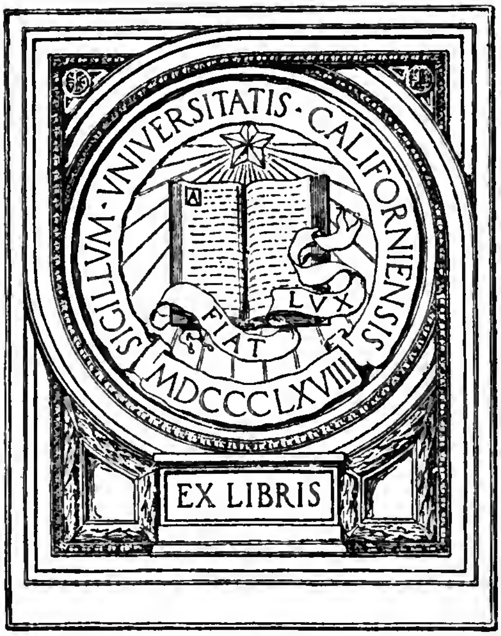

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Washington, D. C., *September, 1892.*

DEPARTMENT OF THE INTERIOR

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OF THE

UNITED STATES GEOLOGICAL SURVEY

VOLUME XX

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1892

UNITED STATES GEOLOGICAL SURVEY
J. W. POWELL, DIRECTOR

GEOLOGY

OF THE

EUREKA DISTRICT, NEVADA

WITH AN ATLAS

BY

ARNOLD HAGUE

WASHINGTON
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LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Washington, D. C., June 20, 1891.

Sir: I have the honor to transmit herewith a report on the Geology of the Eureka District, Nevada.

To yourself and to the Hon. Clarence King, under whose direction the field work was commenced, I am greatly indebted for the personal interest taken in the investigation, and also for the generous facilities afforded me both in the field and office.

Very respectfully, your obedient servant,

Arnold Hague,
Geologist in Charge.

Hon. J. W. Powell,
Director, U. S. Geological Survey.

PREFACE.

The survey of the Eureka District was authorized by the Hon. Clarence King, the first Director of the United States Geological Survey, and the field work, for the most part, was done during his administration. The field season was confined to the summer and autumn of 1880, and was limited to five months, the work being brought abruptly to a close early in December owing to the inclemency of the weather. Visits of a few days' duration were made by different members of the party during the two following years, but these were simply to verify previous observations or to correct apparently conflicting statements.

This monograph is purely geological in its scope and is mainly a careful study and survey of a comparatively small block of mountains, which may be designated the Eureka Mountains, but which should not be confounded with the Eureka mining district, as several other well known but less important mining districts also lie wholly within this mountain area.

As it was unmapped and only occasionally visited by geologists, little had been accomplished, except for the immediate purposes of mining, toward investigating its structure or solving its many geological problems. The Eureka region was known to occupy an exceptionally broad expanse of mountains, affording fine geological sections if carefully worked out, and of special interest for the purposes of comparative study in other regions of the Cordillera. In this direction scarcely anything had been accomplished.

The field work, as planned, could not have been completed in the allotted time except for the untiring energy and interest of all those connected with the survey. In the geological work I was fortunate in having the cooperation of two thoroughly equipped assistants, both of whom have since attained honorable distinction by published writings in their special lines of research. To Mr. Charles D. Walcott was assigned the collection of the paleontological material, while Mr. Joseph P. Iddings was engaged in working among both volcanic and sedimentary rocks.

The report appears in two parts, one a volume of text, the other an accompanying atlas of topographical and geological maps and cross sections, and as the text is, in great measure, explanatory of the atlas, the two can be considered only as parts of the same work.

A paper embodying the more important results obtained at Eureka was prepared in 1882 and published in the Third Annual Report of the Survey as an abstract of the final monograph. It was accompanied by a geological map similar to sheet IV of the atlas. The volume of atlas plates bears the imprint of 1883, but is now issued in complete form for the first time. In its more essential features the present report was prepared several years ago, but the completion of the manuscript has been delayed from time to time for various unforeseen reasons, mainly by pressure of other duties. It presents, as concisely as is consistent with clearness and completeness, the principal geological facts gathered in the field and such general deductions as have been drawn from their study. I have endeavored to make each chapter complete in itself, and this has necessitated the repetition of certain observations, as a large number of facts are more or less related to the subjects discussed in the different chapters. It is an advantage, however, to the special reader, to have such facts as he may need brought together under one grouping, and not to feel obliged to search through the volume for them.

The atlas consists of thirteen sheets. The preparation of the topographical map was intrusted to Mr. F. A. Clark, who employed three able assistants in the field—Mr. G. H. Wilson, assistant topographer with the plane table; Mr. G. Olivio Newman, in charge of triangulation, and Mr. Morris Bien, assistant topographer.

A special paper by Mr. Iddings, upon the microscopical petrography of the eruptive rocks of the Eureka District, appears as an appendix to this report. It presents the results of a careful examination of several hundred thin sections prepared from a large number of rocks, representing every variety known to occur in the region. It is a concise statement of results of a systematic study of the material and is of great interest, bearing directly upon many geological questions connected with eruptive masses. Mr. Iddings's report is illustrated by six plates, four of which are reproductions of photomicrographs, showing some interesting features in structure of fine groundmass, and two of drawings of minute crystals and microscopic objects found in the rocks. At the time these photomicrographs were produced they were superior to anything which had been done in this class of illustration.

Mr. Walcott's report upon the "Paleontology of the Eureka District" was published as Monograph VIII of the U. S. Geological Survey, in 1884. It gives the results of a detailed study of the organic forms obtained throughout a wide range of geological formations, the region having proved an exceptionally rich one in paleontological material from Cambrian, Devonian and Carboniferous rocks. In addition to the descriptions of many forms new to science and the identification of over five hundred species, the report contains notes, more or less full, upon many species which presented in their characters or geographical distribution information not heretofore published. The work is illustrated by over five hundred and fifty accurate drawings of fossils, arranged on twenty-four plates. Four plates represent the fauna of the Cambrian, two that of the Silurian, ten that of the Devonian, and eight that of the Carboniferous. All specific identifications of organic forms from Eureka referred to in this work were made by Mr. Walcott.

After the completion of the field work for the Eureka map, Mr. J. S. Curtis began his investigations of the ore deposits found on Ruby Hill. The surface maps published by Mr. Curtis were taken from the atlas sheets accompanying this monograph. Mr. Curtis's report appeared in 1884 as Monograph VII of the U. S. Geological Survey, and is entitled "Silver-Lead Deposits of Eureka, Nevada." It is a valuable work and one which forms an important part of the scientific memoirs relating to the Eureka District.

The writer's acknowledgments are due to many gentlemen, superintendents of mines and others, who rendered valuable assistance in furnishing information in regard to the country, and who generously afforded every facility in the prosecution of the work. Special thanks are due to Mr. R. Rickard, formerly superintendent of the Richmond Mining Company, and to Mr. Thomas J. Read, superintendent of the Eureka Consolidated Mining Company.

June 6, 1891. ARNOLD HAGUE.

OUTLINE OF THIS VOLUME.

CHAPTER I. The area covered by the geological survey of the Eureka Mountains embraces a region of country 20 miles square. The mountains are situated on the Nevada plateau and form a somewhat isolated mass, surrounded on all sides by the broad detrital valleys so characteristic of the Great Basin. These valleys which encircle the mountains have an average elevation above sea level of 6,000 feet. Rising above them the highest peaks attain altitudes varying from 9,000 to 10,500 feet. In strong contrast with most of the Great Basin ranges, the Eureka Mountains present a rough and rugged appearance, with varied topographical features.

CHAPTER II. Sedimentary rocks belonging either to the Paleozoic or Quaternary age form the greater part of the mountains and valleys. Quaternary beds present little of geological interest, although they extend over wide areas, being mainly superficial accumulations composed of detrital material brought down from the mountains and deposited along their flanks and out over the broad plains. A great thickness of limestone, sandstone, and shale, which make up the Paleozoic series of rocks, was laid down under varying conditions of depth of water and rapidity of deposition with only one well recognized unconformity from base to summit. In this region the Paleozoic age was a time of comparative freedom from dynamic movements. Eureka presents no direct evidence as to the time mountain building took place other than that the region was elevated into a broad continental land mass after the deposition of the Upper Coal-measure limestone. Reasons are assigned for supposing that all the Great Basin ranges owe their origin to a post-Jurassic movement. The folding, flexing, and faulting which outlined the mountains broke up this mass of sediments into six sharply defined orographic blocks, each with well marked structural peculiarities. These mountain blocks have been designated as follows: Prospect Ridge, Fish Creek Mountains, Silverado and County Peak group, Mahogany Hills, Diamond Mountains, and Carbon Ridge and Spring Hill group. Taken together these six blocks present a compact mass of mountains, the result of intense lateral compression and longitudinal strain. Profound longitudinal faults extend the entire length of the mountains, showing a displacement of beds of over 13,000 feet. The Paleozoic sediments measure 30,000 feet in thickness, with Cambrian, Silurian, Devonian, and Carboniferous, all well represented by characteristic fauna. In these four periods fourteen epochs have been recognized.

CHAPTER III. Cambrian rocks measure 7,700 feet, divided into five epochs, as follows: Prospect Mountain quartzite, Prospect Mountain limestone, Secret Canyon shale, Hamburg limestone, and Hamburg shale. The Middle, Lower, and Upper Cambrian are all exposed. On the crest of Prospect Ridge, at the base of the Cambrian limestone, occurs the *Olenellus* shale, the oldest fossiliferous strata recognized in the Great Basin. Hamburg Ridge carries a Potsdam fauna both at its base and summit.

Conformably overlying the Cambrian come the Silurian rocks, 5,000 feet in thickness. They fall readily into three epochs, two limestones and an intervening body of quartzite. They have been designated Pogonip limestone, Eureka quartzite, and Lone Mountain limestone. The quartzite is easily distinguished from both the coarse sands and grits of the Cambrian below and the Carboniferous conglomerate above. An unconformity of deposition exists between the Eureka and Lone Mountain epochs. Both the Trenton and Niagara formations are included within the Lone Mountain epoch.

CHAPTER IV. By imperceptible gradations limestones of the Lone Mountain epoch pass upward into those of the Devonian period. Devonian rocks occupy a larger area in the District than those of any other period, and present a greater thickness than either the Cambrian or Silurian. They measure 8,000 feet, divided into two epochs: A bluish limestone—the Nevada limestone—and an argillaceous black shale—the White Pine shale. The limestone carries a rich invertebrate fauna from base to summit. The black shale is characterized by a flora which, though fragmentary, is sufficiently well preserved to identify the genera as belonging to the Upper Devonian.

The Carboniferous rocks measure 9,300 feet, which, however, does not quite represent their full development, the uppermost beds having undergone more or less erosion. They have been divided into four epochs, as follows: Diamond Peak quartzite, Lower Coal-measure limestone, Weber conglomerate, and Upper Coal-measure limestone. As the limestone is in general favorable to the preservation of organic remains, fossil-bearing strata occur throughout the beds. Three salient features mark the life of the Lower Coal-measures. First, the occurrence near the base of the limestone of a fresh-water fauna; second, the varied development of the Lamellibranchiates a class which has heretofore been but sparingly represented in the collection of Carboniferous fossils from the Cordillera; third, the mingling near the base of the horizon of Devonian, Lower Carboniferous, and Coal-measure species in gray limestone directly overlying beds characterized by a purely Coal-measure fauna.

In the first range to the east of the Eureka Mountains Carboniferous rocks extend for miles along the edge of the valley, in which well developed coal seams occur.

CHAPTER V. This chapter is devoted to the descriptive geology of the sedimentary rocks. Each orographic block is described in detail, beginning with Prospect Ridge, where the oldest rocks occur, followed by the other blocks according to the succession of strata. It gives a connected description of the country and points out the relations of the different mountain masses to each other.

