feldspar must have been present, judging from the large amount of lime found. A determination in another clear crystal chosen for its apparent purity gave nearly 3 per cent. of lime again. The loss is thought by the analyst, Mr. Hillebrand, to be chiefly soda.

DIORITE.

Of the distinctly plagioclastic rocks of the region but very few are granular in structure, the great majority being diorite-porphyries, or porphyrites, as they will hereafter be designated. The three granular diorites found, represent three very distinct varieties, one of them being the only pyroxene-bearing rock occurring within the area of the map. All occur, moreover, in the same gulch, and quite near each other.

QUARTZ-MICA-DIORITE.

This rock occurs on the south side of Buckskin gulch, Park County, as a broad dike, forming for some distance the southeast wall of one of the elevated amphitheaters on Loveland Hill, and thence projecting as a knoll into the gulch opposite the Red amphitheater. It disappears under loose material before reaching the stream bed, and no continuation of the dike on the north side of the gulch was observed. The rock has a fine, evenly-grained structure, with feldspar and quartz strongly predominating over the small, irregular leaves of biotite.

Microscopical examination shows zircon, magnetite, apatite, biotite, plagioclase, orthoclase, and quartz as original constituents. None of the essential minerals is well developed in crystal form and none shows noteworthy peculiarities. Plagioclase is largely in excess over the orthoclase and quartz is quite abundant. All are quite fresh, the biotite alone showing incipient decomposition [117].

HORNBLENDE-DIORITE.

A broad dike crossing the head of Buckskin gulch from Democrat Mountain in a nearly east-and-west direction was found to consist of a very simple, normal diorite

[116]. It is fine-grained, yet shows distinctly to the naked eye all its prominent constituents. Feldspar, a large part of which is clearly plagioclase, subordinate quartz, hornblende in prisms with occasional terminations, a little brown biotite, yellow titanite, and dark ore grains are all easily recognized. The microscope shows zircon and apatite in addition, while chlorite and epidote are seen to result from the alteration of both biotite and hornblende. Muscovite forms in the orthoclase, which here seems much more attacked than the plagioclase. There is no groundmass and of the essential constituents only hornblende is developed in crystal form.

A very similar diorite was obtained from a prospect tunnel in French gulch, Lake County [115], in which pyrite replaces magnetite as the ore and zircon and titanite are very abundantly developed. Biotite and quartz are even less prominent than in the preceding rock.

AUGITE-BEARING DIORITE.

In the Red amphitheater, on the northeast side of Buckskin gulch, there occurs a dike of a darker, finer-grained diorite than either of the preceding types [118]. Hornblende, biotite, plagioclase, and a little quartz may be macroscopically detected. The microscope shows zircon, titanite, magnetite, hematite, apatite, biotite, augite, hornblende, plagioclase, orthoclase, and quartz. Augite appears most abundantly in the freshest specimen, and certainly undergoes alteration to green hornblende, which, though not fibrous, like typical uralite, is still by no means so compact as the common dioritic hornblende. It is not possible, from the specimens examined, to say with certainty that any of the hornblende is original, although the association of the minerals in the freshest specimens is such as to indicate a contemporaneous formation of biotite, augite, and hornblende. The latter two occur in irregular grains and the augite has none of the pinkish tinge common to it when appearing in diorite. This rock is remarkable as the only eruptive of the district in which augite has been found.

Plagioclase appears abundantly in small grains, while orthoclase and quartz form the cementing material. Chlorite and epidote result from the alteration of hornblende and biotite; muscovite and calcite, from the feldspars.

PORPHYRITE.

Under this heading will be discussed a large number of distinct occurrences, which, unlike those of the quartz-porphyries, belong for the most part to small rock masses. There are in this group no markedly prevailing types to which the different rocks can be assigned, and the chief interest here lies in noting the great variations possible, both in structure and composition, in what are practically equivalent masses. One distinction, however, is feasible, viz, that between a variable subgroup, in which a triclinic feldspar is evidently strongly predominant, and a few rocks occurring in larger masses, in which orthoclase is also prominent and which seem at first glance more nearly related to the quartz-porphyries than to the marked plagioclase rocks of the first division. These latter types are referred to in the main report as quartz-porphyries, and are so represented upon the map. They are called by the local names Sacramento Porphyry and Silverheels Porphyry. Later investigation has shown them to be plagioclastic rocks, and as such they will here be treated. In describing them the general and variable group will first be considered and then the local types.

PRINCIPAL GROUP.

The characteristic primary constituents of these rocks are the minerals zircon, allanite, apatite, magnetite, biotite, hornblende, plagioclase, orthoclase, and quartz. To these, as occasional accessories, may be added ilmenite and pyrite. All the common non-essential elements are developed in the ordinary way, and none is so abundant or so rare as to deserve comment. Allanite is not always present in the thin sections examined, but its observed distribution among different types is such as to warrant the belief that it is sporadically present in all the rock masses of this group.

Feldspars.—All crystals of the first period of consolidation which have been identified are plagioclase, with but one possible exception, referred to later (p. 339). Orthoclase may be sparingly developed in this way in a few cases, but the freshness of the plagioclase in nearly all specimens collected and the ease with which the striation can be seen upon the basal cleavage plane make it certain that a monoclinic feldspar must be very rare. In the groundmass, on the other hand, plagioclase is not visibly present at all in many cases, while orthoclase is very abundant.

The plagioclase crystals are small, white, stout in form, and correspond exactly to those described in the quartz-porphyries. They are chemically near oligoclase, judging from the optical properties, for the maximum observed extinction in the zone perpendicular to the usual twinning plane is but 20°. In a number of crystals twinning according to the Carlsbad law is apparently combined with that of the albite law, as, for example, in one section, falling at right angles to the brachypinacoid, there are 20 laminæ, of which five pairs extinguish sharply at 8° 45′, the other five pairs at 6° from the twinning plane. In a few cases more than two directions of extinction were noticed in sections apparently lying in the macrodiagonal zone. In one crystal laminæ were found extinguishing at 1°, 4° 30′, 8°, 13°, and 20°, several pairs showing the last two values. A satisfactory explanation for this action has not been found. It may be that laminæ of different feldspars are here intergrown, but such a conclusion must be supported by further data than are here available.

A delicate zonal structure is occasionally seen in plagioclase crystals, but the slightly varying angles of extinction do not indicate any pronounced changes in basicity of the different zones.

Biotite.—Biotite appears as a constituent in three distinct forms: as macroscopic hexagonal leaves, in aggregates of small irregular flakes, and as minute leaflets in the groundmass. The large leaves are brown when fresh and often exhibit ragged edges when seen under the microscope, caused by the attachment of many flakes corresponding to those in the groundmass. Allanite, zircon, magnetite, and apatite penetrate the larger leaves. The tiny leaflets which enter at times richly into the composition of the groundmass are irregular in shape and rarely over 0.03^{mm} in diameter, sometimes sinking to a minuteness requiring the highest power of the microscope to resolve them into separate flakes. They are greenish in color and at first glance it is not easy to discover their nature as mica; but their marked pleochroism and strong absorption in proper position renders their character certain. These flakes of green mica are often arranged one after another, partially overlapping, making needle-like aggregations, easily mistaken for hornblende with a low magnifying power.

Hornblende.—The hornblende is compact, of a green color in ordinary light, and generally presents quite well-defined crystals, the faces ∞P, $\infty P \grave{\infty}$, $0P$, and P being often visible on macroscopic crystals. It occurs either as a macroscopic element of the rock, in the form of minute needles in the groundmass, or, lastly, in clusters of small irregular individuals, and then usually associated with biotite leaves.

The small needles are sometimes well terminated (see Fig. 3, Plate XX). Still it is the rule to find the ends irregular, while the prism is sharply defined (see Fig. 4, Plate XX). The pleochroism is well marked, and the maximal angle of extinction in the prismatic zone is nearly 18°, measured from the vertical axis. Twinning parallel to $\infty P \bar{\infty}$ is common and is frequently polysynthetic.

The hornblende occasionally includes crystals of apatite, magnetite, rarely biotite, and clear microlites of zircon. It is commonly very fresh, and when decomposition has begun the first product is usually chlorite, from which epidote is formed.

Quartz.—There are but few rocks of this kind in which quartz is prominent as a macroscopic constituent. In some of these, usually the more acid ones, it forms well-defined crystals, but it is more common to see it in rounded grains, seemingly quite variable in quantity, in occurrences which are otherwise nearly identical. These rounded particles undoubtedly represent partially remelted crystals of the first generation, and their variability is here not remarkable. The chief development of the quartz is, as perfectly natural, in the groundmass, with orthoclase. Inclusions are not abundant in any of the crystals, though all earlier minerals do penetrate it in observed instances. Glass inclusions have never been found and those with fluid contents are rare. The groundmass seldom penetrates the large crystals.

Groundmass.—The groundmass of those porphyrites which contain hornblende and biotite mainly as macroscopic elements is very uniform in constitution and structure. It consists of an evenly granular mixture of quartz and feldspar, with small octahedrons of magnetite scattered through it. The feldspar is seldom definitely determinable as such, but its presence is inferred from a formation of muscovite, where the rock is much altered, and because the quartz grains, through their stronger polarization, stand out in contrast to the rest of the colorless groundmass. By far the greater part of this feldspar is monoclinic, for plagioclase was observed to enter into the composition of the groundmass in but few cases, and then in the form of thin plates, quite distinct from the irregular grains of orthoclase. The average size of the grains of quartz and orthoclase is 0.02^{mm}, so that a complete separation of these minerals is never possible. There is never a trace of microfelsitic or glassy substance, and only in contact specimens is the greater part of the groundmass cryptocrystalline. As has been mentioned above, biotite and hornblende enter into the constitution of the groundmass in very varying quantities, and only when present in great abundance do they render the mosaic of quartz and feldspar obscure. The quartz has a tendency to develop in clusters of irregular clear grains in certain cases.

The distinguishing peculiarity of a certain minor subgroup lies chiefly in the character of the groundmass. This consists principally of an intergrowth of quartz and orthoclase, according to no discernible law, now the quartz, now the orthoclase being the inclosing mineral, and their relation is only made clear between crossed nicols, when it is seen that within the limits of certain irregular patches all the quartz and all the orthoclase has each its own optical orientation. The outline of the inclosing mineral has no relation to crystal form, and this intergrowth acts throughout like the ordinary groundmass, filling the interstices between the large crystals. The macro-

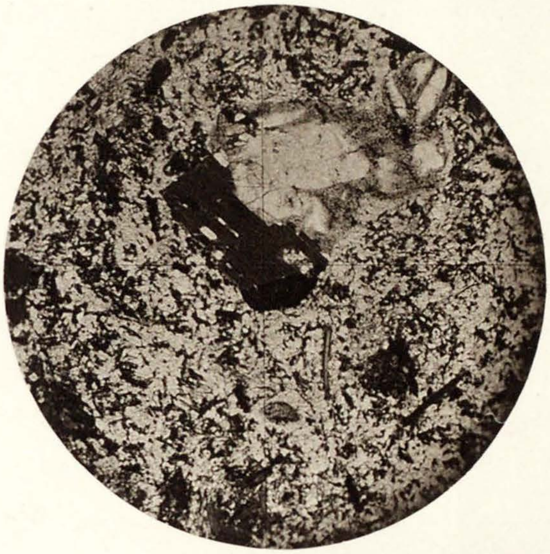

Fig. 1

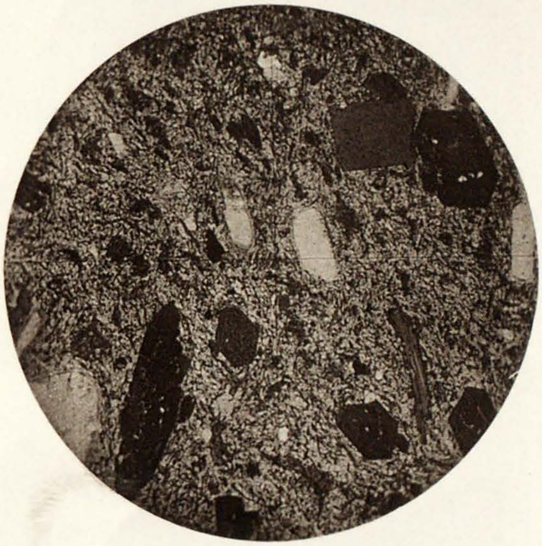

Fig. 2

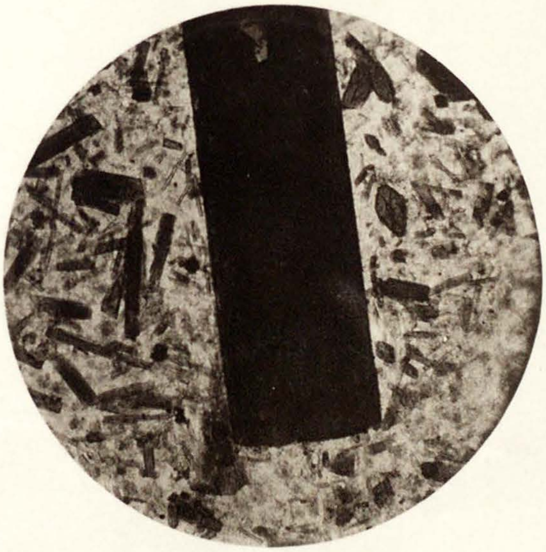

Fig. 3

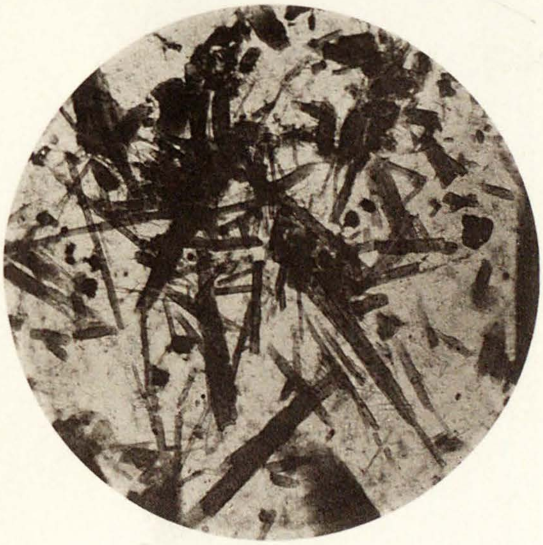

Fig 4

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scopical effect of this structure is to render the groundmass much less distinct in contrast with the crystals than is the case in the types of the main group. Flakes of biotite, grains of magnetite, &c., are scattered about in this groundmass with the same irregularity as in any other.

A tendency to a micrographic-granite structure was noticed in two of the porphyrites. It seems to have been induced by the presence of the rounded quartz grains above described. Each of these is surrounded by a zone in which quartz and orthoclase are more or less regularly intergrown. The appearance, as seen under the microscope, is that of alternate fibers of quartz and orthoclase, with a more or less distinct radiate arrangement about the large quartz grain, all the quartz substance, in both granule and groundmass, having the same optical orientation. A similar phenomenon was not observed in connection with large particles of feldspars, and those portions of the groundmass showing a regular intergrowth apparently independent of any crystal may have been formerly related to a quartz grain situated just above or just below the plane of the present section.

In such a thoroughly crystalline rock a fluidal structure can only be expressed by the position of the hornblende needles or biotite leaves with reference to the large crystals. Such a relation is often observed, and it is also not rare to find hornblende crystals broken and biotite leaves folded and crumpled, attesting to movements in the partially solid rock.

Structural forms.—The greater number of the rocks observed form a continuous series whose extremes are very dissimilar, and the relationship can be most easily understood and explained with the help of the subjoined table:

Primary division.	Subdivision.		Macroscopic development.	In groundmass.
A	I	Biotite	In hexagonal leaves	Entirely wanting.
		Hornblende	Entirely wanting	Entirely wanting.
	II	Biotite	In isolated leaves	Entirely wanting.
		Hornblende	In numerous crystals	Entirely wanting.
B	III	Biotite	Sparingly present	Few minute leaflets.
		Hornblende	Abundant	Entirely wanting.
	IV	Biotite	Abundant	Abundant.
		Hornblende	Slightly predominant	Few small needles.
	V	Biotite	Rare or wanting	Sparingly present.
		Hornblende	Very abundant	Very abundant.
C	VI	Biotite	Numerous small leaves	Very abundant.
		Hornblende	Rare or wanting	Entirely wanting.
	VII	Biotite	Rare	Much subordinate to hornblende.
		Hornblende	Very abundant	Very abundant.

Under Division A are included rocks with a light, homogeneous-appearing groundmass, containing no microscopic individuals of the basic mineral which is so prominent in macroscopic crystals, this in the one case (I) being biotite, in the other (II) hornblende. Under C, at the opposite structural extreme, where the groundmass is filled with minute flakes or needles of a dark mineral, are also two modifications, one a biotite (VI) (Fig. 1, Plate XX), the other prevailingly a hornblende rock (Fig. 2, Plate XX). These are both dark and compact, showing comparatively few macroscopic elements, standing in marked contrast to those forms under Division A. Between these extremes, in regard to both structure and composition, are the forms embraced under B. In these the groundmass contains more or less of one or both of the dark basic minerals, and in proportion as these minerals enter into the composition of the groundmass the macroscopic elements become less distinct, thus forming a gradual transition to the Division C.

Division A.—The plagioclase usually stands out very plainly in these rocks, and it is evident that no orthoclase is present in macroscopic individuals. Quartz occurs in good crystals and rather plentifully. The groundmass is microcrystalline and possesses a very regular granular structure, its components being almost exclusively quartz and orthoclase. A dike in gneiss, near a little lake northwest of Mount Lincoln, represents the typical hornblendic variety [120], while a similar dike in North Mosquito amphitheater is of the corresponding biotite rock [119]. Several occurrences at the head of Buckskin gulch are nearly allied to these type rocks.

Division B.—By far the larger number of the porphyrites in the series fall within this division. In the three subdivisions of the table, one or both of the heavier silicates appear in the groundmass as well as in larger crystals. If the groundmass minerals are regarded as belonging to a second phase of the rock's existence, one of the striking peculiarities of this division is most natural, while from another point of view it might seem strange. The peculiarity referred to is the observed independence of the dark basic silicates occurring in the groundmass, of the species which may be developed as macroscopic constituents. The formation of hornblende in numerous large crystals during the first period of consolidation does not necessarily demand that the same mineral should be developed in the second period. The changed conditions attending the final consolidation may produce biotite or hornblende, or both of them, uninfluenced, or at least uncontrolled, by the earlier crystallizations. The table above shows this, but a study of the variations in the different rocks collected makes the fact much plainer. The rock most frequently met with in all the district belongs to Type V of this division. It is the one found in the intrusive sheets on the sides of Mosquito [127] and Buckskin gulches [126], on Mount Lincoln, or in dikes in the Archean, as on Bartlett Mountain [124] and Democrat Mountain [259]. The lower figure of Plate VII, page 84, shows the macroscopical appearance of this rock very well. Hornblende crystals are frequently well terminated in this modification, and owing to the minute size of many well-shaped prisms, while all intermediate stages are also represented, it becomes difficult to decide whether there has or has not been a recurrence in the formation of hornblende prisms with good crystal form. Fig. 3, Plate XX, was designed to show both large and small prisms of hornblende with good terminal planes, but the imperfect execution of the prints leaves much to the imagination. In Fig. 4 of the same plate are shown needles of hornblende with the more common, irregular terminations.

Division C.—The compact rocks of this division are not very numerous. The two occurrences illustrating best the micaceous and hornblendic varieties occur together in North Mosquito amphitheater. One of these, the biotite rock [260], was analyzed (p. 340), and its micro-structure is indicated by Fig. 1, Plate XX. Two other compact rocks deserve special mention under the next heading.

The Arkansas Dike.—The long straight dike at the head of the Arkansas presents some remarkable phenomena, which cannot be explained satisfactorily from the data collected in the one short visit made to that area. It is a special matter for regret that no time for further examination could be taken. This dike consists of what are regarded as two eruptions of the same magma. The older rock is fine-grained and exhibits a few small feldspars and biotite leaves as sole recognizable macroscopic constituents [130]. The younger rock [129], which cuts irregularly through the former, now on one side, now on the other, or even running along the center, is also very dark and compact in the main, but is sharply distinguished by numerous large quartz crystals and by worn and well-rounded fragments of slightly pinkish orthoclase.

A heliotype representation of this curious rock is given in the upper figure, Plate VII, natural size. These orthoclase fragments are all like pebbles, showing no trace of sharp angles. They reach a maximum observed diameter of over 5^{cm}, and none was noticed of less than 1^{cm}. While never glassy, they seem quite fresh, represent but one crystallographic individual each, and are in no way related to anything seen in other occurrences of the porphyrites. The quartz crystals reach a diameter of over 1^{cm} in this rock and are always quite well-defined in crystalline form. Hornblende takes a prominent place beside the biotite in the microscopical constitution. It is a curious fact, commented upon later, that in spite of its large quartz crystals the younger porphyrite has but 59.26 per cent. SiO_2, while the dark, compact, older rock contains 66.29 per cent. Repeated determinations for both rocks show similar results.