CHAPTER VI. A discussion of the Paleozoic rocks follows, based upon the facts presented in the earlier chapters. It is shown that during Paleozoic time a pre-Cambrian continent existed in western Nevada which furnished to an ocean lying to the eastward an enormous amount of detrital material. It is pointed out that the Eureka region was situated not far from the eastern border of this land mass, and that a large part of its coarse conglomerates and mechanical sediments must have been offshore deposits. The geological record affords proof of elevation and depression throughout Paleozoic time with intervals of shallow water and proximity of land areas between periods of relatively deep seas. Fresh-water life, plant remains, and coal seams at different horizons furnish additional evidence of shallow water and offshore deposits. A study of Paleozoic rocks in other parts of southern and western Nevada exhibit nearly similar geological conditions as regards sequence of beds. This is especially well shown both at White Pine and in the Highland and Piñon ranges. The sequence of strata, both to the north and south, indicates a closer agreement with the conditions of sedimentation at Eureka than the many exposures situated but a short distance eastward of the latter area. The structural relations of the different orographic blocks to each other and the outbursts of igneous rocks are well brought out in cross-section. An instructive feature at Eureka is the close relationship between the anticlinal and synclinal folds to the profound north and south faults.

CHAPTER VII. Pre-Tertiary igneous rocks play a very subordinate part. They may be classed under three heads: Granite, granite-porphyry, and quartz-porphyry. The granite occupies a limited area on Prospect Ridge. Both the granite and quartz-porphyries occur as dikes. Structural variations in the dikes are mainly dependent upon the chilling effect of cold contact walls upon a rapidly cooling molten mass. The width of the dike has much to do in determining the physical conditions governing crystallization. As regards the age of the dikes little is known other than that they penetrate Silurian strata.

CHAPTER VIII. The Eureka District offers no direct proof of the age or duration of volcanic energy, although evidence based upon observations elsewhere in the Great Basin points to the conclusion that the lavas belong to the Tertiary period, and probably the greater part of them to the Pliocene epoch. They broke out in four ways: First, through profound fissures along meridional lines of displacement; second, following lines of orographic fracture, they border and encircle large uplifted masses of sedimentary strata; third, they occur as dikes penetrating the sedimentary rocks; fourth, they occur in one or two relatively large bodies, notably Richmond Mountain and Pinto Peak, along lines of displacement. The sequence of lavas was hornblende-andesite, hornblende-mica-andesite, dacite, rhyolite, pyroxene-andesite, and basalt. The lavas display a great variety of volcanic products in both chemical and mineral composition. They are all derived from a common source, a homogeneous molten mass. They are due to a process of differentiation by molecular change within the molten mass under varying conditions of pressure and temperature. Starting with a magma of intermediate composition, the extreme products of such a differentiation are rhyolite and basalt.

CHAPTER IX. In the Eureka District the ores occur in sedimentary rocks belonging to the Cambrian, Silurian, and Devonian periods, and may be found in all horizons, except the Secret Canyon and Hamburg shale, from the base of the Prospect Mountain limestone to the summit of the Nevada limestone. Through 17,000 feet of strata ores have been deposited in sufficiently large bodies to encourage mining exploration. The most productive deposits have been found in Cambrian rocks, but this is owing to orographic and structural conditions rather than the geological age of strata or chemical nature of sediments. Nearly all the more productive mines are included within the beds which form the Prospect Mountain uplift between the Hoosac and Spring Valley faults. The ore followed the rhyolite and is consequently Pliocene or post-Pliocene age. All the ores came from below and were originally deposited as sulphides. They were subsequently oxidized by atmospheric agencies, mainly surface waters percolating through the rocks.

In Appendix A, Mr. C. D. Walcott gives a systematic list of fossils from each formation found at Eureka.

In Appendix B, Mr. Joseph P. Iddings discusses the microscopical petrography of the crystalline rocks. It is a thorough study of the mineral and structural character of the rocks and is illustrated by several plates.

GEOLOGY OF THE EUREKA DISTRICT.

By Arnold Hague.

CHAPTER I.

GENERAL DESCRIPTION.

The Eureka District is situated on the Nevada plateau in the central part of the state of Nevada, midway between the basin of Lake Lahontan westward and the basin of Lake Bonneville eastward. The area covered by the geological and topographical survey embraces a region of country 20 miles square, lying partly in the county of Eureka and partly in the county of White Pine.

The meridian of 116° west from Greenwich passes just westward of the center of the examined area, and the 39° 30′ parallel of north latitude crosses Ruby Hill, the seat of the present activity in precious-metal mining.

Nevada Plateau.—On the Nevada plateau the broad central north and south valleys, lying between meridional mountain ranges, reach an average altitude of 6,000 feet above sea-level, the country falling away gradually on both sides till at Salt Lake, in Utah, the altitude is 4,250 feet, and at Carson and Humboldt Lakes, in Nevada, 3,800 feet above sea level. These valleys, however, compared with those of the depressed areas adjoining the plateau, are relatively narrow, with few marked exceptions, seldom measuring more than 10 or 12 miles in width. In general the broader physical features of the Great Basin ranges are much the same all the way from the bold escarpment of the Sierra Nevada of California to the precipitous wall of the Wasatch Mountains of Utah, the distance across the widest part in an east and west line being about 425 miles. These ranges form long, narrow mountain uplifts with sharply defined limits, rising with more or less abruptness above dreary intervals of desert. Their nearly uniform trend and the remarkable parallelism of the lines of upheaval of the older sedimentary ridges present the most marked feature of the region. In width they seldom exceed 8 miles, but frequently extend in an unbroken line for more than 100 miles in length, with serrated peaks and ridges rising from 2,000 to 6,000 feet above adjacent valleys. For the most part they possess a simple topographical structure and a simple drainage system. They are characterized, more especially the lower ranges, by absence of trees, and in many cases are nearly bare of all vegetation, presenting rough, rugged slopes of naked rock.

On the higher parts of the plateau the ranges, reaching a greater altitude, partake more of an Alpine or sub-Alpine character. Precipitation of moisture is more abundant, as seen both in the more frequent rains of summer and snows of winter. A greater precipitation produces larger and more frequent streams, and a continued moisture favors a varied vegetation—the spurs and ridges being more or less covered with a dwarfed and stunted forest growth, and the long slopes with nutritious grasses.

These salient features distinguish the ranges of the Nevada plateau from those of Lake Lahontan and Lake Bonneville Basins, which present a more arid and desolate aspect. A striking feature of nearly all these ranges is their isolated position, only a few of them presenting outlying spurs or low lines of rolling foothills. Occasionally inferior ridges of sedimentary beds stretch diagonally across valleys from one range to another, completely shutting in the intermediate valley, and still more frequently outbursts of volcanic rocks in irregular flows serve to unite in confused masses bodies of sedimentary formations otherwise distinct.

Midway between the Sierra and the Wasatch stand the East Humboldt Mountains, the most prominent range in the Great Basin. They present, not only by reason of the greater number of rugged and commanding peaks, many of them attaining an elevation over 11,000 feet above sea level, but by their broad, massive proportions, long, unbroken ridges, and Alpine character, the boldest uplift on the Nevada plateau. Next west from the Humboldt occurs the Diamond Range, followed by the Piñon Range, with the broad Diamond Valley lying between them. Southward the southern extremities of these two ranges enter the Eureka District and form a part of its mountainous region.

On the plateau, among the more marked exceptions to the long narrow ranges which rib the surface of the country, may be mentioned the Roberts Peak Group, connecting the Wahweah with the Piñon Range, the White Pine Mountains, and the subject of the present report, the mountains of the Eureka District.

Eureka Mountains.—The Eureka District forms a rough mountain block standing out prominently by itself, except for its narrow connections with both the Piñon and Diamond Ranges, almost as completely isolated from its neighbors as the longer parallel ranges. As a mountain mass, however, although well deserving such a distinction, it has never received any definite appellation which would include all its members, it being made up of portions of several ranges and short uplifted blocks so intimately connected and inosculated as to form both topographically and geologically a single group, hemmed in on all sides by the characteristic detrital valleys. To the north Diamond Valley, which may be taken as a type of the higher valleys of the Great Basin, extends for over 40 miles in an unbroken plain, the lowest part of the depression being covered in winter by a broad, shallow sheet of water, which, upon evaporation, presents during the greater part of the year a hard, level floor, strongly impregnated with salt. Considerable quantities of salt for metallurgical purposes have been collected from the shores of the small lakes at the northern end of the valley. To the south of the district lies the broad basin of Fish Creek Valley, connecting with Newark Valley on the east side of Diamond Range, while the Antelope Valley cuts off the Eureka District on the west side from the neighboring mountains. All these valleys stand at about the same elevation above sea level, and offer to the eye a monotonous olive-gray color derived from a vigorous growth of the *Artemesia tridentata* which covers all the lowlands except the central portions of the broader basins.

It is doubtful if any area of equal extent in Nevada possesses more varied physical features with such strongly marked contrasts than the Eureka District. In close proximity may be seen long serrated ridges, broad summits, gently inclined tables of nearly horizontal sedimentary beds, with abrupt escarpments along canyon walls, and highly tilted strata in rough irregular spurs. And, as might be expected in a country made up of individual blocks and parts of ranges and so interlocked as to form one broad mass, the region is characterized by broad shallow basins, long narrow ravines, and winding valleys, presenting a more than ordinarily accidented surface with an intricate structure. Above the broad base of the surrounding sage-brush valleys rise many prominent peaks from 2,500 to 4,500 feet. Diamond Peak, in the northeast corner of the district, at the southern extremity of Diamond Range, is the culminating point, measuring 10,637 feet above sea level, and, with the exception of the high summits in the East Humboldt Range, is one of the loftiest peaks on the Nevada plateau. Prospect Peak, on the central ridge, and the second point in the district, measures 9,604 feet, while Atrypa Peak, to the southwest on the same ridge, has an altitude of 9,063 feet above sea level. Other points are White Cloud Peak, the highest point on a broad plateau-like ridge, 8,950 feet; Alpha Peak, 8,985 feet; and Woodpecker's Peak, 8,598 feet; all of them being formed of sedimentary rocks. Among volcanic mountains may be mentioned Richmond Mountain, just east of the town of Eureka, which rises to a height of 8,392 feet, and Pinto Peak, an isolated cone in the center of the district, reaches an altitude of 7,880 feet above sea level.

Up to the time of the rapid development of the mining interests upon Ruby Hill and Prospect Mountain, the slopes and ridges about Eureka were exceptionally well supplied with an arborescent growth, a condition which was due partly to the number of high peaks but in great part to broad masses of mountains acting as condensers of desert moisture. To-day, so great has been the demand for wood and charcoal in the reduction of lead ores, that the mountains are as bare of trees as any part of the Great Basin. Several species of pines, dwarfed junipers (*Juniperus occidentalis*), and mountain mahogany (*Cercocarpus lædifolius*), which attains a height of over 20 feet, are, or rather were, the prevailing trees, but are now found only in a few areas preserved by their owners for future use, at no distant day. Not only have the Eureka Mountains lost their forests, but the neighboring mountains for long distances have been devastated to furnish fuel for the smelting furnaces. Some idea may be obtained of the enormous consumption of wood from the statement that 10,000 bushels of charcoal are required daily for the smelting furnaces when the works are running their usual force, and that for five or six years the daily consumption was rather over than under that amount.

Soil.—Nature presents a barren, arid appearance. Perennial streams in the ravines are exceptional, other than those found on the slopes of Diamond Peak. Fresh water springs lie scattered about the mountains and furnish a scanty supply of water, barely sufficient to meet the wants of the people. A few deep wells have been successfully sunk in the broader valleys. Vegetation is everywhere limited, and is mainly confined to bunch grasses on the mountain slopes and sage brush in the open valleys.

As the valleys are mainly filled with coarse detrital material from mountain slopes, soils suitable for agricultural purposes occupy very small areas, and are found only in the broader basins. In the favored spots where water for irrigation purposes can be readily obtained, all the more hardy vegetables grow well, and are of excellent quality, but nearly all crops suffer from early frosts. In no sense can the country be regarded as an agricultural one, and cultivation of the soil is remunerative to the farmer only by reason of the very high prices received for his produce.

Climate.—A rigorous winter, a long hot summer, a dry atmosphere, with a light precipitation of moisture, are characteristic climatic features of the Eureka District. In summer, rainfalls are limited to showers, frequently very severe, but of short duration, and what are commonly known as cloudbursts are by no means uncommon during late July and early August. The clouds, late in the afternoon, centering over Prospect Peak, break with such force that many people caught without warning have been drowned. In July, 1874, a severe storm and flood destroyed seventeen lives, and carried off property to the value of many thousands of dollars.