The origin of these orthoclase pebbles is very problematic. To consider them as earlier secretions of the porphyrite magma is to assume conditions to which no other rocks of the group have been subjected, judging from the total absence of such orthoclase in them. Inclusions of basic microlites would seem to be almost inevitable, if these orthoclase individuals had formed in the midst of the minerals which one must suppose to have reached consolidation before them. A thin section of one of these pebble-like fragments shows that the feldspar is common orthoclase and that it contains inclusions of magnetite, biotite, and quartz. No zircon, allanite, or apatite was seen. The included quartz grains are small and crowded with fluid inclusions, in many of which the bubble is in active motion.

From the above considerations it is difficult to reach a conclusion as to the origin of these feldspar masses. The absence of zircon and apatite and the presence of quartz with such numerous fluid inclusions seem to indicate that the mineral is not an earlier secretion of the porphyrite magma. The fact that, while rounded fragments of gneiss and granite are abundant in many dikes in the Archean, they were not found accompanying these pebbles, would seem to throw doubt upon the accidental nature of the fragments in question. Until a more thorough examination of the occurrence can be made no satisfactory conclusion seems possible.

Chemical composition.—The analyses given below were made by W. F. Hillebrand. Under I is given the composition of the typical hornblendic variety, occurring in thin intrusive sheets on the sides of Buckskin and Mosquito gulches. It is Type V of the table above; its macroscopical appearance is shown in Plate VII, lower figure, and its microstructure in Plate XX, Fig. 3. The specimen analyzed came from the Northern Light claim, in lower Buckskin gulch [126]. The rock as a whole is quite fresh, although the few biotite leaves and occasionally a hornblende crystal are more or less decomposed, chlorite and calcite being the chief products. The plagioclase is still quite fresh, but some filmy calcite is scattered through the groundmass. Apatite is rather rare in this rock.

Analysis II was made upon a compact biotite rock, Type VI of the table, from North Mosquito amphitheater, where it occurs as a dike in gneiss [260]. There is no hornblende present in this rock and biotite appears mainly in numberless minute, greenish flakes. Quartz is abundant in clusters of small grains in the groundmass, but seldom reaches macroscopic dimensions. Apatite is quite abundant. Pyrite is the chief ore of the rock, accompanied by some magnetite. Except for some calcite and chlorite the rock seems to be very fresh.

	I.	II.
SiO_2	56.62	64.81
TiO_2	....	0.08
Al_2O_3	16.74	15.73
Fe_2O_3	4.94	1.68
FeO	3.27	2.91
MnO	0.15	0.08
CaO	7.39	4.22
SrO	Trace	Trace
MgO	4.08	2.82
K_2O	1.97	1.43
Na_2O	3.50	3.98
H_2O	0.92	0.62
CO_2	1.15	1.08
P_2O_5	Trace	0.23
Cl	....	0.04
FeS_2	....	0.90 = 0.48 S.
Total	100.73	100.61
Specific gravity, 16° C	2.768	2.740

Discussion of analyses.—There is far more difference between the two rocks than one would surmise from the microscopical study, but it is after all not so remarkable when one considers how little substance is actually represented by the minute flakes of biotite in contrast to that in the numerous prisms of hornblende. The difference lies chiefly in the large amount of hornblende, while the feldspars in both are plainly soda-lime-bearing varieties to a very large extent.

In order to test the influence of the amount of hornblende present, as indicated by the macroscopical appearance of the rock, special silica determinations were made by Mr. Hillebrand upon various types. First, two rocks having closely the habit of that furnishing Analysis I, but occurring as dikes in the Archean, one in Ten-Mile amphitheater [125], the other on the east wall of Arkansas amphitheater [131], were tested, and yielded, respectively, 57.76 per cent. and 57.33 per cent. SiO_2, figures agreeing quite closely with those of the analysis. Secondly, the compact hornblendic rock from North Mosquito amphitheater [132], which occurs side by side with the corresponding biotite rock (Analysis II), was found to contain 54.54 per cent. SiO_2. Thirdly, a rock from the extreme head of Buckskin gulch [121], which contained very little hornblende in the groundmass and had a number of the rounded quartz grains macroscopically visible, proved to carry 65.73 per cent. SiO_2. The range in silica is thus more than 10 per cent., and it is chiefly affected by the amount of hornblende present in the rock.

SACRAMENTO PORPHYRITE.

This rock, which was at first classed as a quartz-porphyry and is so represented on the map, occurs in a large mass at the head of Big Sacramento gulch, whence intrusive bodies extend to the north and to the southeast.

Description.—In structure this rock resembles those modifications of the Lincoln Porphyry in which the formation of the large orthoclase crystals has been hindered. It shows many white plagioclase crystals of the usual stout habit and a number of smaller, less distinct individuals which are less fresh, most of them being orthoclase. Both biotite and hornblende are present in distinct individuals, and quartz occurs in round grains, which are not very plentiful. The groundmass containing these elements is subordinate but yet distinct. It contains pyrite and magnetite, and a sufficient number of small biotite leaves to be dark-gray in color, when fresh. Chloritic decomposition products render it darker in most specimens collected. Epidote, which is often prominent in more or less altered specimens, will be spoken of below.

With the microscope it is found that zircon, allanite, apatite, and titanic iron, the last recognized by cleavage and alteration products, are further components of the rock. Allanite is not so plentiful as in some other types described, but it is observed in one or two slides and is probably a regular but sparsely distributed constituent.

The microscope shows that plagioclase is developed almost exclusively in the form of porphyritic crystals and that but few of these are certainly orthoclase, although the latter mineral forms with quartz nearly the entire groundmass, the dark silicates seldom appearing as constituent particles in this later product of consolidation. Orthoclase is usually more decomposed than plagioclase, being cloudy after the manner commonly seen in much older rocks. The majority of the plagioclase crystals are clear in the center, but show incipient decomposition in the outer zones. The laminæ composing them are either broad or very narrow and the maximum angle of extinction in the macrodiagonal zone is 20°, indicating that varieties more basic than oligoclase are rare if present at all.

Hornblende and biotite have a thoroughly normal appearance, and are only interesting through their decomposition products, to be considered below. Inclusions of the early accessory constituents are a matter of course in all the large crystals, but they are never abundant and are never accompanied by glass, so far as observed. Fluid inclusions occur sparingly in quartz and feldspar.

Decomposition products.—Noteworthy facts concerning the decomposition of rock-building minerals may be observed in the Sacramento Porphyrite. The specimens collected are divisible into two classes, the one showing a bleached rock, the other containing macroscopically developed epidote. In the latter rocks [83–85] the microscope shows a more or less marked tendency to the formation of epidote from both feldspars, as well as from biotite and hornblende. In the last two minerals a dark, strongly pleochroic chlorite is the forerunner of the epidote, while in the feldspar no intermediate stage of any kind can be detected. Muscovite and calcite, the common products of alteration in feldspars, are here but slightly developed.

In the second class mentioned the processes of decomposition have produced a light-colored rock, in which the biotite is replaced by a light, straw-colored substance with silvery luster, while hornblende and ore particles have almost entirely disappeared. The microscope shows that decomposition has from the beginning taken an entirely different course from that just described, although here, as there, the tendency has been to the formation of a particular mineral, that mineral being muscovite instead of epidote. Muscovite resulting from the decomposition of biotite has been described (p. 324) in the case of the Mount Zion Porphyry, and the present instance is very similar. The muscovite is filled with minute, pale-yellowish needles and grains (rutile ?), which cause the macroscopically visible tinge of color. That this mineral is really muscovite it may be difficult to prove beyond all dispute, but the feldspars in the same specimen are almost entirely altered to an apparently identical substance, with some calcite, while no chlorite or epidote is found, showing that conditions favorable to the formation of muscovite certainly existed. In general it can be stated that those specimens in which the development of muscovite is most distinct occurred in masses covered by drift or exposed in the workings of mines [86], while those containing epidote are from more exposed positions, usually above timber-line. The observations are, however, too few to be considered as indicating any rule in the matter.

Chemical data.—A silica determination proves that quartz must be prominent in the groundmass, as the quartz macroscopically visible is much less than in the Lincoln Porphyry, while the amount of silica found, 65.08 per cent., is but little less than that in the latter rock, viz, 66.45 per cent. [85*a*]. The Sacramento Porphyrite also contains 3.55 per cent. of soda to 2.57 per cent. of potash [85*a*], which confirms the classification as a plagioclase rock.

SILVERHEELS PORPHYRITE.

Occurrence and previous classification.—The intrusive sheets of eruptive rock occurring in Mount Silverheels, two of which appear in the northeastern part of the Mosquito Range map, belong to a rock which is not easily classified. It is colored as rhyolite upon the Hayden Atlas of Colorado, and called "(trachyte ?)" by A. C. Peale in his report upon the region.[1] Unfortunately, its relations were not at first correctly understood by the present writer, and consequently the rock is colored upon the map as quartz-porphyry, while he now regards it as a plagioclastic rock and as belonging to the series of porphyrites.

Description.—This rock is of a greenish or gray color and very fine grained, but it still exhibits a distinct porphyritic structure when not too much decomposed. Its macroscopically visible constituents are feldspar, biotite, hornblende, and, sparingly, quartz, all of them in very small individuals, seldom exceeding 3^{mm} in diameter. The groundmass is usually obscured by chloritic decomposition products. Microscopical study shows the usual accessory minerals, including allanite and pyrite.

With regard to the feldspar crystals it is difficult to decide which may have been predominant from simple microscopical study, for many of them are entirely decomposed and the mixture of calcite and muscovite resulting in all cases does not give a

[1] Annual Report United States Geological and Geographical Survey of Territories, 1873, pp. 214–216.

certain clew. An alkali determination in one of the freshest specimens [109] yielded Na_2O 4.08 per cent. and K_2O 2.70 per cent., which must be decisive in confirming the present classification, for it is to be expected from analogy with the fresher rocks previously described that the larger part of the soda will be contained in the porphyritic crystals of the first generation, while the potash will remain chiefly in the groundmass. When nearly balanced alkalies are, as a matter of fact, so disposed in the solid rock, the soda feldspar certainly becomes the more prominent and should determine the classification.

The groundmass is holocrystalline, in most cases coarsely microcrystalline, and is made up of quartz, orthoclase, and plagioclase, with some biotite. Its constitution is often obscured by chlorite. The amount of quartz seems less than in most porphyrites described, and a silica determination gave but 60.42 per cent. [109*b*]. Epidote and chlorite are the products of the decomposition of both biotite and hornblende. What seem at first sight to be included fragments of amphibolite are most probably secretions of hornblende from the magma in an earlier period of the rock's history. Biotite and some feldspar accompany the hornblende.

On the extreme southern spurs of Mount Silverheels, beyond the limits of the present map, between the forks of Crooked Creek, a variety of much more distinct porphyritic habit was found, which is colored on the Hayden map as "Porphyritic Trachyte" [108]. Its crystals reach 1^{cm} in diameter and predominate over the light-grayish groundmass. All the elements are the same in character as in the Silverheels rock, and it can be regarded only as a modification of the same.

MISCELLANEOUS PORPHYRITES.

The "Green Porphyry," a peculiar fine-grained rock, was found occurring in three different places: first, as a dike, running from the northern edge of Bross amphitheater toward Mount Silverheels [98*a*]; secondly, on the north side of Mosquito gulch, near its mouth, interbedded in Cambrian quartzites [98]; and thirdly, as an interstratified bed on lower Loveland Hill, near the Fanny Barrett and Eagle Bird claims [98*b*]. It is macroscopically compact, light green in color, with an abundant chloritic decomposition product, which renders it difficult to distinguish clearly each crystal individual, although it is sometimes plain that the rock is almost wholly macrocrystalline. Quartz, feldspar, biotite, and hornblende are, however, recognizable, the latter two being much altered.

Some of the thin sections prepared show no normal groundmass at all, although a distinction can be made between certain well-crystallized elements and wholly irregular fragments. There seem to have been original crystals of feldspar, hornblende, and biotite, all quite small, while the remainder of the rock, solidifying later, was formed of the same minerals, with quartz, in irregular grains, which sometimes have reached the size of the crystals, but more frequently have not.

The feldspars are largely replaced by muscovite and calcite; the dark silicates by chlorite and epidote. Quartz is not abundant, a silica determination yielding but 63.85 per cent. A few fluid inclusions are observed in quartz and feldspar.

In connection with the above rocks should be mentioned several occurrences not to be classed under any of the described varieties, though most closely allied to the last one [100–106]. In the hand specimen they show but little that can be identified. They are green in color and fine-grained, with some visible feldspar and biotite or hornblende, and, rarely, quartz. The principal decomposition product is chlorite, which renders the structure obscure. The microscope reveals a fully crystalline structure, in which a granular groundmass of quartz and feldspar is of varying importance. Quartz and orthoclase, intimately but irregularly intergrown, make up in some cases the greater part of the rock. Muscovite is the chief decomposition product of the feldspars and seems also to result from the alteration of biotite, after several intermediate stages.

The Green Porphyry and the ones just mentioned are now thought to be more probably porphyrites than quartz-porphyries.

YOUNGER ERUPTIVES.

RHYOLITE.

Among the acid orthoclastic rocks of the district are a few occurrences plainly distinct from any that have been referred to the group of the quartz-porphyries. Their mode of occurrence is different (see p. 194) and they possess to an eminent degree the habit formerly considered characteristic of the younger eruptives. No exact data as to age are available, but they all seem to be more recent than the period of folding and faulting.

The most important body of rhyolite is that upon the northern boundary of the region under consideration, forming the mass of Chalk Mountain. As this rock has very closely the habit of that subdivision of the rhyolites recently defined as Nevadite by Messrs. Hague and Iddings,[1] that name will be applied in this description. According to the definition of the writers cited, Nevadite is a rhyolite "characterized by an abundance of porphyritic crystals imbedded in a relatively small amount of groundmass," while liparite is a rhyolite "characterized by a small number of porphyritic crystals imbedded in a relatively large amount of groundmass." These terms simply designate structural extremes in a group which is so large as to need some such treatment. They occupy about the same position as the terms "granite porphyry" and "felsite porphyry."

CHALK MOUNTAIN NEVADITE.

General description.— This rock is characterized by the appearance of very numerous dark quartz crystals and clear sanidines, with but very little biotite or ore, imbedded in a light gray groundmass. On the western and eastern parts of the mountain the feldspars are nearly all small and clear, and, as in this modification there is an almost total absence of biotite and ore particles, the feldspars are scarcely distinguishable at first glance from the enveloping groundmass, which has under the lens an exceedingly fine-grained, homogeneous texture. All this only serves to bring out the more strikingly the abundant dark, smoky quartz crystals, which usually present the prism in very distinct development. They are here invariably fissured in all directions, and fractured surfaces have an unusually brilliant, vitreous luster. In this modification of the rock the quartz crystals seldom reach 1^{cm} in diameter, and the feldspars, though occasionally more than 2^{cm} in length, are usually less than 1^{cm} in greatest diameter.

[1] American Journal of Science, III, XXVII, p. 461, 1884.

On the southern edge of the mountain and on the northwestern slope the rock has an even more striking development than that just described. Both quartz and sanidine, but specially the latter, occur in large crystals, and, while the quartz is dark, as before, the sanidine possesses a most beautiful, brilliant, satiny luster upon a surface nearly parallel to the orthopinacoid, which is particularly marked in fractured crystals. At the same time biotite and ore specks appear in sufficient quantity in the subordinate groundmass to give it a tinge of gray and cause it to stand out plainly from the feldspars. The dark, smoky tinge of the quartzes, the delicate but brilliant luster of the sanidines, together with the general freshness of all constituents, give to the rock an extraordinarily beautiful appearance. On Plate VIII, page 88, is a heliotype representation of this Nevadite, which but feebly expresses the strong contrast between various constituents.

Macroscopic constituents.—Of the feldspars in this rock only the sanidine is at all prominent, although plagioclase appears in small crystals and sparingly in the groundmass. The plagioclase must be an oligoclase poor in lime, as is shown by the rock analysis later. Sanidine, much more glassy and fresh in appearance than the plagioclase, is by far the most interesting component of the rock. Many of its crystals are Carlsbad twins, sometimes polysynthetic, and exhibit the faces ∞P, $\infty P \grave{\infty}$, $0P$, and $2P \grave{\infty}$. The luster which has been mentioned is highly characteristic and is described in detail below.

Some of the large, lustrous sanidines exhibit a peculiar internal structure. On breaking open several crystals there appeared a kernel partially detached from an outer zone or shell about 1^{mm} in thickness. All free surfaces of the kernel are glistening crystal faces, and the inner surfaces of the shell are likewise regular crystal planes, upon which minute projections are found to be like attached crystals, with the same orientation as the larger individual. The shell usually exhibits the satiny luster more markedly than the kernel, but no other difference was noticed between the substance of the two parts.

From a clear crystal in which the luster was not pronounced a section was prepared nearly at right angles to the edge between $0P$ and $\infty P \grave{\infty}$, and the optical axes were found to lie near together in a plane normal to $\infty P \grave{\infty}$.

The quartz crystals and grains of this rock are quite free from mineral inclusions; glass has never been observed in them and arms or inclusions of the groundmass are alike rare. Gas pores are, on the other hand, quite abundant, being in part negative crystalline in form. Many pores, seeming at a low power to be merely filled with gas, are really fluid-inclusions with a relatively small amount of fluid. This is very plain if the cavity is irregular, the fluid being pressed into the angles or projecting arms, while the main part of the cavity is occupied by the bubble.

Biotite is very sparingly developed in small hexagonal leaves. Magnetite is the only ore mineral and is present in very small quantity. Apatite and zircon are the remaining accessories, and both are much less abundant than is usual in the rocks of the district.

The groundmass.—Quartz and feldspar in a very even-grained mixture are almost the sole constituents of the groundmass. In the coarser variety of the Nevadite the average size of the grains is 0.02^{mm} to 0.05^{mm}, and the greater part can be identified as quartz or feldspar, the larger portion of the latter being monoclinic. The groundmass of the more compact varieties of the rock is cryptocrystalline. Gas pores of irregular shape are present between the granules in all modifications.

While there is no microfelsitic substance and no persistent glassy base, properly speaking, there are irregular, disconnected patches or particles of a clear, structureless, isotropic matter, with branching arms filling spaces between grains of the groundmass. This substance is most clearly developed in the coarser parts of the rock mass, and it is apparently identical in character with the glass observed in the rhyolite from the Hohenburg near Berkum, on the Rhine, Germany, first described by Zirkel.[1] In manner of occurrence of this glass residue the two rocks are very similar, though it is more abundant in the German rock. The latter contains plagioclase abundantly in the groundmass and its basic silicate is hornblende.

Drusy cavities.—In the coarser-grained parts of the Nevadite body are numerous small cavities lined by minute crystals. At the northwestern point of Chalk Mountain they reach the maximum in size, some observed being several centimeters in greatest diameter. In the larger ones the crystals reach a determinable size and are found to be chiefly sanidine, in delicate glassy tablets that are always Carlsbad twins, with some quartz, biotite, and *topaz*. A few stout crystals seem likely to be triclinic feldspar, but they could not be definitely determined. A coating of manganese binoxide is often upon the crystals and dark spots in the mass of the rock seem due to the same substance. Both sanidine and topaz from these druses are worthy of special notice and are described below. No minerals which can be considered alteration products are found in these druses and a natural explanation for the occurrence is to regard all the crystals as sublimation products.

Topaz.—Usually but a single topaz is present in one of the druses, and that is larger and more perfect in development than any other crystal. The topaz is attached directly to the walls of the cavity and often bears small tablets of sanidine upon it. The crystals which can be recognized vary from 0.5^{mm} to 3^{mm} in length, but it seems quite probable that there are some smaller ones, indistinguishable from quartz.

The determination rests upon the crystalline form, which is very distinct and is that of common topaz. One crystal, measuring 3^{mm} in length and 1^{mm} in thickness, was removed from the rock, and its angles were measured with a Fuess reflection goniometer. This crystal presents $\infty \breve{P}$, $\infty \breve{P}2$ and $2\breve{P}\infty$ as the dominant forms; 0P is a narrow face and $4\breve{P}\infty$, $2\bar{P}\infty$, 2P, and P are minute, but very distinct. The angles measured are as follows:

$\infty P \wedge \infty P$	124° 16′
$\infty \breve{P}2 \wedge \infty \breve{P}2$ over $\infty \breve{P}\infty$	93° 7′
$0P \wedge 2\breve{P}\infty$	136° 30′
$0P \wedge P$	134° 11′
$0P \wedge 2P$	115° 55′

$2\bar{P}\infty$ appears as a very narrow face in the zone of 2P to 2P. This is the usual habit, with the occasional addition of $\infty \breve{P}\infty$, and a more prominent development of 0P. This crystal is also imperfectly terminated at the attached end, showing $2\breve{P}\infty$ most prominently, with $4\breve{P}\infty$ and 2P also recognizable, and there are no signs of hemimorphism.