During the period of our survey careful meteorological observations were made throughout the summer. Snow fell in the month of May no less than eight times, and again on June 10 and 11. In summer the days are warm, and for the most part cloudless; the nights cool. The daily variation between the maximum and minimum thermometers was always very considerable, frequently showing a difference of 40° F. For the three summer months of June, July, and August, of 1880, the maximum thermometer in the shade stood over 90° F. on eighteen days, or one day in six. As the climate is very dry, the heat was seldom oppressive, except in some inclosed basin or valley. As early as August 30, the thermometer fell below the freezing point, and on October 9 a light fall of snow covered both mountain and valley.

History.—In the summer of 1864 the first locations of mining property were made in New York Canyon, on the eastern side of Prospect Mountain, near the present "76" Mine. This property was known as the Eureka Mine, and although it never fulfilled the expectations of its original owners, it transferred its name to the very successful property on Ruby Hill and subsequently gave a name to the town, to the mining district, to the county, and finally to the neighboring group of mountains. The original property gave so little promise that the district was finally abandoned. In mining operations very little was accomplished until the spring of 1869, when important discoveries were made on Ruby Hill and active, intelligent work was undertaken. The Champion and Buckeye claims on the south side of Ruby Hill were the first properties located, and soon afterward the ground was broken on the now famous Richmond and Tip Top Mines. From that time forward mining operations on Ruby Hill have gone on steadily, and to-day the Eureka District is the most successful mining region in the state of Nevada. Success on Ruby Hill was quickly followed by active enterprise developing mining locations on both slopes of the ridge of Prospect Mountain, in Secret Canyon, and in the Silverado Hills in the southwest corner of the district.

Estimates of the value of the ore production of the district since the first shipment of crude bullion in 1869 are as follows:

From 1869 to 1873	$10,000,000
From 1873 to January, 1883	50,000,000
Total	60,000,000

One-third of this amount, according to the best estimates, was gold, and two-thirds silver. The product in lead is not so easily determined, but it is not far from 225,000 tons, an amount sufficient to affect the market price of lead in all the great commercial centers of the world.

Around this industry has grown up the town of Eureka, which is the center of population and trade for this part of the state. It is a long, narrow settlement, lying in the main northern drainage channel of the mountains, and sheltered on the east side by Richmond Mountain. Here are located the smelting furnaces of both the large companies.

The Eureka and Palisade Railway, 88 miles in length, connects the town with the Central Pacific Road at Palisade. Branch tracks connect with the Eureka Consolidated and Richmond furnaces, the former at the lower, and the latter at the upper end of the town, and these again by a somewhat sinuous course with the principal mines, which are situated about two and one-half miles southwest of Eureka. There are an imposing, well built court house, three or four churches, and several blocks of brick stores and warehouses in the town. It supports two daily papers, which have a considerable influence and a wide circulation throughout the state.

Ruby Hill, the only other town of any importance in the district, is a flourishing place, nearly the entire population being actively engaged in mining in the immediate neighborhood. It is built on the north and east sides of an isolated hill which bears the same name, and on which are located all the more prominent mines, including the Albion, Richmond, Eureka Consolidated, Phœnix, and Jackson properties. On the slopes to the north are situated the Bullwhacker and Williamsburg mines, while to the southward of Ruby Hill, on Prospect Ridge, are found the Dunderberg and Hamburg properties and others of more or less importance.

CHAPTER II.

GEOLOGICAL SKETCH OF THE EUREKA DISTRICT.

Sedimentary rocks, belonging either to the Paleozoic or Quaternary period, form by far the greater part of the mountains and valleys of the Eureka District. The beds of the Quaternary present but little of geological interest, and although they extend over wide areas they are, in most instances, superficial accumulations composed of detrital material brought down from the mountains and deposited along their flanks, concealing the underlying rocks of the foothills. Igneous rocks play a most important part in the geological history of the region, but nevertheless do not form an imposing feature of the individual mountain uplifts, appearing either as extravasated masses along lines of faulting, or as larger bodies encircling and lying outside the main blocks of sedimentary formations. The older crystalline rocks offer a still less marked topographical feature of the country, occupying very limited areas in the older Paleozoic limestones, where they appear as intruded masses exposed by erosion.

It is doubtful if within the province of the Great Basin there can be found any region of equally restricted area surpassing the Eureka District in its grand exposures of Paleozoic formations, especially of the lower and middle portions.

The great thickness of limestone and sandstone of which the Paleozoic is composed was laid down under varying conditions of depth of water and rapidity of deposition, with only one well recognized unconformity from its base to summit. In this region the Paleozoic age was a time of comparative freedom from dynamic movements. Most geologists who have given any attention to the history of the Great Basin ranges substantially agree that the movements that finally built up the mountains began after the close of Paleozoic time, and that between the Carboniferous and the close of the Jurassic period took place the folding, flexing and faulting of the beds which outlined the structural features of nearly all the meridional ranges between the abrupt walls of the Wasatch and those of the Sierra Nevada. At Eureka no direct evidence is offered as to the time when this mountain building took place other than that the region was finally lifted above the ocean after the deposition of the Upper Coal-measures. So far as the mountains themselves are concerned, there is a total lack of evidence that the blocking out of the ridges did not begin at the close of the Paleozoic period, but, on the other hand, all observations tend to show that whenever and by whatever causes the other Great Basin ranges were uplifted, the same orographic conditions which prevailed elsewhere held true for the Eureka Mountains. In other words, the Eureka Mountains were a part of a more extended geological province.

According to the conclusions of Mr. Clarence King,[1] based upon the observations of the geologists of the Fortieth Parallel Exploration, the mountains west of the Havallah Range and the meridian of 117° 30′ belong to a post-Jurassic upheaval, and to the west of this line there existed during Paleozoic time an elevated continental area which furnished the material accumulated in an ocean basin to the east. At the close of the Paleozoic this oceanic area, stretching as far eastward as the Wasatch, was lifted up into a broad land-mass, and the former continental region sank below the water and in turn became an ocean basin. From the Wasatch westward to this ancient shore line the mountain ridges exhibit much in common in their structural and physical features, being made up in great measure of Paleozoic strata, whereas from this boundary westward the ranges show a marked contrast in the nature of their sedimentation and bear ample paleontological evidence of their Mesozoic age. Over this latter area, notably in the West Humboldt, Piute, and Augusta Mountains, limestones characteristic of the Triassic and Jurassic have been described in detail by the geologists of the Fortieth Parallel Exploration,[2] while to the east of this shore line no Mesozoic rocks occur. Mr. King assigns excellent reasons for

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[1] Geological Exploration of the Fortieth Parallel, vol. I, Systematic Geology, p. 733. Washington: 1878.

[2] Geological Exploration of the Fortieth Parallel, vol. II, Descriptive Geology, pp. 657, 711, and 724. Washington, 1877.

the opinion that all the Great Basin ranges across Utah and Nevada were uplifted at the same time under identical dynamic influences, and consequently owe their origin mainly to a post-Jurassic movement.

This indicates a marked unconformity between the Carboniferous and Triassic, but it neither necessitates nor precludes the beginning of mountain building over the Paleozoic area at the time of the uplifting of the continental land-mass from beneath the ocean. Nowhere throughout this region, any more than at Eureka, have the Great Basin ranges as yet offered any direct evidence of folding accompanying this elevation, yet it would seem highly probable that some crumpling of strata might have taken place before the main blocking out of the mountain ridges at the close of Jurassic time.

Most of the Great Basin ranges are narrow, longitudinal ridges, and while they present much in common as to their origin and primary structure, each possesses its own special physical features due to local dynamic conditions. Most of them are formed by direct lateral compression resulting in anticlinal folds, occasionally accompanied by synclines. Some of them are simple monoclinal ridges, representing one side of an anticlinal axis. Still others exhibit great complexity of structure with both folding and faulting along the meridional axes of the ranges, with which are associated transverse faults and folds striking obliquely across the topographical trend of the uplifted mass.

Orographic Blocks.—The Eureka Mountains lie near the western edge of what was at one time the Paleozoic ocean. The nearness of these uplifted beds to an older pre-Paleozoic continent is in some measure indicated by the relatively great amount of disturbance of strata and plication of mountain masses as compared with the more gently inclined strata, and simplicity of structure found farther to the eastward. Unlike the ordinary type of narrow ridges, the Eureka Mountains exhibit a solid mountain mass over 20 miles in width, including several uplifted blocks whose length does not greatly exceed their width. Taken together they present a compact mass of mountains thrown up by intense lateral compression accompanied by longitudinal strain. The forces which brought about the elevation of the mountains produced an intricate structure with powerful flexures and folds and broke up this immense thickness of sediments into individual blocks accompanied by profound longitudinal faults, several of which extend the entire length of the mountains, and have played a most important part in bringing about the present orographic conditions.

Although these mountain masses stand so intimately related to each other that it is frequently difficult to draw sharp topographical lines between them, the Eureka Mountains may be divided into six blocks with well marked structural and geological differences. These blocks may be designated as follows:

Prospect Ridge.
Fish Creek Mountains.
Silverado and County Peak group.
Mahogany Hills.
Diamond Mountain.
Carbon Ridge and Spring Hill group.

Paleozoic Section.—As already mentioned, the Eureka Mountains lie just eastward of the old shore line. In this and the following chapters the evidence is presented, derived from the history of the rocks themselves, to show the close proximity of a land area when the beds were laid down. The nature of these off-shore deposits near the western border of an old Paleozoic sea form one of the principal objects of this investigation. Much of the material, such as the coarser conglomerates, must necessarily have been off-shore deposits The sedimentary rocks which make up the mountains present a great development of limestones, quartzites, sandstones, and shales, comprising many thousands of feet of Cambrian, Silurian, Devonian, and Carboniferous beds. From the lowest exposed members of Cambrian strata to the top of the Coal-measures there are represented a series of sedimentary deposits 30,000 feet in thickness. Nowhere within the limits of the Eureka district can there be found any one exposure which shows the beds without a break in their continuity, the longest unbroken section representing about one-third of the entire sequence of strata, yet the region offers in so many instances such continuous exposures of beds and so many in which the series of strata overlap each other with such a constant repetition of beds, that the reconstruction of the entire section is easily made out when the individual parts are carefully compared and studied. The reason why there is no one unbroken section may be readily understood by a glance at the map which shows how the sedimentary strata have been broken up into separate mountain blocks, each made up of a portion of the entire thickness of beds.

In the four grand periods of Paleozoic time represented at Eureka, 14 epochs have been recognized: 5 in the Cambrian, 3 in the Silurian, 2 in the Devonian, and 4 in the Carboniferous.

With a single exception local geographical names have been employed to designate the different epochs into which the Cambrian, Silurian, and Devonian have been divided. Heretofore, throughout the Great Basin the division of the larger periods into epochs has not been deemed necessary, the individual horizons not having been studied sufficiently in detail to require it. The exception is made in favor of the Pogonip limestone, a name first applied by the Geological Exploration of the Fortieth Parallel to the belt of limestone which forms the base of the Silurian. In the Carboniferous period a large quartzite body at the base of the series has been designated the Diamond Peak quartzite, but for the remaining epochs the well known names Lower Coal-measures, Weber conglomerates, and Upper Coal-measures are retained, notwithstanding some serious objection to the use of the term Coal-measures in this region.

Each of the six blocks expose several thousand feet of strata, and while they frequently overlap each other no two of them represent precisely the same horizons, although the Diamond Range includes within its strata the beds which make up the Carbon Ridge and Spring Hill blocks. The six blocks essentially correspond to the following periods:

Prospect Ridge: Cambrian and Silurian.
Fish Creek Mountains: Silurian.
Silverado and County Peak: Silurian and Devonian.
Mahogany Hills: Devonian.
Diamond Mountain: Devonian and Carboniferous.
Carbon Ridge and Spring Hill: Carboniferous.

In the subjoined section, which may be best designated as the Eureka section, the relative thickness and general lithological characters are given for all the geological divisions which have been made of the sedimentary rocks. A plane of unconformity in the Silurian is indicated by double dividing lines between the Eureka quartzite and Lone Mountain limestone.

Eureka Section, Nevada, 30,000 feet.