[1] Mik. Beschaf. der Min. und Gesteine, p. 343.

No occurrence of topaz in eruptive rocks has been previously described, so far as is known to the writer. Topaz is found in other parts of the Rocky Mountains, and in Mexico, where eruptive rocks are said to occur, but the connection between the two has not been demonstrated.

The satin-like luster of the sanidines.—The lustrous surface is in the orthodiagonal zone and inclined a few degrees to the orthopinacoid, as is evident in the Carlsbad twins, usually polysynthetic, the luster reaching its maximum of brightness simultaneously in alternate planes. Microscopical investigation shows a most perfect parting parallel to the surface of luster, and with a knife-blade flakes can be split off in this direction, even more readily than parallel to the basal cleavage-plane. Thin plates parallel to the base (0P) show a very fine striation at right angles to the line of $\infty P \grave{\infty}$ and $\pm$ to the directions of extinction. Thin flakes split off parallel to the lustrous surface show, under the microscope, that the luster is due to interference of light in passing the films of air between the extremely thin plates produced by the parting. The thinnest flakes, composed of a few plates, are transparent and exhibit delicate colors of interference, while those composed of more plates are dull translucent or opaque, the light having been completely extinguished by the repeated interference. The luster is then due to reflected light from the air films near the surface and to its interference. By examination with a good hand lens, a delicate play of colors may be seen upon the lustrous surface of the crystals.

In the drusy cavities above described the sanidines are thin tablets, almost invariably Carlsbad twins, with prominent development of the clinopinacoid. Such crystals examined under the microscope, as they lie upon the predominant pinacoidal face, afford a means of determining approximately the position of the plane parallel to which the parting referred to takes place. The adjoining cut represents one of these crystals, a normal Carlsbad twin, with a third and smaller plate, also in twin position. The faces shown are: ∞P, $\infty P \grave{\infty}$, $P \infty$, 0P, and $2P \grave{\infty}$, as indicated. From all the outlines and from basal cleavage or irregular fissures run dark lines, in uniform direction for each individual of the twin, and penetrating varying distances into the crystal. This undoubtedly represents an incipient stage of that parting, which, in the large crystals of the rock, occasions the brilliant luster, for these dark lines do not represent needles of any mineral substance, but the air films filling the fissures.

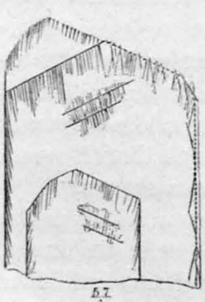

FIG. 1.—Sanidine from Nevadite.

This parting may be seen upon all microscopic sanidine crystals of the rock, and even the irregular grains of that mineral in the groundmass, when cut in the right direction, show a very fine, delicate striation, which is undoubtedly due to the same cause. As seen from the figure, the position of the surface is that of a positive hemi-orthodome, for the cleavage plates of large crystals show the plane to be at right angles to the clinopinacoid. Assuming the axial ratio

$$\grave{a} : \bar{b} : \grave{c} = 0.653 : 1 : 0.552 \text{ and } \beta = 64^\circ,$$

as determined by Strüver,[1] for free crystals of sanidine, the face corresponds closely to $\frac{15}{2} P \grave{\infty}$. This would require an angle of 72° 40′ with the basal plane, while that

[1] Cited by Tschermak, Lehrbuch der Mineralogie, p. 455, 1883.

measured in the crystal figured was 72° 53′. Of course this cannot be regarded, under the circumstances, as anything more than an approximate determination.

Chemical composition.—The specimen subjected to quantitative analysis is from the northeastern part of Chalk Mountain [397] and is of the relatively finer-grained modification. This was chosen in order to obtain more easily an average sample of the rock. The analysis is by W. F. Hillebrand.

SiO_2	74.45
Al_2O_3	14.72
Fe_2O_3	None
FeO	0.56
MnO_2	0.28
CaO	0.83
MgO	0.37
K_2O	4.53
Na_2O	3.97
Li_2O	Trace
H_2O	0.66
P_2O_5	0.01
	100.38

The rarity of biotite and of magnetite in this rock, which has already been emphasized, is certainly confirmed by this analysis. In fact, it is evident that no minerals, aside from quartz and feldspar, play any important rôle. The large amount of soda shown by the analysis made it desirable to know how large a share of it was contained in the sanidine, and an analysis of a large clear crystal was therefore made. The result was as follows:

SiO_2	65.04
Al_2O_3	20.40
CaO	0.79
K_2O	9.74
Na_2O } Li_2O }	4.11
H_2O	0.29
	100.37

From this it may be safely assumed that a large part of the soda found in the rock belongs to the sanidine, for no visible impurities were present, such as plagioclase grains. The same holds true for the lime. It is worthy of note that the silica percentage is the highest yet obtained in any rock of the region.

BLACK HILL RHYOLITE.

The rhyolite forming Black Hill, in the southeastern corner of the mapped district, is like the Chalk Mountain Nevadite in being composed almost wholly of quartz and feldspar, but the resemblance otherwise is not very marked, for the Black Hill rock possesses a groundmass which is fully equal quantitatively to the small imbedded crystals. Both feldspars are present in numerous crystals, but orthoclase alone is prominent in the groundmass. Quartz occurs in abundant, slightly smoky crystals. Biotite, in small hexagonal leaves, is sparingly scattered through the whole, and magnetite is also insignificant as a constituent.

Fluid inclusions appear in both orthoclase and quartz, particularly in the latter, and sometimes carry white cubes, apparently of salt. There are glass inclusions also in the quartz, but not plentifully. The groundmass is granular and shows no glass substance like that in the Nevadite.

The orthoclase, though fresh looking, has none of the glassy appearance of sanidine, and it must be confessed that there is little evidence in the observed characteristics of the rock demanding that it be separated from the quartz-porphyries. There is no direct evidence of its age, and its classification as a younger rock rests chiefly upon the following facts. In mode of occurrence and in composition it is more nearly related to the Chalk Mountain Nevadite than to any other rock of the region described. It lies separated by a considerable space from all other eruptives of the map, but is adjoined at no great distance on the south and southeast by a large series of rhyolites and andesites. It is regarded as most probably related to these in its origin. A silica determination in fresh rock gave 69.54 per cent. [140].

McNULTY GULCH RHYOLITE.

Occurrence.—On the northern boundary of the area mapped, at the western base of Bartlett Mountain, occurs a rhyolite of peculiar character. It appears in one large and several small bodies at the head of McNulty gulch (not indicated on the map), which runs north and enters the Ten-Mile River at Carbonateville. White Ridge, between Chalk ranch and Chalk Mountain, is also formed of this rock, as are one or two minor bodies west of Chalk Mountain, which are not shown upon the map.

At the head of McNulty gulch this rock cuts porphyrite and the fresh-looking quartz-porphyry which occurs in the synclinal fold at this point. All these rocks extend northward into the Ten-Mile district, and they will be more fully treated in the forthcoming report upon that region.

Description.—In the largest body of this rhyolite, indicated upon the map, the prevailing habit is that of a light-colored rock, showing numerous slightly pinkish quartz crystals, white glassy feldspars, and bright brown biotite leaves, with a subordinate ashen-gray groundmass between them. Few crystals exceed 0.5^{cm} in diameter, and the average is much less. Intimately associated with the above variety, usually in alternating bands or streams, with rapid though gradual transitions, is a darker modification, in which the development of the quartz in particular has been hindered, while feldspar and biotite are abundant in smaller individuals than before. The groundmass becomes at once more prominent and darker brown in color, determining the general hue of the rock. The thicker these dark portions are the more completely the quartz disappears. In the most compact parts of the rock a fluidal structure is macroscopically visible and small glistening prisms of hornblende appear. About included fragments of sandstones, etc., this rhyolite grows compact in a similar manner, and also on the contact with wall rock.

The smaller masses, though sometimes light-colored, seldom contain much macroscopically visible quartz, and hornblende is usually more or less abundant with the biotite.

Microscopical.—The quartz-bearing variety shows under the microscope a decided preponderance of sanidine over plagioclase. The former is in most cases in fragments of crystals, while the plagioclase is often in well-defined individuals. A few glass inclusions were seen in both quartz and feldspar, while no fluid inclusions were noticed. Apatite and magnetite are rather sparingly present. No hornblende could be found accompanying the biotite in this form. The groundmass is cryptocrystalline and is made up of colorless grains and ferritic specks which are undeterminable. It seems probable that there is some microfelsitic matter present, but it could not be definitely recognized and there is certainly no glass base.

The microscope shows almost as much hornblende as biotite in the compact rock and there is also a larger determinable amount of plagioclase than in the preceding variety, with the same distinction noticed before in contrast with the sanidine, viz, that the latter mineral is more frequently in a fragmentary state, while the former is well crystallized. Quartz is present in clusters of small irregular grains and rarely in crystals. The groundmass is, as before, cryptocrystalline, but its component particles are often minute prisms or flakes and there are more yellowish or opaque grains.

In the darkest modifications a small amount of quartz can always be recognized, but by no means enough to represent the crystals of the light-colored variety. Still everything seems to indicate that the various forms are modifications of one magma and do not differ greatly in chemical composition. So far as the silica is concerned, the truth of this idea was fully established by three determinations made, respectively, in the quartz-bearing variety, the compact form associated directly with it, and, thirdly, in a very light-colored rock from a small isolated occurrence not visibly connected with any other. These yielded, in the order named, 65.75 per cent., 65.21 per cent., and 65.63 per cent. of silica.

EMPIRE GULCH RHYOLITE.

About opposite the Long and Derry mine, on the south side of Empire gulch, there is a small body of rhyolite occurring as a bed below the Silurian Limestone [268]. This is unlike any other of the rocks examined and deserves a short description. It is white, barring the specks of biotite, and very fine-grained, although the lens shows many clear and sharp quartz crystals. The feldspar is distinguishable from the groundmass through its superior whiteness and is apparently no longer fresh. The average size of the visible crystals is about 1^{mm}.

Under the microscope the minute quartz crystals are seen to be well-shaped and to contain very characteristic clear glass inclusions, with none of fluid or groundmass, and a very few apatite needles. The feldspars are chiefly orthoclase, though accompanied by plagioclase, and both seem to be much altered, calcite being the most prominent decomposition product. They contain some inclusions of glass, now much devitrified. The biotite is fresh and characteristic. Magnetite is very sparingly present.

The groundmass has a mottled appearance in ordinary light through the gathering of exceedingly minute brownish particles about certain centers, but no optical proofs of a radiate structure could be detected. The quartz crystals are surrounded by a zone of similar constitution. Seen in polarized light, the whole groundmass seems cryptocrystalline, no isotropic matter being visible. The substances forming it could not be identified, and they seem to be rather needle-shaped or foliate than granular. An alkali determination in this rock gave 3.50 per cent. of potash and 2.17 per cent. of soda, while the silica was determined at 68.05 per cent., thus confirming the identification as an acid orthoclastic rock.

OTHER RHYOLITES.

Rhyolitic tufa in South Park.—Four miles south of Fairplay and one mile east of the limit of the map is a small outcrop of rhyolitic tufa occurring in the red sandstones of the Upper Carboniferous [141]. It is of very limited extent and is apparently the extremity of an arm reaching out from some of the larger masses of rhyolite lying to the south or east. It is of a pink color, very light and porous, and includes many fragments of sandstone as well as pieces of a still lighter tufa. Glassy feldspar, swarming with delicate glass inclusions, quartz, biotite, and hornblende, can all be recognized. The cementing matter is dull, stained, fibrous, and largely microfelsite. The tufa contains 70.3 per cent. of silica.

Dike in the Ten-Mile amphitheater.—A rock which seems to be related to the Chalk Mountain Nevadite occurs in the amphitheater forming the source of Ten-Mile Creek, just east of Chalk Mountain [139]. It appears as a dike in the Archean, for the amphitheater lies immediately east of the great Mosquito fault. On account of decomposition of the feldspars, forming a light greenish-yellow mica, the exact parallelism between the two rocks cannot be absolutely established. The macroscopical appearance suggests an intimate relationship.

Breccia in the Eureka shaft.—In the Eureka shaft, Stray Horse gulch, near Leadville, a brecciated material was found, in which, among other rocks, is a rhyolite containing biotite and larger crystals of feldspar than the type from Empire gulch, but with a similar groundmass [204]. The sanidines abound in glass inclusions, and, besides the quartz, which is not specially abundant, there are aggregates of tridymite.

QUARTZIFEROUS TRACHYTE.

At the head of Little Union gulch, south of Leadville, a rock was found traversing the Archean and Lower Quartzite in an irregular dike, which must be regarded as a quartz-bearing trachyte [142]. Owing to its small area and minor geological significance, it has not been designated by a distinct color on the map, but has been included under that of rhyolite.

Its macroscopical appearance is very different from that of any other rock of the region. The color is dark gray, its most prominent constituent being a glistening-brown biotite, with small glassy feldspars and a number of rounded yellowish quartz grains. Between these is an ill-defined, gray groundmass, which is quantitatively much subordinate to the crystalline constituents. None of the crystals exceeds 0.5^{cm} in diameter.

Microscopical.—Orthoclase (sanidine) and plagioclase seem nearly equal in importance. Both are very fresh and in most cases contain few interpositions, although a few crystals carry a very large number of devitrified inclusions. Hornblende in yellowish-green individuals is quite plenty beside the biotite and both minerals are fresh. The amount of quartz seems limited to the macroscopically visible, rounded grains, and these, by their freedom from all inclusions and worn appearance, seem like accidental rather than normal constituents of the rock. Their number is small, and even if original it seems more proper to consider them as accessory. A silica determination of an average specimen yielded but 61.22 per cent., so that it is evidently not to be classed with the acidic group. Magnetite is abundant, as well as pale mineral in irregular oblong grains, which may be titanite. Apatite is inclosed in all the larger elements excepting the quartz.

The groundmass is microfelsitic in large degree and contains few crystalline particles. It shows a distinct fluidal structure, made plain by the contrast between the portions carrying indistinct brown needles and colorless portions. The needles are sometimes grouped in an imperfectly radiate manner about some small crystal, in a manner similar to that in felso-spherulites. These act feebly on polarized light, giving a faint black cross when seen between crossed nicols. Some colorless isotropic spots seem to be glass. The movements which produced the fluidal structure are also indicated by the crumpled biotite leaves and broken hornblende prisms.

ANDESITE.

Andesitic rocks have not been found within the limits of the Mosquito Range map, but at the Buffalo Peaks, a few miles south, a large variety occurs. In the course of a hurried trip a number of specimens were collected from this locality, representing several types; of these, two are sufficiently marked in character and occurrence to merit particular notice.

PYROXENE-BEARING HORNBLENDE-ANDESITE.

Macroscopical.—The rock which in the form of a sheet caps the mountain is a pronounced hornblende-andesite [143]. Macroscopically it is dark brown in color and contains feldspar in clear or ashen-gray crystals and dark, glistening hornblende prisms as most prominent constituents. With the aid of the lens green prisms of pyroxene and ore particles are quite abundantly visible. The brownish groundmass, which gives tone to the whole rock, is rather more abundant than all the crystals together.

Microscopical.—Under the microscope the hornblende is found to possess the usual characteristics of that mineral in such rocks. It has a dark, granular border, or is occasionally entirely replaced by a mass containing opaque ore grains, augite prisms, and some calcite as secondary elements. Besides the hornblende appear both hypersthene and augite, in smaller crystals, but more numerous. The former of these minerals possesses the same characteristics as in the accompanying hypersthene-andesite. Most of the feldspars are distinctly plagioclase and some of them contain irregular glass-inclusions in great number, many of which are now much devitrified. Magnetite and large dusty apatite prisms are sparingly present among the porphyritically imbedded crystals.

The groundmass is a mixture of delicate plagioclase staves, minute prisms of hypersthene and augite, with magnetite and a scanty glass base between them, the latter devitrified by brownish globulites.

HYPERSTHENE-ANDESITE.

On the northeast shoulder of the mountain a very dark compact rock occurs, which seems to be an almost typical augite-andesite. Macroscopically there are numerous small glassy feldspars visible and a few green grains and ore specks, but the black, generally vitreous groundmass is much more prominent [144]. The microscopical examination shows a very close resemblance to the well-known Hungarian "augite-andesites" of similar macroscopical habit. The rock contains no hornblende and no biotite, while the pyroxene consists in part of *hypersthene* and in part of common augite. Hypersthene is the more characteristic bisilicate in this rock, and the name is therefore given as above. Its determination rests upon careful optical and chemical investigations.

Comparative study in connection with the above rock has shown that a large number of so-called augite-andesites, both in this country and in Europe, are more correctly to be considered as hypersthene-andesites. Detailed investigations in regard to the Buffalo Peak rock and a comparative microscopical examination of allied occurrences are given in Bulletin No. 1 of the series published by the United States Geological Survey, "On Hypersthene-Andesite," &c.

On Plate XXI are heliotype reproductions of photographs showing the composition and structure of the chief andesite types of the Buffalo Peaks. The result is so unsatisfactory that the figures convey but an indistinct impression. In Fig. 2, however, the small prisms of hypersthene are distinguishable from augite, which occurs chiefly in peculiar aggregates, with magnetite, feldspar, and sometimes with biotite, as shown in the lower left-hand portion of the figure.

TUFACEOUS ANDESITES.

The tufaceous rocks of the Buffalo Peaks are chiefly if not entirely of andesitic character, although they exhibit a very wide range in composition and texture. Some of them are loose or friable ash-beds, others contain a large amount of dark pearlitic glass with the ashy material, and still other beds are so compact as to resemble massive rocks. In composition they vary greatly, especially in regard to the more basic silicates, for hornblende, biotite, hypersthene, and augite are respectively the characteristic minerals in different beds, while they frequently occur together.

The pebbles included in these tufas represent as many types of massive andesites as are indicated by the various beds of tufa. Granite is also frequently found, especially in some layers, and sometimes in large bowlders.

RÉSUMÉ.

In the following lines are brought together, in concise form, the results and particular features of the preceding description which are deemed of special importance or interest:

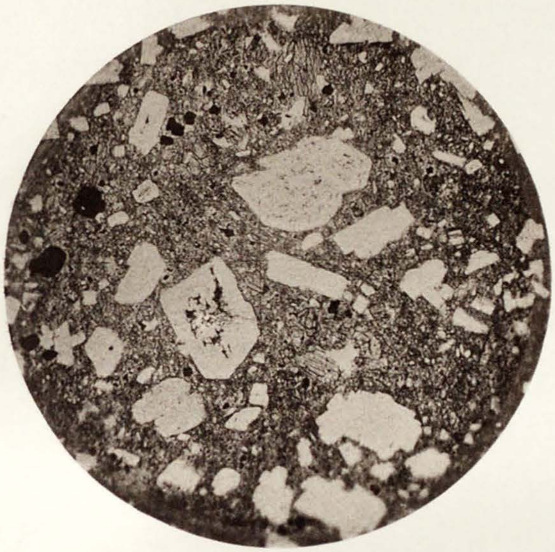

Fig. 1

Fig. 2

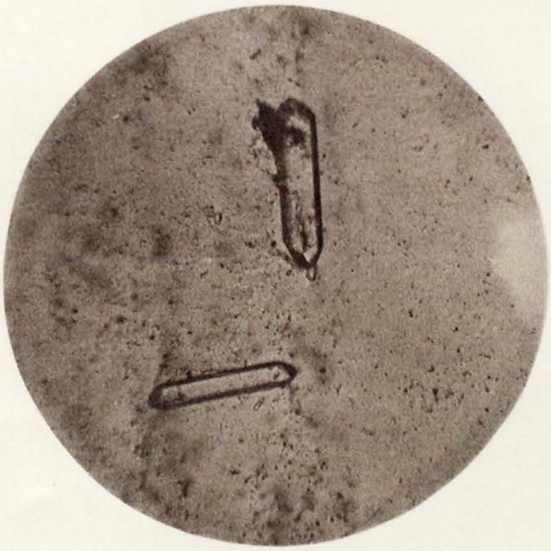

Fig. 3

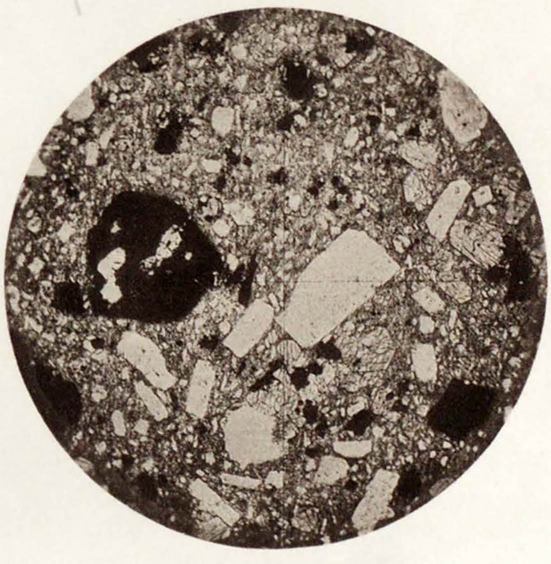

Fig. 4

Heliotype Printing Co. 211 Tremont St. Boston

THE ROCK STRUCTURES OBSERVED.