CARBONIFEROUS, 9,300 feet.	Upper Coal-measures	500	Light colored blue and drab limestones.
	Weber conglomerate	2,000	Coarse and fine conglomerates, with angular fragments of chert; layers of reddish yellow sandstone.
	Lower Coal-measures	3,800	Heavy bedded dark blue and gray limestone, with intercalated bands of chert; argillaceous beds near the base.
	Diamond Peak quartzite	3,000	Massive gray and brown quartzite, with brown and green shales at the summit.
DEVONIAN, 8,000 feet.	White Pine shale	2,000	Black argillaceous shales, more or less arenaceous, with intercalations of red and reddish brown friable sandstone, changing rapidly with the locality; plant impressions.
	Nevada limestone	6,000	Lower horizons indistinctly bedded, saccharoidal texture, gray color, passing up into strata distinctly bedded, brown, reddish brown, and gray in color, frequently finely striped, producing a variegated appearance. The upper horizons are massive, well bedded, bluish black in color; highly fossiliferous.
SILURIAN, 5,000 feet.	Lone Mountain limestone	1,800	Black, gritty beds at the base, passing into a light gray siliceous rock, with all traces of bedding obliterated; Trenton fossils at the base; *Halysites* in the upper portion.
	Eureka quartzite	500	Compact, vitreous quartzite, white, blue, passing into reddish tints near the base; indistinct bedding.
	Pogonip limestone	2,700	Interstratified limestone, argillites, and arenaceous beds at the base, passing into purer, fine grained limestone of a bluish gray color, distinctly bedded; highly fossiliferous.
CAMBRIAN, 7,700 feet.	Hamburg shale	350	Yellow argillaceous shale, layers of chert nodules throughout the bed, but more abundant near the top.
	Hamburg limestone	1,200	Dark gray and granular limestone; surface weathering, rough and ragged; only slight traces of bedding.
	Secret Canyon Shale	1,600	Yellow and gray argillaceous shales, passing into shaly limestone; near the top, interstratified layers of shale and thinly bedded limestones.
	Prospect Mountain limestone	3,050	Gray, compact limestone; lighter in color than the Hamburg limestone, traversed with thin seams of calcite; bedding planes very imperfect.
	Prospect Mountain quartzite	1,500	Bedded brownish white quartzites, weathering dark brown; ferruginous near the base; intercalated thin layers of arenaceous shales; beds whiter near the summit.

NOTE.—Plane of unconformity indicated by double dividing line.

Longitudinal Faults.—The most profound faults, those which mark the greatest amount of displacement and have exerted the most influence in producing the present structural features of the region, cross the mountains at varying intervals with an approximately north and south trend from Fish Creek Basin to Diamond Valley. These faults constitute the principal factors in outlining the individual orographic blocks, and probably from the beginning of mountain building up to the present time, and certainly through the Tertiary period, have played a most important part in their development. The amount of displacement along those faults that extend the entire length of the mountains is very great, measuring at some points in their course as high as 13,000 feet.

The four principal lines of displacement are the Spring Valley and Sierra fault, on the west side of Prospect Ridge; the Hoosac fault, separating Prospect Ridge from Spring Hill and Carbon Ridge; the Pinto fault, lying between the Spring Hill and Carbon Ridge on the one side and the County Peak and Silverado Mountain block on the other, and the Rescue fault, on the east side of the latter block. These main faults will be described here. Numerous other longitudinal faults, while they express powerful orographic movements, are more restricted in their influence and confined within the limits of one or the other mountain blocks into which the country is broken up. They will be mentioned with more or less detail when describing the particular region in which they occur.

Spring Valley and Sierra Fault.—The Spring Valley fault adheres closely to the west base of Prospect Ridge and sharply defines the ridge both in physical and geological structure from the Mahogany Hills on the opposite side of the narrow valley which has given its name to the fault, and through which the line of the displacement runs Along the base of Prospect Ridge the oldest Cambrian strata yet recognized in the Great Basin come up against the fault and are separated by it from the Silurian and Devonian beds which form the mountains to the west. On the west side of the fault and opposite Prospect Peak, the culminating point on the ridge, the Eureka quartzite of Spanish Mountain is exposed against the fault line. The stratigraphical position of the Eureka quartzite along the Hoosac fault on the east base of Prospect Ridge, where it overlies the great development of

Cambrian strata and the Pogonip limestone of the Silurian, thoroughly well establishes the fact that there occurs a displacement of over 11,000 feet along the Spring Valley fault at the west base of Prospect Peak. At the southwest corner of Prospect Peak a fault runs up the steep slope of the mountain with a somewhat irregular course till reaching the summit, where it joins the Sierra fault on the south side of the peak. This cross fault going up the side of the mountain has been designated the Prospect Peak fault. By this fault the entire series of beds belonging to the Cambrian quartzite are abruptly cut off, and Silurian strata are found lying unconformably against it. The Sierra fault resumes the longitudinal trend and, with an occasional break in its course, continues southward until the Cambrian ridge which it limits on the west gradually sinks below the plain. Along the Sierra fault the Eureka quartzite for the greater part of the distance lies next the Prospect Mountain limestone, the Cambrian quartzite not being exposed south of Prospect Peak; otherwise the Sierra fault presents much in common with that of the Spring Valley, having the same general trend, and with the Cambrian on one side and the Silurian on the other. From many points of view these three faults, the Spring Valley, Prospect Peak, and Sierra, may be regarded as a single line of faulting making a sharp turn or fold in its course up the steep slope of Prospect Peak and on reaching the summit of the ridge, swinging back again to the normal north and south direction. The three faults taken together extend the entire length of the mountains, from Diamond to Fish Creek valleys, completely isolating the Cambrian strata from the Silurian and Devonian lying to the westward. As evidence of the continuity of the faults, it may be stated that along the course of the Sierra fault on the summit of the ridge, no displacement of strata has been recognized north of its junction with the Prospect Peak fault, the base of the Cambrian limestone resting conformably on the summit of the Cambrian quartzite.

Hoosac Fault.—A sharp contrast between the Hoosac fault lying on the east side of the Prospect Ridge and the Spring Valley fault on the west side, is shown by the large amount of lavas that have broken out along the former and that are wholly wanting along the latter. Indeed, the course of the Hoosac fault can be traced only approximately, owing to the vast accumulation of these lavas poured out along the line of displacement, in places concealing the underlying rocks for considerable distances on both sides. Within certain limits, however, there is no great difficulty in determining its main course, as on the one side only Silurian rocks occur, while on the other all the beds known to be in their true structural position belong to the Lower Coal-measures. At the southern end of the mountains, where the sedimentary beds emerge from beneath the Quaternary, the fault is completely obscured by rhyolite flows that flank the slopes of a long ridge of Eureka quartzite, the uppermost member of the Prospect Ridge series just to the westward. Opposite Pinto Peak, where the rhyolite flows are of exceptional width and of great thickness, no indications of its trend are visible, and not until east of Hoosac Mountain do the sedimentary rocks rise above the rhyolite. At Hoosac Mountain occurs the only case of Silurian beds found on the east side of the fault line, and this is more apparent than real, as it is rather an instance where a body of quartzite has been thrust eastward by powerful volcanic forces and lies superimposed either upon igneous rocks or a body of Carboniferous limestone. It is probably only a thin capping of quartzite, and evidently out of place, as just eastward of it the limestones may be seen in their true position.

Proceeding northward the Eureka quartzite, at the base of Hamburg Ridge, marks the fault on the west, and in direct contact with it lies the Lower Coal-measures of Spring Hill Ridge, a contact which is maintained nearly to New York Canyon, only here and there slightly obscured by Quaternary accumulations. At New York Canyon the fault bifurcates, one branch turning to the northeast and the other to the northwest, the easterly branch being the main one and retaining the name, Hoosac fault. The fault trending to the northeast still continues to mark the boundary between the Silurian and Carboniferous, following the course of New York Canyon, and from here northward the contact is nowhere obscured by outbursts of lava, the Lone Mountain Silurian of McCoy's Ridge being found on the northwest side of the displacement, with the Lower Coal-measures on the southeast. A short distance beyond the entrance to New York Canyon, near the Richmond smelting works, the fault ceases to be traceable toward the north. No precise measurement of the amount of displacement along the east base of Prospect Ridge can be given, but estimating it from the known thickness of the strata lying between the summit of the Eureka quartzite and the base of the Lower Coal-measures as given in the Eureka section, we have a vertical movement of 12,800 feet. Now, if we suppose, and it seems highly probable, that there are 300 or 400 feet of limestones beneath the beds exposed at the surface, and that the upper portion of the Eureka quartzite is also wanting, we have a displacement of over 13,000 feet. Probably the vertical movement at its maximum displacement amounted to more than 2½ miles, lying wholly within Paleozoic rocks.

Ruby Hill Fault.—The branch fault which leaves the main one just after it enters New York Canyon from the south trends northwesterly across the slope of Prospect Ridge, thence across Ruby Hill, probably connecting with the Spring Valley fault although it has never been traced beyond the Richmond and Albion mines. It has been designated the Ruby Hill fault. On the atlas sheet its course is indicated only a short distance beyond the Jackson fault, its true position on Ruby Hill not having been accurately located until after the printing of the map. Although the Ruby Hill fault possesses features of great economic importance bearing upon the ore deposits of the district, it is by no means so profound a displacement as the Hoosac and is measured by hundreds instead of thousands of feet. The dynamic movements which produced it have not influenced in any marked manner the structural features of the country, presenting, in this respect, the greatest possible contrast with the main Hoosac fault. There is some reason for the opinion that the Ruby Hill fault is of later date than the main fault, and belongs to the period of Tertiary eruptions. A more detailed description of this fault will be found in the chapter devoted to the discussions of the ore deposits.

Pinto Fault.—This fault is situated about 2 miles to the east and nearly parallel with the Hoosac fault, which it closely resembles in structural features. Like the Hoosac, its course can not be traced with precision, yet the geological characters are so distinctive that there exist scarcely any difficulties in the way of determining its main trend across the mountains as it sharply defines the boundary between the elevated County Peak and

Silverado block on the one side and the depressed Spring Hill and Carbon Ridge block on the other. On the west side, wherever the volcanic and detrital material fails to conceal the underlying rocks only Carboniferous strata are exposed, whereas, on the opposite side Silurian strata everywhere rise above the fault line in bold and abrupt ridges.

Starting from the southern end of the mountains the fault follows up Pinto Valley, with Carbon Ridge on the west and English Mountain on the east, the intermediate valley being filled with pumices and tuffs. Not until nearly opposite Dome Mountain do the sedimentary beds on both sides of the fault come in direct contact at the surface, but here we find the Lower Coal-measures limestone brought up unconformably against the Lone Mountain limestone. From here a deep, narrow limestone gorge extends northward, along which the limestones of the two different epochs stand out boldly on opposite walls, the direction of the gorge coinciding with the line of the fault. Where the drainage channel following the gorge turns abruptly toward the west the Eureka quartzite comes in beneath the Lone Mountain strata, but the fault, without deviating in the least from its course, continues northward with the Carboniferous limestone still on the west side. A short distance farther northward the sedimentary strata are buried beneath the lavas of Richmond Mountain. The vertical displacement along the Pinto is probably quite as great as that found along the Hoosac fault; the same geological horizons are here brought into juxtaposition, although higher beds form the contact along the Pinto fault, and at Carbon Ridge the Weber conglomerates come in as the uppermost beds. The enormous development of Devonian strata and the Diamond Peak quartzite, which, as shown by the section, have an estimated thickness of 11,000 feet, is wholly wanting.

Rescue Fault.—About 2¾ miles east of the Pinto fault, and on the east side of the Silverado and County Peak block, runs the equally persistent but less profound Rescue fault. It derives its name from Rescue Canyon, which, in turn, owes its origin primarily to the fault. The canyon, a longitudinal mountain valley nearly 2 miles in length, opening out into Fish Creek Basin, is now occupied for the entire distance by rhyolite extravasated along the course of the fault. At the head of the canyon the rhyolite gives out and the fault enters the Nevada limestone with a course a little east of north, and follows along under the abrupt east wall of Sugar Loaf. A short distance beyond Sugar Loaf the fault coincides with the contact of the Nevada limestone with the White Pine shale, maintaining this course until both the limestone and shale pass beneath the basalt tableland toward the north. That the fault continues beyond this point beneath the basalt is clearly established by geological structure, the Devonian strata of County Peak passing under the tableland on the west side and the Weber conglomerate and Upper Coal-measures dipping toward it and passing beneath it on the east. There can be no doubt that the Rescue fault sharply defines a great physical break separating the County Peak from the Diamond Peak block. After entering the region occupied by the basalt field, there is no means of determining the precise course of the fault, everything being obscured by recent lavas. Upon leaving the basalt area the fault probably follows along the east base of Richmond Mountain, but is hidden beneath the andesitic rocks that, flowing eastward, rested against the base of the gently inclined slopes of the Upper Coal-measure limestones of the Diamond Range. Beneath the lavas the trend of the fault, while in a great degree conjectural, can not vary far from the course of the contact between the Nevada limestone and the White Pine shale as exposed to the south and the line of the Carboniferous rocks to the north and east. In the region of the volcanic rocks the displacement along the fault can not be measured, although it must be very great, as is shown by the Devonian beds on the one side and the upper members of the great development of the Carboniferous sediments on the other. South of the basalt the fault runs wholly within the limits of the upper portion of the Nevada limestone, or else at the base of the White Pine shales. Nowhere along its entire course, from Packer Basin to Fish Creek Valley, does the downthrow apparently exceed 3,000 feet of vertical displacement.

OROGRAPHIC BLOCKS.

Prospect Ridge.—This ridge stands out as the most prominent orographic feature of the Eureka Mountains. It is situated in the very center of the mountains and presents a bold, serrated outline, extending with an approximately north and south trend from Diamond Valley to the Fish Creek Basin. From Diamond Valley the northern slopes rise gradually out of the plain to the summit of Ruby Hill, beyond which the mountains assume a more rugged aspect, continuing southward in an unbroken ridge until cut off sharply by eruptive masses or concealed beneath Quaternary accumulations of the valley.

As already described, this orographic block is sharply outlined along its entire eastern base by the Hoosac fault, evidence of which is shown in the geological character of the opposite walls and in the extravasated rocks that have broken out along the line of dislocation. The Spring Valley, Prospect Mountain, and Sierra faults as clearly define it on the west, except that along the entire length of these combined faults no lavas reach the surface. The Sierra fault marks a more decided geological than topographical break, since along the displacement an intricate and confused mass of mountains unites Prospect Ridge with the country to the west of it, the Silurian and Devonian rocks resting against the Prospect Mountain limestone high up on the summit without any intervening valley or depression. With these clearly defined boundaries the Prospect Ridge block measures 10 miles in length and across its broadest development, in the region of Prospect Peak, between 2 and 2¼ miles in width. Topographically this mountain block is quite simple—a longitudinal ridge rising abruptly on the west side with Prospect Peak, the culminating point, descending for 2,500 feet toward Spring Valley with an average slope of 30°, but on the east side falling away much more gradually and with far less regularity towards the Hoosac fault.

In structure Prospect Ridge is an anticlinal fold, and affords an admirable example of such structure, accompanied by profound north and south faults approximately parallel with the strike of the beds. The axis of the fold lies wholly on the western side of the ridge and is well shown on the slopes of Prospect Peak, the beds on both sides of the axial plane standing inclined at an angle of nearly 80°. While the crest of the ridge trends north and south, the axis of the fold, striking west of north, follows obliquely down the slope and is finally lost in the valley toward the west. The rocks which constitute this great body of folded strata between the two lines of faulting present a conformable series of sediments inclined throughout their entire thickness at angles seldom less than 75°.

From the axis of the anticline, near the summit, on the west side of Prospect Peak, to the Hoosac fault along the eastern base of the ridge, there is exposed a series of strata measuring nearly 10,000 feet in thickness, and wholly made up of Cambrian and Silurian rocks. The axis of this fold occurs in the Prospect Mountain quartzite, the underlying member of the Cambrian, and is in turn overlain successively by the Prospect Mountain limestone, Secret Canyon shale, Hamburg limestone, Hamburg shale, Pogonip limestone, and Eureka quartzite. Along the Hoosac fault the Eureka quartzite is well exposed at Caribou Hill, McCoy's Ridge, Hoosac Mountain, and the narrow ridge east of Round Top.

Prospect Ridge affords the grandest section of Cambrian rocks yet recognized in the Great Basin, and with the exception of one or two insignificant exposures of slight importance east of the Sierra fault, the rocks of this period are confined to this orographic block. Section CD–EF (atlas sheet XIII), constructed across the central portion of the Eureka Mountains, intersects Prospect Ridge about 3,000 feet to the north of the peak at a point well chosen to bring out the anticlinal structure of the uplifted block and its relations to the fault lines. There is represented on Pl. II, Fig. 4, a geological section drawn at right angles to the strike of the beds across the culminating point of Prospect Peak, from Spring Valley to the Hoosac fault. The Prospect Mountain limestone is here shown capping the peak and the entire east slope, and it is again exposed at the base of the ridge on the west side of the anticline, rising above the detrital material of Spring Valley. In Fig. 3 of the same plate will be found a section of the same strata across Ruby and Adams Hills. Here the beds are inclined at a much lower angle, otherwise the structural features and succession of strata are nearly identical, Ruby Hill corresponding to Prospect Peak and Adams Hill to the Hamburg Ridge, with the intermediate Secret Canyon shale occupying a depression between them.

Fish Creek Mountains.—To the southwest of the Sierra fault the character of the country changes, and a confused and intricate series of ridges come in, presenting a strong contrast to the adjacent region. In place of the single ridge structure, as seen toward the north, the configuration of the country shows a broad, rough mass of mountains, from 4 to 5 miles in width, of very diversified topographic forms and deeply scored by narrow gorges. In the region of Atrypa Peak, Gray's Peak, and Lookout Mountain a classification of the mountain masses becomes a matter of much difficulty, the orographic structure being complex, and the resultant of forces in some respects different from those which elevated Prospect Ridge or the Fish Creek Mountains. Southward from Castle Peak the latter mountains become a distinct range, and with a north and south trend stretch off southward several miles beyond the limits of this survey. They are situated in the extreme southwest corner of the Eureka District, and are sharply defined by the broad valley of Fish Creek on the one side and Antelope Valley on the other, which partially disconnects them from the Eureka Mountains. They measure about 5 miles in width and rise over 2,000 feet above the adjoining Quaternary plain. They present the impressive appearance of a solid mountain mass gently inclined to the west, but falling off somewhat abruptly on the east, accompanied by a steep escarpment just beneath and parallel with the summit of the ridge. The structure is that of an anticlinal fold whose axial plane coincides with the escarpment along which there has been a downthrow of 600 feet. The origin of the escarpment is due to the faulting. At the base of the cliff the faulted strata are uniformly inclined toward the valley at an angle of about 15°. Along the west side of the anticlinal axis the beds lie at much lower angles, exhibiting first a slight synclinal fold followed by an equally gentle anticlinal, beyond which for nearly 2 miles they fall away with a nearly uniform dip toward Antelope Valley.

The Fish Creek Mountains may be considered as essentially made up of Silurian rocks, in marked contrast with Prospect Ridge, which is, as has been already shown, formed of Cambrian strata with outlying slopes of Pogonip limestone and Eureka quartzite. Here are exposed the two lower members of the Silurian in a manner which can hardly be excelled for simplicity of structure elsewhere in the Great Basin. Nearly all the more elevated portions of the mountains consist of Upper Pogonip limestone, the axis of the fold occurring not far below the top of the horizon. The Eureka quartzite overlies the limestone on both sides of the mountains, but as the dip of the strata coincides closely with the inclination of the western slope, it comes to the surface only near the base of the ridge. As the strata dip away both to the north and south from the central body of Pogonip limestone, a belt of the quartzite may be observed encircling it on all sides. Nowhere do the Fish Creek Mountains expose a section of the Pogonip limestone for more than one-quarter of its thickness, as given in the general section, although numerous excellent partial sections are shown of the Upper Pogonip beds. Northward of Bellevue Peak, and in the region of Castle Mountain, the Lone Mountain, limestone overlying the Eureka quartzite comes to the surface, and again at the southern end of the range, but beyond the limits of the map.

From this description, and by the aid of the map (atlas Sheet XI), a clear idea may be obtained of the broader features of the Fish Creek Mountains, and in the chapters devoted to the Silurian rocks and the descriptive geology there will be found the evidences in detail for the conclusions presented here as to their age and structure.

Mahogany Hills.—The Mahogany Hills are situated on the west side of the Eureka Mountains. They occupy by far the largest area of any of the mountain blocks into which the country has been divided, and are as sharply defined as any of the others by natural physical outlines. Spring Valley and Canyon serve as an excellent boundary between them and Prospect Ridge, but everywhere else, except along the narrow belt which connects them with the Fish Creek Mountains, the broad Quaternary plain rests against the upturned edges of the outlying ridges. From Spring Valley the Mahogany Hills extend westward, a mountain mass over 8 miles in width; in a north and south direction they present an unbroken body of limestone, 12 miles in length. This broad mountain mass may be divided into two nearly equal parts, separated by the level plain of Dry Lake and the narrow gorge of Yahoo Canyon, the lake at one time draining northward through the canyon into Hayes Valley. The country to the east of the lake and canyon, while it has much in common with the western side, is, in structural features, closely related to the Piñon Range. This latter range, which is made up of a number of longitudinal ridges extending from the Humboldt

River to the Eureka Mountains, may be said to terminate at the deeply eroded pass known as The Gate, as it there loses its distinctive features. The monoclinal character of the uplifted ridges is, however, still maintained nearly to Spanish Mountain, or until cut off by the Spring Valley fault.

From Dry Lake westward the mountains rise abruptly, frequently in steep cliffs, presenting a somewhat monotonous aspect of dark bluish gray limestone covered with a scanty growth of mountain mahogany (*Cercocarpus lædifolius*), from which the region derives its name. A few culminating points attain elevations above the general level, but these gradually fall away to the westward in long uniform ridges, sharply defined by drainage channels that cut down hundreds of feet into the limestones with nearly vertical escarpments.

Mahogany Hills are made up for the most part of Nevada limestone, which everywhere forms all the more elevated portions. Silurian rocks occur in one or two localities, but principally at Spanish Mountain, where the Eureka quartzite is admirably shown, with all its peculiarities of structure, overlain by the Lone Mountain limestone, which in turn passes conformably into the Nevada limestone. For purposes of stratigraphical geology, the position of Spanish Mountain is most fortunate, as its relation to the overlying Devonian limestone is well brought out, while its relation to the underlying limestones and shales of the Lower Silurian and Cambrian is demonstrated beyond question in both the Fish Creek Mountains and Prospect Ridge. Spanish Mountain happens to be the only area of Eureka quartzite in the Mahogany Hills. On the southern slope of Comb's Peak the upturned beds afford an excellent exposure of the limestones overlying the Eureka quartzite, and give a section of Lone Mountain rocks lower than found elsewhere, including a series of beds whose geological position is determined by a characteristic Trenton fauna. The relationship of this fauna just above the Eureka quartzite to the fauna found elsewhere immediately below the quartzite offers an important link in the paleontological history of the Eureka District. One of the best sections across the Nevada limestone may be found on the ridge north of Modoc Peak, where the beds throughout a great vertical thickness present a nearly uniform strike and dip, with but little disturbance or dislocation. The Modoc section measures about 5,400 feet in thickness. It is given in detail in the chapter devoted to a discussion of the Devonian rocks, on page 66.

Silverado and County Peak Group.—This mountain block stands almost completely isolated from the others, being cut off by profound faults on all sides, along which igneous rocks have reached the surface in enormous masses. In this way it is clearly outlined from the Diamond Range on the northeast by the broad basalt table of Basalt Peak and the Strahlenberg, on the north by Richmond Mountain, and on the west in great part from Carbon Ridge and Spring Hill group by the extravasated rocks along the Pinto fault. A glance at the map will show how closely these lavas surround the mountains and there is good reason to believe that if the Quaternary deposits along the foothills were removed this encircling belt of lavas would be still more noticeable. Here and there a few isolated patches of lava rise above the level of the plain in Fish Creek and Newark valleys, but in most instances the exposures occupy too limited areas to permit of their being located upon the map. The outlines of the knobs and knolls of rock partially concealed by recent deposits indicate their probably volcanic origin.

The mountains are roughly broken up into three groups—northern, southern and southeastern. Wood Valley, a relatively broad drainage channel open to the west, and Charcoal Canyon, a narrow but deep ravine south of Sentinel Peak on the east, separate the two former, while the latter is somewhat isolated by the deep valley of Rescue Canyon and an arm of Newark Valley. For convenience the northern region may be designated as the County Peak Mountains, the southern as the Silverado group, and the region to the southeast as the Alhambra Hills. Taken together they stretch from Fish Creek Valley to Richmond Mountain and in an east and west direction from the Pinto fault to the Quaternary plain.