But three granular rocks were found, all of them diorites. In striking contrast to this rarity, it is observed that all the numerous quartz-porphyries and porphyrites are holocrystalline and that the groundmass is in nearly all cases evenly granular. Although these rocks occur both in dikes and in relatively large masses, this markedly crystalline structure is wonderfully persistent through the extent of the existing variation in conditions.

INDIVIDUAL ROCK TYPES.

Of the various rock types described, the following seem specially noteworthy:

1. White Porphyry.—This rock illustrates a transition stage between the granular and porphyritic structures. Its imbedded crystals are few and small, but they evidently correspond to the more prominent constituents of the typical porphyry, whether viewed from the structural standpoint or considered in the light of the genetic principle discussed in the introduction. In mineralogical composition this is an interesting type, because of the absence of biotite or a bisilicate as an essential constituent. Even the intimate relationship to a biotite-bearing rock indicates nothing more than the possible presence of biotite in very insignificant quantity. The common accessories, apatite and magnetite, are also very rare.

2. Lincoln Porphyry.—This widely distributed type is remarkable for its large orthoclase crystals, developed during the later stages of consolidation, in the presence of abundant plagioclase. The persistency with which these crystals are found in masses of various conditions of occurrence gives at first a somewhat erroneous impression as to the distinctness of the type. Only the observance of many occurrences leads to a correct understanding of the relations of this rock.

3. Nevadite.—This variety has solidified at a stage seldom illustrated by instances which have been previously described. In its granular groundmass, consisting almost wholly of quartz and orthoclase, are still a few isolated particles of clear glass, a case directly analogous to but one occurrence known to the writer. The present form may be considered as a fair type of the division of the rhyolite called "Nevadite" by Messrs. Hague and Iddings. The peculiar mineralogical components are referred to below, and a glance at the quantitative analysis will show a wonderfully simple chemical constitution. Silica, alumina, potash, and soda make up 97.67 per cent. of the whole, no other element reaching 1 per cent.

4. Hypersthene-bearing andesite.—The rocks from the Buffalo Peaks, in which hypersthene[1] was identified as a prominent constituent, are especially noteworthy only as the first ones in America in which the important rôle played by that mineral was recognized. The experience of the last two years has shown the writer that andesites containing hypersthene as an essential constituent are very abundant in Southwestern Colorado, while their distribution in the Great Basin and among the volcanoes of the Pacific coast has been shown by the publications of Messrs. Hague and Iddings[2] and Diller.[3]

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[1] Bulletin No. 1, United States Geological Survey, 1883.

[2] American Journal of Science, III, XXVI, 222, 1883. *Idem.*, XXVII, 453, 1884.

[3] American Journal of Science, III, XXVIII, 252, 1884.

MUTUAL RELATIONS OF ROCK TYPES.

The large number of porphyrites constitute a series connecting the most distinctly plagioclastic forms with those in which orthoclase assumes a very prominent place by virtue of its abundant large crystals. The full significance of this transition will be shown in a forthcoming report upon the Ten-Mile mining district, which lies immediately north of the Leadville region.

ROCK CONSTITUENTS.

During the study of the eruptives which have been described several constituents were found to possess unusual development, while some of great rarity were noticed.

1. Lustrous sanidine.—The sanidine of the Chalk Mountain Nevadite is characterized by a delicate but perfect parting, parallel to a plane in the orthozone, determined approximately as $\frac{15}{2} P \bar{\infty}$. When this parting is highly developed it causes a brilliant satiny luster parallel to the plane of parting. (See p. 348.)

2. Zircon.—Minute but highly perfect crystals of nearly colorless zircon are regularly, and sometimes abundantly, scattered through nearly all of the rocks described.

3. Allanite.—The main group of the quartz-porphyries and porphyrites contains allanite regularly, but sparsely, distributed through it. With the exception of the contemporaneous identification by Mr. Iddings, no instance of the occurrence of this mineral in such rocks is known to the writer. (See p. 329.)

4. Topaz.—This does not appear as a rock constituent proper, but is found in drusy cavities in the Nevadite. It is associated here with quartz, sanidine, and biotite crystals and seems to be a sublimation product. (See p. 347.)

5. Orthoclase fragments.—In a dark porphyrite containing abundant hornblende and biotite and occurring as a dike in the Archean, were found numerous pebble-like fragments of orthoclase, each belonging to a single individual and unlike anything observed in other rocks of the region. These rounded pieces are analogous to worn fragments of foreign rocks often seen in neighboring dikes, but their true nature could not be definitely established. (See p. 339).

DECOMPOSITION OF ROCK CONSTITUENTS.

Notwithstanding the uniform and simple composition of the rocks described, a few points of great interest were observed in connection with the decomposition of their constituents.

1. The Sacramento Porphyrite illustrates the tendency to the formation of a single end product from all the chief decomposable elements, to a degree hitherto unknown to the writer, either in literature or in personal experience. Some specimens of this rock show epidote replacing hornblende, biotite, orthoclase, and plagioclase, all other secondary products being comparatively insignificant in these cases. In certain other specimens of the same rock a common result of the decomposition of biotite, orthoclase, and plagioclase is muscovite, epidote and all other alteration products being here subordinate. (See p. 341.)

2. Muscovite from biotite.—The unusual process by which biotite is replaced by a mineral indistinguishable from the adjacent decomposition product of orthoclase is further illustrated in the Mount Zion (p. 324), Lincoln (p. 330), and Mosquito (p. 328) Porphyries. The intermediate stages are referred to in the text.

3. Epidote.—This mineral undoubtedly replaces both feldspars in several rocks where no intermediate stage can be seen. While the chemical replacement of orthoclase substance by epidote is not easily understood, it is a fact that the replacement does occur when the conditions, whatever they may be, are favorable (p. 341).

4. Hornblende outlines.—The Gray Porphyry has fresh or partially decomposed biotite, while containing evidences that hornblende was a former constituent, although it is now always represented by various extreme decomposition products in areas having the characteristic outline of hornblende. This hornblende must represent an early product of consolidation, destroyed in the manner commonly noticed in andesites, and both its former existence and its destruction are very probably connected with the fact that the Gray Porphyry sheet at Leadville is 12 miles away from the eruptive channel upon Eagle River. (See p. 331.)

5. Rutile and anatase from biotite.—The early stages of the decomposition of biotite are usually accompanied by the formation of yellow needles or of small, apparently tetragonal tablets, or of both forms. The identity of the former with rutile is exceedingly probable, as they are often twinned in the characteristic manner and correspond to what have been elsewhere identified. The nature of the latter forms is less easily shown, but they agree well with the descriptions of anatase by Diller,[1] while the association with the needles seems confirmatory of this determination.

NEGATIVE OBSERVATIONS.

The *absence* of certain minerals as constituents in some cases is worthy of note. Thus in the White Porphyry no biotite or bisilicate appears, even in small quantity; apatite is very rare in the same rock and seems to be wanting entirely in the Pyritiferous Porphyry; augite appears in a single rock, and olivine-bearing types are wholly wanting.

CHEMICAL COMPOSITION.

The simple composition of the Nevadite and of the White Porphyry has been referred to above. The relations of the types are noteworthy and will be apparent from an examination of the accompanying table, in which the analyses previously given are reproduced.

[1] Diller, J. S. Neues Jahrbuch für Mineralogie, etc., I, 187, 1883.

Analyses of eruptive rocks.

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	BaO	SrO	MgO	K_2O	Na_2O	Li_2O	H_2O	CO_2	P_2O_5	Cl.	Total.
Mount Zion Porphyry, p. 323	73.50	....	14.87	0.95	0.42	0.03	2.14	....	Tr.	0.29	3.56	3.46	....	0.90	....	....	....	100.12
White Porphyry, p. 324	70.74	....	14.68	0.69	0.58	0.06	4.12	0.03	Tr.	0.28	2.59	2.29	....	2.09	2.14	....	Tr.	100.29
Mosquito Porphyry, p. 327	68.01	....	....	....	....	....	....	....	....	....	4.36	4.26	....	....	....	....	....	....
Pyritiferous Porphyry, p. 326	....	....	....	....	....	....	....	....	....	....	4.62	2.91	....	....	....	....	....	....
Lincoln Porphyry, p. 328	66.45	0.10	15.84	2.59	1.43	0.09	2.90	....	0.07	1.21	2.89	3.92	Tr.	0.84	1.35	0.36	0.05	100.09
Gray Porphyry, p. 330	68.10	0.07	14.97	2.78	1.10	0.09	3.04	....	0.08	1.10	2.93	3.46	....	1.28	0.92	0.16	0.03	100.11
Sacramento Porphyrite, p. 341	65.08	....	....	....	....	....	....	....	....	....	2.57	3.55	....	....	....	....	....	....
Silverheels Porphyrite, p. 342	60.42	....	....	....	....	....	....	....	....	....	2.70	4.08	....	....	....	....	....	....
Hornblende mica Porphyrite, p. 340	56.62	....	16.74	4.94	3.27	0.15	7.39	....	....	4.08	1.97	3.50	....	0.92	1.15	Tr.	....	100.73
Biotite Porphyrite, p. 340	64.81	0.08	15.73	1.68	2.91	0.08	4.22	....	Tr.	2.82	1.43	3.98	....	0.62	1.08	0.23	0.04	FeS_2 0.90 100.61
Nevadite, p. 345	74.45	....	14.72	none	0.56	MnO_2 0.28	0.83	....	....	0.37	4.53	3.97	Tr.	0.66	....	0.01	....	100.38
Rhyolite, Empire Gulch, p. 351	....	....	....	....	....	....	....	....	....	....	3.50	2.17	....	....	....	....	....	....