Between the two great lines of displacement, the Pinto and Rescue faults, the broad mass of limestone presents a gentle synclinal structure, the beds dipping toward the center from both fault lines and away from the lines of igneous outbursts. The mountains are almost wholly made up of limestones belonging to the Silurian and Devonian periods, all the more elevated portions being formed of characteristic strata of the middle and upper portions of the Nevada limestone. At the extreme northeast corner the Eureka quartzites occupy a small area, but are of no special importance themselves except in determining the basal rocks of this elevated mass and the position of the overlying strata. Numerous narrow gorges with mural-like faces cut deeply into the limestones, affording excellent comparative sections across the strata, datum points being readily established by the brown, red and gray beds of the middle Devonian. Represented in this uplifted mass occur between 6,000 and 8,000 feet of limestones. That the upper beds of the Nevada epoch are represented here is shown just to the east of Sugar Loaf and Island Mountain where the White Pine shales lie conformably upon the uppermost beds of limestone.

Diamond Mountains.—This range is one of the best defined mountain uplifts on the Nevada plateau, extending 40 miles along the east side of Diamond Valley. Only the southern end of it, however, in the northeast corner of the map, comes within the limits of this survey, as the range properly terminates with Newark Mountain. Its immediate proximity to the County Peak limestones, from which it is separated only by an overflow of igneous rocks, relates it in the closest possible manner with the Eureka Mountains. Diamond Peak (10,637 feet), the highest and broadest in the range, lies within the limit of this survey, and the geological structure and continuity of beds exposed upon the flanks of both Diamond Peak and Newark Mountain, add greatly to our knowledge of the sequence of Paleozoic sediments. For the greater part of its length Carboniferous rocks flank both sides of the Diamond Range, and, as is so often the case throughout Nevada, no beds immediately underlying them had previously been recognized toward the north. Here, however, Newark Mountain consists exclusively of Devonian rocks passing beneath the east base of Diamond Peak, where they are conformably overlain by an immense thickness of Carboniferous beds. Newark Mountain rises abruptly out of the plain and offers a typical example, so common in the Great Basin, of an anticlinal ridge with one side of the fold dropped down along the line of the axial plane. In this instance the downthrow lies on the east side and the mountain presents along the summit a bold escarpment 1,000 feet in height, facing Newark Valley. At the base of the escarpment easterly dipping beds come in, and dark blue massive limestones of the Upper Devonian form the remainder of the steep slope for about 1,000 feet and then stretch far out into the valley in a line of low hills and isolated buttes, still dipping toward the east. The entire western side of the mountain, including the summit of the ridge, dips uniformly toward the west, and is in turn overlain by the White Pine shales through which Hayes Canyon has been eroded. On the north side of Newark Mountain these flexible shales curve around to the northeast and form the east base of Diamond Peak, only the uppermost beds of the Nevada limestone here appearing above the level of the valley, the remaining portion of the Devonian beds upon both sides of the fold having dropped completely out of sight.

Diamond Peak rises above Newark Valley over 4,000 feet, with an exceptionally steep slope, the White Pine shales presenting smooth rounded ridges along the base of the mountain. The shales are overlain by a great thickness of rough and rugged Diamond Peak quartzites, followed by the Lower Coal-measure limestones which for a long distance form the summit of the ridge. In its structure the Diamond Range is in strong contrast with the anticlinal structure of Newark Mountain, presenting a synclinal fold whose axis lies in the Lower Coal-measures. The identical series of beds found dipping into the peak on the east side come in again on the west side, but with a reverse dip, except that the White Pine shales are not brought to the surface, owing to a longitudinal fault which extends along the west side of Diamond Peak, completely cutting them off and bringing up still higher Carboniferous formations than those found near the summit. From the axis of the anticline on the east slope of Newark Mountain diagonally across Diamond Peak there is exposed an admirable section, including Nevada limestones, White Pine shales, Diamond Peak quartzites, and Lower Coal-measure limestones. The geological importance of this section lies in the fact that it offers, across the middle of the Paleozoic rocks, a conformable and continuous series of beds rarely found elsewhere, uniting the upper Paleozoic with the great development of Silurian and Cambrian rocks beneath. From Bold Bluff, at the southern end of Diamond Peak, the Newark fault brings the Lower Coal-measures against the White Pine shales, the entire development of Diamond Peak quartzite having been displaced along the west side of Newark Mountain. North of Newark Mountain, however, the limestones occupy their true geological position, overlying the quartzite and dipping westerly.

Alpha Ridge for its entire length is made up of Lower Coal-measure limestones uniformly inclined toward the west and in turn overlain by the Weber conglomerates and Upper Coal-measures. In the Weber conglomerates there is a synclinal and anticlinal fold, the latter being well shown in long narrow ridges stretching in north and south lines parallel with the bedding. Of the Upper Coal-measures there occurs only a limited exposure above the conglomerates, but they are admirably displayed with their stratigraphical position well brought out and their geological age determined from ample paleontological evidence.

In the area north of Newark Canyon, stretching northward as far as the limit of the map and west of the Alpha fault, a north and south fault on the west side of Alpha Peak ridge, occurs an inclined table wholly made up of Upper Coal-measure limestones. Its identity upon both lithological and paleontological grounds, with the body of Carboniferous limestones overlying the Weber conglomerates south of Newark Canyon seems conclusive, and the finding of Carboniferous species unlike those known to occur in the Lower Coal-measures at Eureka and characteristic of the Upper Coal-measures elsewhere establishes the geological position of these beds.

Carbon Ridge and Spring Hill Group.—This block occupies a far less conspicuous position than any of the others, and seen from any commanding point of view it would not be in the least likely to attract attention as a prominent physical feature of the country. Unlike the adjoining uplifted blocks which rise boldly out of the plain, this one has rather the appearance of a depressed region without any persistent or distinctive characteristics. Nevertheless, it is sharply defined, geologically, by parallel lines of displacement, the Hoosac and Pinto faults. On the one side rises Prospect Ridge and on the other rises the broad mass of County Peak and Silverado Mountains. This relatively depressed block measures 6½ miles in length, but between the faults has an average width of only 1¾ miles. Estimating from the thicknesses of the different epochs given in the Eureka section both faults show profound vertical displacements of 12,000 to 15,000 feet.

Embraced within these lines of faulting only Carboniferous beds are exposed, whereas the inclosing outer walls on both sides consist of Silurian rocks traceable the entire length of the mountains except where concealed by volcanic overflows. Fissures along these fault lines have served as conduits for extravasated lavas, through which have poured out, either upon one side or the other, vast accumulations of volcanic material, for nearly the entire length of the mountains. So extensive have been these flows over the Carboniferous rocks that not only have the fault planes become obscured, but large areas of the sedimentary beds lie concealed beneath the lavas, while in the region of the Hoosac Mountain they have so spread out over the country as to completely bury all the underlying rocks between the two faults. Naturally such an amount of volcanic energy displayed all along the line has broken and dislocated the strata, caused minor faultings and displacements, and over much of the area rendered it difficult, if not impossible, to work out the structural relations of the exposed beds. Many fractures and breaks in the inclosed rocks, although not of any great magnitude, are frequently sufficient to render any precise measurement of the beds impossible, the amount of faulting being undeterminable. On the other hand great blocks of strata have been tilted up at high angles with only slight disturbances, affording fairly good cross-sections.

The volcanic rocks separate the sedimentary beds, which otherwise would form a continuous body, into two or more distinct areas, the northern known as the Spring Hill group and the southern as the Carbon Ridge, while between them lies a much smaller area of limestones everywhere surrounded by eruptive rocks. The middle area serves in a measure to connect the other two, the same beds found here occurring both north and south. Across the southern end of Spring Hill, where the strata are less disturbed than elsewhere, the limestones present a synclinal fold whose axis lies on the west side of the ridge east of Spring Hill. Adjoining the Hoosac fault lies a low, narrow ridge separated from the main body of limestone by a north and south fault, beyond which the limestones on Spring Hill dip easterly at an angle of 30°, the beds on the opposite side of the fold attaining angles as high as 60° westerly. Measured on the line of the main section there are about 3,400 feet of limestones included between the Hoosac and Pinto faults. This entire series of beds belongs to the Lower Coal-measures, evidence of their age being found in the characteristic fossils obtained at both the top and the bottom of the limestones. Carbon Ridge possesses a simple structure, a single block inclined uniformly to the east, the beds varying slightly from 60°. Here, however, the position of the uppermost beds of limestone is determined by the overlying Weber conglomerates. Limestones form the west base and crest of the ridge, the conglomerates coming in all along the east slope and stretching out toward the Pinto fault until buried beneath the acidic pumices and tuffs. The limestones afford about the same thickness of beds as developed on Spring Hill, and the overlying Weber conglomerates measure 1,900 feet, assuming a uniform dip and the absence of all faulting. This series of beds of Lower Coal-measure limestones and Weber conglomerates is similar to the section exposed on Alpha Ridge and Weber Peak in the Diamond Mountains, the thickness being about the same. It is the sequence of strata most commonly met with in the Great Basin ranges wherever we find a broad limestone body overlain by one of sandstone.

TERTIARY ROCKS.

Tertiary Lavas.—Subsequent to the movements that folded and faulted by powerful dynamic forces this great body of Paleozoic strata came the pouring out of volcanic lavas, the only other rocks that play an important part in the geological history of the Eureka Mountains. These lavas were forced to the surface not only after the crumpling of the beds and blocking out of the mountains, but after very considerable erosion had carved the deepest canyons and brought about the configuration of the country much as it is seen to-day. Evidence of this erosion before the pouring out of the lavas is shown by the position of many extensive bodies of lava in the bottoms of the largest canyons, and by the blocking up of ancient drainage channels through the welling out of erupted masses, necessitating new outlets. It is evident that a very long period of time must have elapsed subsequent to the building up of the Paleozoic masses before the breaking out of the lavas. Although no direct evidence of the age of these lavas can be found in the Eureka District, they are regarded as belonging to the Tertiary period. In many ways they bear the closest resemblance in their mode of occurrence, to similar lavas elsewhere in the Great Basin, where evidence of their age has been determined by their relation to sedimentary strata carrying a Miocene or Pliocene fauna or flora. In mineral and chemical composition the lavas show great variations, hornblende-andesite, dacite, rhyolite, pyroxene-andesite, and basalt being well represented, with a wide range in structural and physical features. A description of these different lavas and their relations to each other, as well as their geological relations to the orographic blocks, will be found in the chapter devoted to a discussion of the Tertiary rocks.

QUATERNARY DEPOSITS.

Quaternary Valleys.—The Eureka Mountains rise out of a broad plain everywhere covered by Quaternary deposits that stretch away in all directions far beyond the limits of the present survey. The atlas sheets accompanying this work fail to indicate the relative area occupied by the mountains to that of the desert plains, but an extension of the map only a few miles more on all sides would at least have shown how completely the mountains were surrounded by a broad expanse of the so-called sage-brush deserts. With a single exception these broad plains open one into the other, the only barrier being the Diamond Mountains, which separate Diamond Valley from Newark Valley.

Newark Valley and Fish Creek Basin are simply extensions of the same great plain, the former situated on the east and the latter on the south of the Eureka Mountains. The Fish Creek Basin connects, by means of a narrow pass south of the Fish Creek Mountains, with Antelope Valley, a few miles beyond the limits of the map. Antelope Valley may be regarded as a southern extension of the broad, desert-like expanse of Hayes Valley, which stretches far toward the north on the west side of the Piñon Range. Hayes Valley connects with Diamond Valley by the narrow gorge known as The Gate, which is simply a low pass cut down to the level of the plain through which the former valley at one time drained into the latter.

Little time has been devoted to the investigation of the Quaternary geology in the immediate region of Eureka, but so far as the deposits have been studied they resemble closely those found in the neighboring valleys, and do not offer much of special or local interest.

During the Quaternary period vast accumulations of detrital material were brought down from the mountains and transported far out upon the neighboring plain or laid down upon the flanks of the outlying foothills. These deposits have been classed under two distinct epochs—an upper and a lower Quaternary.

Lower Quaternary.—The earlier deposits, or the lower Quaternary, are for the most part lacustrine, made up of finely comminuted stratified sands and clays carrying varying amounts of calcareous material. All the beds have a prevailing light yellowish color. They form the so-called alkali flats of Nevada, and when dry resemble a hard tile pavement, but when moist have all the disagreeable qualities of a plastic clay, well nigh impassable. Nowhere within the neighborhood of Eureka have they been cut by water channels for more than a few feet, and at the time of our investigation no deep borings for water had been made. In consequence no reliable data exist for a correct estimate of their thickness, which in places may reach several hundred feet. No recent shells have as yet been found in the few exposures observed along the stream beds. On the map the line of demarcation between the upper and lower divisions of the Quaternary has been drawn somewhat arbitrarily, it being by no means easy to separate, sharply, the finer material of the upper series from the lacustrine deposits underlying them.

Upper Quaternary.—The upper or mountain Quaternary is made up of angular material varying in size from large bowlders to fine sand and gravel. It is in all cases traceable to the neighboring mountains, the nature of the coarser fragments depending upon the rock exposure above it. The material is subaerial in origin. It everywhere fringes the flanks of the mountains, encroaching upon the area of the underlying lacustrine beds for shorter or longer distances, according to the configuration of the hill-slopes or the transporting power of floods and freshets. The finer material is, naturally, transported the greater distance, consequently it gradually becomes mingled with and forms a superficial layer over the lower Quaternary deposits. South of Prospect Peak and opposite the entrance to Secret Canyon, these upper Quaternary accumulations extend up the flanks of the mountains for 1,500 feet above the lowest part of Fish Creek Valley, everywhere concealing the nature of the underlying rocks.

Most of the intervening meridional valleys lying between the parallel ranges of Nevada consist of narrow, trough-like depressions, in comparison with the level plains bordering the Eureka Mountains. In western Utah and eastern Nevada these valleys exhibit great similarity as regards their physical and geological history. They have been described at great length by Mr. Clarence King[1] and Mr. G. K. Gilbert,[2] both of whom have devoted much time to the study of the Quaternary accumulations and the climatic conditions under which the material was laid down. Many local details of these valleys may also be found in the volume devoted to the descriptive geology of the Fortieth Parallel Exploration,[3] and the reader who desires to pursue the subject further is referred to the works quoted.

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[1] U. S. Geol. Explor. of the Fortieth Parallel, vol. I. Systematic Geology.

[2] U. S. Geol. Surv., Monograph I. Lake Bonneville.

[3] U. S. Geol. Explor. of the Fortieth Parallel, vol. II. Descriptive Geology.

CHAPTER III.

CAMBRIAN AND SILURIAN ROCKS.

CAMBRIAN ROCKS.

Rocks of the Cambrian period, with the exception of two small exposures, are confined to Prospect Ridge, forming all the more elevated portions and the steep slopes of both sides. Indeed, the ridge is almost wholly made up of Cambrian sedimentary beds. Silurian rocks perfectly conformable with the upper beds of the Cambrian come in only along the outlying spurs and foothills to the east and north. All along the east slope of the ridge these beds exhibit a nearly uniform thickness, but attain their greatest development in the region of Prospect Peak, where the lowest members of the group are best exposed. Here the Cambrian rocks measure about 7,700 feet from base to summit. They have been divided into five epochs, designated by local names, as follows: Prospect Mountain quartzite, Prospect Mountain limestone, Secret Canyon shale, Hamburg limestone, and Hamburg shale. The varied physical differences in the composition of the sediments cause them to fall readily into these five epochs, each characterized by its own distinctive geological and topographical features. The fauna also agrees with geological divisions and adds its own evidence to strengthen them. So far as known, nowhere else in the state of Nevada do the Cambrian rocks afford as fine geological sections as at Eureka; nor have they elsewhere been subjected to as careful a survey. The great thickness of the group, the simplicity of structure in the region of Prospect Peak, the slight metamorphism of the strata, and the uniformity of dip over wide areas and across many thousand feet render a study of the sediments a comparatively simple matter and far easier than most Cambrian areas in other regions of the world.

Prospect Mountain Quartzite.—This group lies at the base of the Cambrian series at Eureka and is consequently the oldest sedimentary rock exposed. It takes its name from the peak, the highest point along the ridge, where it reaches its broadest development and forms the greater part of its western slope. With one or two breaks in the continuity, the quartzite may be traced along the base of the ridge northward to Ruby Hill, where, as the footwall of the Richmond and Eureka Consolidated Mines, it becomes of considerable economic interest. There can be no question that the quartzite of Prospect Peak and that of Ruby Hill are identical. From Ruby Hill the quartzite curves around the end of the mountain, following the east side of the ridge, and stretches southward for more than a mile until abruptly lost by a fault. The only occurrence in the district of this quartzite is on Prospect Ridge. On Prospect Peak the strata have a thickness of 1,500 feet and occur distinctly bedded, but in some localities all lines of stratification appear to be wanting. At the base of the series the beds are largely composed of conglomerates and brecciated masses firmly cemented together with ferruginous material, with the weathered surfaces deeply stained by iron. In the conglomerates quartz pebbles may occasionally be seen, showing compression and flattening on their broader sides, arranged in beds parallel to the planes of stratification. The upper beds are usually finer grained, carrying less iron oxide. In the Charter Tunnel, the only locality where they have been exposed by mining exploration, they show highly metamorphosed beds derived from impure siliceous material.

Interstratified throughout the quartzite are occasional bands of fine grained arenaceous and micaceous shales only a few feet in thickness. No organic remains have been found in this group, although diligent search was made in the interstratified shales, as, if they occur, they would be of the highest paleontological interest, extending the Cambrian fauna lower than has yet been known in the Great Basin. The Prospect Mountain quartzite differs from the Eureka quartzite, the next overlying siliceous group, in being more ferruginous and in general less uniform in texture, carrying throughout more or less clayey material, while the latter quartzite is a nearly pure, highly altered sandstone.

Prospect Mountain Limestone.—Directly over the Prospect Mountain quartzite occurs the Prospect Mountain limestone, which forms the greater part of the ridge and both slopes of the mountain all the way from Ruby Hill southward to the entrance of Secret Canyon. Beyond the limits of the mountain these beds are unknown in the district. It is difficult to define sharply the characteristic features of this group, changes are so frequent in the deposition of the sediments, not only in the vertical, but lateral extension. Secondary alterations caused by the intrusion of eruptive rocks and variations in color near the ore bodies tend to conceal the original nature of the rock. Breccias firmly held together by calcite are of common occurrence, while throughout the group there is abundant evidence that the beds have been crushed and broken and subjected to an enormous pressure. In general, however, the group possesses a light bluish gray tint when observed over large areas, although nearly all colors from white to black are found in the limestone, which at the same time is characterized throughout the entire thickness of beds by seams of calcite varying from one-half to 6 inches in width, and frequently forming a network of white bands.

In texture the limestone is crystalline and granular and over wide areas is so highly altered as to obliterate all traces of organic life; and, while in places planes of bedding may be distinctly seen all the way from Ruby Hill southward, they are wholly wanting over the greater part of the ridge. Stratification is well shown on the seventh level of the Richmond Mine and in the Eureka and Prospect Mountain tunnels, where the beds are usually bluish gray in color.

Coarse and fine white marbles, occasionally highly crystalline, are found on the north end of the mountain, and white and light gray marbles more than 600 feet in width are cut by the Prospect Mountain tunnel, good varieties being observed at 750 feet and again at 1,700 feet from the entrance of the tunnel. Analyses show them to be nearly pure carbonate of lime. Characteristic black limestone is found near the Geddes and Bertrand Mine, in Secret Canyon.

Numerous analyses of the rock from Ruby Hill, Prospect Mountain Tunnel, and localities on both sides of the ridge prove that the beds throughout the formation are a magnesian limestone. Nearly pure dolomites in thin layers have been recognized in several localities, but the percentage of carbonate of magnesia in most instances is too low to allow the beds, for any considerable thickness, to be classed as dolomite, neither is there any evidence that dolomitic rock is characteristic of any particular portion of this great thickness of beds. Both dolomite and pure limestone have been shown to occur near the large ore bodies, analyses demonstrating, however, that there exists no possible relation between the chemical composition of the limestone and the occurrence of ore. Analyses of limestone from the neighborhood of several large ore bodies situated in widely separated localities along the ridge and from different geological horizons throughout the epoch give the following results:

	Mine.	Insoluble residue.	Carbonate of magnesia.
1	Hodgson	0·36	14·00
2	Geddes & Bertrand	13·83	1·09
3	Dugout	5·79	1·84
4	Jackson	0·20	26·32

An analysis of the stratified limestone from the seventh level of the Richmond mine may be taken as a fair sample of the limestone body. It yielded as follows:

Carbonate of lime	88·34
Carbonate of magnesia	4·98
Iron	1·59
Silica	4·83
Total	99·74

Mr. Thomas Price, of San Francisco, made a careful chemical study of the limestones of Ruby Hill, collecting his samples for examination from the most important points on the surface and from different levels in the mines. Among the localities from which the rocks were selected, were the contact beds between the limestone and the overlying Secret Canyon shale, stratified beds on the seventh and eighth levels of the Richmond mine, the underlying rocks of Potts Chamber, the mouth of the Bell Shaft, and near the ore body of the Tiptop Incline. In sixteen analyses the amount of carbonate of magnesia varies from 1·06 to 44·35 per cent; three of them yielded less than 2 per cent. In nine out of the sixteen the amount of the silica in the limestone was less than 2 per cent.

Many of the beds, more especially the darker limestones, give evidence of the presence of organic matter, even where no signs of fossils are seen. Proof of this is found in the presence of phosphoric acid in the rock. Two specimens yielded 0·13 per cent, evidently derived from the fossil remains now almost wholly obliterated.

Sandstone layers are rarely seen in this group. Interstratified in the limestone are irregular beds of shale, lenticular or wedge-shaped bodies varying greatly in width. Indeed, throughout the entire thickness of this group they are a characteristic feature of the beds, which pass by insensible gradations from pure limestone to hard argillaceous shales. Occasionally they may be traced interstratified in parallel bands for long distances, and again the shale will develop considerable thickness, then rapidly thin out in all directions. For the most part they can be followed for no great distance. Two of these shale beds are quite distinctly marked on the top of the ridge to the northward of Prospect Peak, but all traces are lost on the surface to the south of that point. One of these shale beds on the east slope, however, attains so great a thickness that it has been designated Mountain shale, to distinguish it from the Secret Canyon horizon. Unlike the larger body of overlying shale they are of slight geological significance, the limestone both above and below presenting nearly identical physical features, and so far as known carrying the same organic forms. The Mountain shale comes to the surface on the ridge near the Industry mine and on the steep slope of the ridge above the Eureka Tunnel, across its widest development reaching over 300 feet in thickness. It differs from the Secret Canyon shale in carrying alternate layers of argillaceous and calcareous shales, the latter frequently passing into stratified shaly limestone. This body of intercalated shale presents some features of economic interest bearing upon the ore deposits, and may possibly be the same bed found in all the deep mines on Ruby Hill. The thickness of the Prospect Mountain limestone across its broadest expansion may be taken at 3,050 feet. On Ruby Hill, owing to faulting, it never attains its full development.

Secret Canyon Shale.—The Prospect Mountain limestone passes by gradual transition from shaly limestone into brown and yellow argillaceous shales, which, with the exception of one or two thin calcareous layers, present a very uniform character for the entire distance from the extreme southern end of Secret Canyon, where they first crop out, northward until cut off by a fault a short distance northwest of the Eureka Tunnel. Toward the upper portion of the series the shale becomes gradually interbedded with thin layers of limestone. The designation of the group is taken from the name of the canyon where it appears most characteristically shown. These beds are recognized only on Prospect Mountain ridge and north of Ruby Hill. The topographical features of Prospect Mountain are largely modified by this shale body, which, eroding more readily than either the overlying or underlying limestone, has been largely instrumental in determining the drainage channels of the ridge. There are few finer examples of the wearing away of a soft, easily eroded body lying between two harder rock masses than can be seen in Secret Canyon, where the Prospect Mountain limestone rises like a wall on one side and the Hamburg limestone nearly as abruptly on the other, while the canyon for over 3 miles is carved out of the shale in a deep, trough-like valley. In their broadest development the shale measures 1,600 feet, although in places where they are encroached upon by the Hamburg limestone they occur somewhat thinner. As yet no organic forms have been found through the entire group, though diligent search was made for them in the more promising calcareous layers.