NOTES UPON THE HENRY MOUNTAIN ROCKS.[1]

The Henry Mountain rocks are of two principal classes, one hornblendic, the other augitic, with plagioclase as the predominant feldspar in both cases.

HORNBLENDIC ROCKS.

Macroscopical.—The hornblendic varieties have as a class a much more recent appearance than the Mosquito Range porphyrites, with which they agree in composition and microscopical structure. This arises from the prevailing light-grayish tone of the groundmass and the glassy luster of the feldspars. Nearly all specimens show a decidedly porphyritic structure, although they vary greatly in the relative proportions of the groundmass to macroscopic elements. A white or glassy, colorless feldspar, in short, stout crystals, or less frequently in tablets, and a glistening dark hornblende are the only macroscopic minerals of prominence. A few rounded quartz grains are visible in some of the specimens, and pale-yellow, brilliant crystals of titanite can be detected in most of them; also, minute ore grains. The groundmass in which these minerals lie is gray or tinged with red when fresh, but is greenish or dull gray when attacked. Careful search with the lens shows the characteristic striation of triclinic feldspars on many individuals, but it is much less prominent than usual. The hornblende is subordinate both in size and number of its crystals, and seldom appears in the groundmass in sufficient quantity to give it a greenish tinge, as was common in the Mosquito Range porphyrites. Few feldspars reach a diameter greater than 1^{cm}, while the average is below 0.5^{cm}.

Microscopical.—No. 04 will be first described, as it corresponds so nearly to our Mosquito gulch type, and the mutual relations of the two rock groups can thus be made most easily apparent. The only minerals appearing in large crystals are feldspar and hornblende. No quartz grains fall in the section. Other minerals to be distinguished from those in the groundmass are zircon, apatite, magnetite, and possibly some titanic iron. An unknown pale-green mineral, polarizing strongly, is present in irregular grains in the groundmass (pyroxene?). It is not abundant.

The feldspar is clearly plagioclase in nearly all cases when seen in polarized light. Most crystals show distinct laminæ running fully across them, but others con-

[1] These notes were prepared at the request of Mr. Emmons for purposes of comparison with the eruptive rocks of the Mosquito Range. The examinations were made upon small specimens and thick sections, comparatively few new sections having been made. As the material was in a measure incomplete and is no longer at hand for further study, the notes are presented without elaboration in substantially their original form. The references are to the notes of Capt. C. E. Dutton in G. K. Gilbert's report upon the Henry Mountains.

sist chiefly of one individual, in which a few thin wedges are inserted at one end, or on one side, in twinning position. These are, I presume, the crystals described by Captain Dutton as orthoclase at one end and plagioclase at the other. A zonal structure is often present, which is at times interrupted by the twinning. Inclusions in the plagioclase are not very abundant. There are sometimes minute dark inclusions, regular or irregular in shape and arrangement, which seem to be early inclusions of the groundmass or devitrified matter. Distinct glass and fluid inclusions were seldom found. Hornblende occasionally penetrates the feldspar, but inclusions of other minerals are rare.

The hornblende itself is well developed crystallographically. In this particular case (04) it shows an unusual tendency to an alteration, by which dark ore grains are formed on and adjoining the outer surface and on cleavage and other fissure planes. The appearance is, however, entirely different from that of andesitic hornblende. In one place hornblende is apparently forming from pale pyroxene. This is, however, an isolated case, as elsewhere the distinct outlines of the hornblende crystals prove them to be original as such. The hornblende is green and fibrous rather than compact and yellow.

Titanite, which appears in most of these rocks, does not seem to be present here in good crystals. *Apatite* is not abundant, but occurs in short, stout prisms. But little magnetite occurs in large grains.

The *groundmass* is granular throughout and has the same composition as in the Mosquito Range porphyrites; that is, it consists chiefly of quartz and orthoclase.

Of the other Henry Mountain rocks, Nos. 8, 9, 16, 18, 20, 23, 32, 35, 40, 44, 46, 47, and 50—thirteen in all—seem identical in all essential points with that described above. Other accessory minerals appear in some of these sections. *Biotite* appears as a subordinate constituent in No. 35, corresponding in this respect to our porphyrites, and being the sole case noticed.

Isolated grains of pink *garnet* occur in Nos. 23, 37, and 47. *Titanite* is present in nearly all and ilmenite in some of them. In 40 the latter seems to be producing titanite through its alteration. In 46 and 23 (new section) I find allanite corresponding exactly in appearance to that of the Mosquito rocks.

It can hardly be asserted that plagioclase predominates in all of the rocks, from the evidence of these sections alone, as some of them are very small; there can be no doubt, however, that all belong to the same rock type. I cannot convince myself that orthoclase exists in more than isolated crystals among the macroscopic elements.

Inclusions in feldspar are seldom more numerous or distinct than in the first case described. Occasionally, however, a crystal is filled with minute hornblende microlites and clear crystals of zircon, with other ill-defined matter.

The feldspars are usually quite fresh, but the hornblende is sometimes entirely decomposed. The common result is a mixture of chlorite, filmy calcite, and opaque particles. Epidote is often a further product. Granular calcite is visible in some cases and its origin doubtful. The minute ore grains of the groundmass are often hydrated, giving a dingy tinge to the rock.

In none of the above rocks can there be any question as to the thoroughly crystalline nature of the groundmass, but it varies in relation to the crystals and in composition. Plagioclase in thin plates may be seen to enter into its constitution and the quantity of quartz doubtless varies. It even seems probable that in extreme cases the groundmass may be entirely feldspathic.

In nine other rocks, 24, 31, 33, 56, 61, 62, 67, 68, and 69, the groundmass is extremely fine grained and acts but feebly on polarized light. The granular structure is preserved, and I can find no proof of the glassy or strictly microfelsitic base. The varying relative quantities of groundmass and crystals are particularly marked in these fine-grained rocks (see 31 and 33).

AUGITIC ROCKS.

The rocks included here are Nos. 28, 43, and one of those numbered 31. Hand specimens of 31 and 43 were among those sent.

Macroscopical.—Specimen 31 is distinctly porphyritic, the greater part is dull ashen-gray in color, and in this portion feldspar and groundmass are not clearly distinguishable throughout. There are a few fresh pink feldspars in tabular crystals, presumably orthoclase, reaching in one case nearly 2^{cm} in length. Similar feldspars were not noticed in any of the hornblendic rocks.

The dark basic mineral is very black and occurs in short stout crystals, mostly small, which lack the luster of hornblende. A careful examination with the lens shows also that the section of the prism is octagonal, with alternate sides but slightly developed. This mineral is not so abundant as the hornblende in preceding rocks. Glistening ore particles and yellow titanite are distinct, though small.

Microscopical.—(Of No. 31.) It is rather difficult to determine the nature of the dominant feldspar in this rock. I think it is plagioclase, but cannot say that I can prove it from the microscopical examination alone. In the first place, this feldspar does not seem to polarize light so strongly as is common. Captain Dutton probably referred to this rock when he said that certain feldspars "had almost ceased to polarize." In the second place, those crystals determinable as plagioclase are apparently oligoclase of medium composition, for the direction of total extinction in the sections examined does not vary far from the line of the twinning plane. It is therefore often difficult to recognize the polysynthetic structure. By the aid of the quartz plate many are found to be distinctly triclinic, but still so many remain undeterminable that it is possible that orthoclase predominates in the rock as a whole. The feldspars resemble those in granitic rocks in their dirty appearance, the result of incipient decomposition proceeding from innumerable cleavage planes.

Inclusions of augite are rare. Glass inclusions were not noticed and fluid ones are indistinct and rare. The *augite* is unique in its optical behavior in that it appears as bright green by ordinary light and has a pleochroism as strong as is usually found in green hornblende, giving, too, almost exactly the same colors. In all other and more important respects this mineral shows the characteristics of augite. Contours of prism, cleavage, and maximal angle of extinction in prismatic zone (nearly 45°) all indicate augite. Titanite and magnetite often penetrate the augite.

The groundmass seems wholly crystalline, yet is unlike that common in the hornblendic rocks. It seems composed of feldspar and augite, with no visible quartz. The feldspar is chiefly present in tabular particles, and not in irregular grains. The pale-green microlites and grains, which are quite abundant, seem to be of augite, as there is more or less of a gradation in size from the large ones to these in the groundmass. Very minute ore particles are present.

No. 43 is of quite different macroscopical structure. It appears almost macrocrystalline, the groundmass occupying simply the interstices between the small white tablets of feldspar, while the augite occurs in minute grains not recognizable by the naked eye.

Microscopical.— The feldspars have a duller appearance even than those in 31, and there is the same difficulty in determining which species predominates. The augite is the same in character, but does not appear in the groundmass as in 31.

In No. 28 (the slide alone examined) exists still another form of structure. The whole mass is here microcrystalline and consists chiefly of feldspar, concerning which the same doubts exist as before. The augite is very distinct. The groundmass is made up of small feldspars and nearly every one is determinable as feldspar. Quartz does not appear; the same accessory minerals are here as in others, titanite, magnetite, &c. Hornblende is exceedingly rare, if, indeed, it occurs at all in these three rocks. No. 29, however, shows both minerals. The hand specimen shows large, distinct hornblendes, but in the slide, among the few minute irregular grains (no large ones being present), augite appears fully as abundantly as hornblende. The remainder of the rock is entirely feldspathic, both orthoclase and plagioclase being recognizable.

But one rock remains, No. 57. This is the sanidine-trachyte of Dutton. Not having the hand specimen and with only one slide, but little can be made out of it. It seems like a tufa or fragmental rock of some kind. The minerals recognizable (plagioclase, orthoclase, quartz, and hornblende) are chiefly in irregular fragments of crystals and the groundmass, though cryptocrystalline for the most part, has some isotropic substance.

RÉSUMÉ.

The greater part by far of the Henry Mountain rocks correspond very closely in composition and structure to our Mosquito Range porphyrites, or in particular to those varieties in which biotite is rare or is wanting and in which the hornblende does not appear in the groundmass in large quantity. Both consist of plagioclase and hornblende, with a granular groundmass, composed essentially of quartz and orthoclase. They differ—

- *a*, in outward appearance.
- *b*, in almost total lack of biotite.
- *c*, in frequent presence of titanite.
- *d*, in that the grain of the groundmass sinks in certain cases to exceeding fineness.

None of these is weighty in comparison with the resemblances.

The outward difference seems due to the fact that the specimens were taken from the surface in a region essentially dry and arid.