Hamburg Limestone.—Transition beds of shaly limestone, varying in thickness from 25 to 200 feet, pass gradually into the overlying Hamburg limestone, which forms a prominent, bold ridge between the easily eroded overlying and underlying shales, and, as it is cut through at regular intervals by east and west drainage channels, presents one of the most striking topographical features of the region, and a geological horizon most easily traced in the field. On the surface this limestone is dark gray, frequently grayish black, and throughout the greater part of the thickness presents a granular texture. Layers of fine sandstone and hard cherty bands occur at irregular intervals. In chemical composition it offers no essential difference from the Prospect Mountain limestone, presenting quite as wide a range, both in silica and magnesia. Two complete analyses were made of this limestone, one from the summit and the other from the base of the epoch, each representing a well defined and persistent bed, as follows:

	Base of Hamburg limestone.	Summit of Hamburg limestone.
Silica	24·00	3·94
Alumina	·12	·64
Ferric oxide	·12	·43
Ferrous oxide	....	·20
Manganese	....	·61
Lime	41·97	51·96
Magnesia	·80	·52
Water	·16	·37
Carbonic acid	32·62	40·71
Phosphoric acid	·07	·50
Chlorine	·01	·01
Organic matter	trace	·03
Alkalies	trace	trace
Total	99·87	99·92

An examination made of a dark compact limestone from the base of the Hamburg, collected on the north side of the ravine opposite the dump of the Richmond shaft, gave

Silica	·84
Carbonate of magnesia	1·18

A gray dolomite from the 350-foot crosscut in the Dunderburg mine yielded

Silica	·07
Carbonate of magnesia	40·04

In general, this limestone is sharply contrasted in its lithological habit with the Prospect Mountain body, as it is darker in color, carries siliceous material in place of the clayey beds of the latter, and possesses a characteristic rough and ragged surface produced by weathering. The thickness of this limestone may be taken at 1,200 feet, and except in the shaly limestones at the top and bottom of the series, no planes of bedding are traceable for any great distance. At Adams Hill, however, where the beds lie inclined at a much lower angle and have undergone much less movement and compression, stratification may be frequently observed.

Hamburg Shale.—This shale body in general resembles the one underlying the Hamburg limestone, except that it is by no means as uniform in composition, showing very rapid changes in conditions of deposition, becoming more or less arenaceous or calcareous throughout its entire thickness as well as in its lateral extension. It is characterized by cherty nodules, and near the top by more or less persistent layers of chert and sand, followed by calcareous shales which pass into the overlying Pogonip limestone of the Silurian. Across its broadest development it measures 350 feet, yet it rarely maintains a uniform thickness for any long distance. The best exposures are seen opposite the Hamburg and Dunderburg mines, and again in the ravine north of Adams Hill, where it attains as great a thickness as anywhere on the eastern slope, and is in every way as well shown. This group is not as thick as the Mountain shale in its broadest development in the Prospect Mountain limestone, yet its persistency, stratigraphical position, and its relations to the fauna of the Cambrian render it of far greater importance.

Cambrian Fauna.—As has already been mentioned, no evidences of organic remains have been observed in the Prospect Mountain quartzite, and the conditions under which the beds were deposited could hardly be considered favorable to life. In the overlying Prospect Mountain limestone obscure fragments of fossils may be detected at various places throughout the epoch, but localities showing any grouping of species or forms, sufficiently well preserved for identification, are limited to three horizons. The lower of these horizons occurs at the base of the limestone, in a narrow belt resting on the quartzite; the second is found in strata of calcareous shales several hundred feet higher up, while the third horizon, which may be two or three hundred feet in thickness, lies at the top of the limestones just below the Secret Canyon shale.

Directly overlying the quartzite, in strata which may be regarded as transition beds between it and the Prospect Mountain limestone, occur the lowest organic forms obtained in the district, and the equivalent of the lowest Cambrian fossiliferous strata in the Great Basin. Along the east side of

Prospect Peak, near the summit of the ridge, there may be traced for over a mile a red arenaceous and calcareous shale, which is lost to the southward, but which, followed to the northward, may be seen to pass gradually into a dark gray shaly limestone. This arenaceous shale may be taken at 100 feet in thickness, and, from the organic remains which it carries and from its paleontological and geological importance, has been designated the *Olenellus* shale. From this horizon the following species have been obtained:

Kutorgina prospectensis.
Ptychoparia sp.?
Olenellus gilberti.
Olenellus iddingsi.

About one-half mile northward of this locality, and in a bed of limestone 100 feet in thickness, underlying the fossiliferous arenaceous shale, and, in the same manner, resting directly upon the quartzites, species indicating an identical geological horizon were found, as follows:

Olenellus gilberti.
Olenellus iddingsi.
Anomocare parvum.
Olenoides quadriceps.
Scenella conula.

These two groupings represent all that have as yet been identified from this lower horizon.

The *Olenellus* shales pass upward into a great thickness of bluish gray limestone, with an occasional thin band of interstratified shale. The beds, however, yield no well defined organic remains for nearly 500 feet, but at that horizon they furnish forms which might belong both to the *Olenellus* shales below and the next fossiliferous strata above. Although localities yielding well defined fossils from this second horizon are seldom met with, indistinct traces of life are seen in the limestone underneath the Mountain shale. The best known locality is found at the head of New York Canyon on the long sloping ridge south of the Fourth of July mine. Here were obtained the following:

Olenoides quadriceps.
Scenella conula.
Agnostus interstrictus.
Ptychoparia prospectensis.

The species of *Ptychoparia prospectensis* has not as yet been found at a higher horizon. Above this horizon the limestone is much metamorphosed and altered to marble, and is so broken up that well defined beds favorable to the preservation of fossils are rarely met with, even the calcareous shale presenting but slight indications of them. Not till within 300 or 400 feet of the summit of Prospect Mountain limestone and 2,000 feet higher up in the strata was there any grouping of fossils observed. From this horizon, and extending up to the base of the Secret Canyon shale, numerous localities occur all along the east slope of Prospect Mountain, which present a fauna with much the same grouping at each, and showing a mingling of both Georgia and Potsdam faunas.

These organic forms occur both in compact limestone and shaly calcareous beds, and constitute the third and upper fossiliferous strata of Prospect Mountain limestone. The following list contains most of the species collected at this horizon in New York Canyon, many of them being found at several localities:

Obolella (like O. pretiosa).
Lingula manticula.
Agnostus communis.
Agnostus bidens.
Agnostus neon.
Agnostus richmondensis.
Protypus senectus.
Dicellocephalus nasutus.
Ptychoparia oweni.
Ptychoparia occidentalis.
Ptychoparia dissimilis.

From the corresponding beds in Secret Canyon near Geddes and Bertrand mine, and in a compact black limestone a short distance above the base of the Secret Canyon shale belt, were collected the following species:

Kutorgina whitfieldi.
Orthis eurekensis.
Stenotheca elongata.
Agnostus communis.
Agnostus bidens.
Agnostus neon.
Protypus expansus.
Ptychoparia oweni.
Ptychoparia haguei.
Olenoides spinosa.

In a well defined stratified black limestone exposed for several hundred yards on the seventh level of the Richmond mine were obtained the following forms:

Obolella ———.
Lingula manticula.
Agnostus communis.
Agnostus bidens.
Agnostus neon.
Agnostus richmondensis.
Ptychoparia oweni.

The finding of this grouping of fossils in the mine is of some special importance as it adds paleontological proof to structural evidence to show the geological age of the limestone in which the great bodies of ore upon Ruby Hill occur.

The Prospect Mountain limestone carrying this fauna passes by gradual transition into the Secret Canyon shale, the passage beds being mainly thin interstratified layers of limestone and calcareous shale. No fossils have been obtained from the argillaceous strata of the Secret Canyon shale throughout its development, but imperfect fragments more or less obliterated have been observed in several of the more calcareous beds. At the top of this group the calcareous shales appear, which must be taken as forming the base of the well known Hamburg limestone, inasmuch as they indicate new conditions of sedimentation. It is the coming in of these calcareous deposits that renders possible the development and preservation of a higher fauna. These calcareous shales may be recognized readily all along the line of contact. In places it is well characterized by its grouping of fossils, the same species being observed from both the east base of Hamburg Ridge and the corresponding beds north of Ruby Hill, presenting a higher Cambrian fauna. The following species have been determined from this horizon:

Protospongia fenestrata.
Lingulepis mæra.
Lingulepis minuta.
Lingula manticula.
Iphidea depressa.
Acrotreta gemma.
Kutorgina minutissima.
Hyolithes primordialis.
Agnostus communis.
Agnostus bidens.
Agnostus neon.
Agnostus seclusus.
Dicellocephalus nasutus.
Dicellocephalus osceola.
Dicellocephalus richmondensis.
Ptychoparia pernasuta.
Ptychoparia laticeps.
Ptychoparia bella.
Ptychoparia linnarssoni.
Ptychoparia oweni.
Ptychoparia haguei.
Ptychoparia similis.
Ptychoparia unisulcata.
Ptychoparia læviceps.
Chariocephalus tumifrons.
Ogygia problematica.

After leaving the calcareous shales, which form the base of the Hamburg limestone, the next fossil horizon occurs in the shales at the summit of the same group, and in thin interlaminated limestones in the overlying Hamburg shale.

This horizon has yielded the following species:

Lingulepis mæra.
Lingulepis minuta.
Lingula manticula.
Obolella discoidea.
Acrotreta gemma.
Kutorgina minutissima.
Hyolithes primordialis.
Agnostus communis.
Agnostus bidens.
Agnostus neon.
Agnostus prolongus.
Agnostus tumidosus.
Agnostus tumifrons.
Dicellocephalus nasutus.
Dicellocephalus angustifrons.
Dicellocephalus marica.
Dicellocephalus bilobatus.
Dicellocephalus osceola.
Ptychoparia affinis.
Ptychoparia oweni.
Ptychoparia haguei.
Ptychoparia granulosa.
Ptychoparia simulata.
Ptychoparia unisulcata.
Ptychoparia breviceps.
Arethusina americana.
Ptychaspis minuta.

The *Olenellus* shales lie not only at the base of the fossiliferous rocks at Eureka, but are equivalent to the lowest fossiliferous strata as yet recognized in the Great Basin. Their known stratigraphical position overlying the Prospect Mountain quartzite and at the base of a conformable series of limestone and shale of Cambrian and Silurian age, measuring 9,000 feet in thickness, renders the question still a matter of some doubt whether older fossil bearing strata will ever be found in Utah or Nevada. Wherever the *Olenellus* shale is known to occur, it is always found resting upon siliceous beds, and in no single instance, where they occur together, is the thickness of the lower quartzite so great as at Eureka. Unfortunately no sedimentary beds are known to come to the surface below the Prospect Mountain quartzite, and of the latter we are wholly ignorant as to its thickness. What is needed in working out the stratigraphy of the Great Basin ranges is a locality exposing a section of Lower Cambrian rocks still lower than those at Eureka, but at the same time showing their relations with the *Olenellus* shale and Prospect Mountain limestone above. In the many uplifts of quartzose strata which have been provisionally assigned to the Cambrian upon theoretical grounds, investigation may yet furnish proof that certain interstratified shale bands carry either a similar or still lower fauna, and if their structural relations with the *Olenellus* horizon can be shown, it will make a Cambrian section much to be desired. Organic forms closely allied to the *Olenellus* grouping of species have been found in four places in the Great Basin: in the Oquirrh Range, in Utah; in the Highland and Timpah-Ute Ranges, and at Silver Peak, in Nevada. In all these they are described as occurring in a similar arenaceous shale conformable to and overlying a body of quartzite, the base of which is not exposed.

As early as 1874, Mr. F. B. Meek[1], in a letter to Dr. C. A. White, described the two species, *Olenellus gilberti* and *O. howelli*, from Pioche, Nevada. He called attention to the relationship existing between them and *Olenellus vermontana* and *O. thompsoni*, Hall, from the Georgia slates of Vermont, and to him belongs the honor of first correlating these widely separated beds.

Quite recently, after a careful review of all the material at his command, and a comparative examination in the field of the well known New York, Vermont, and Newfoundland regions with the more recently studied Great Basin areas in Nevada and Utah, Mr. C. D. Walcott[2] suggests dividing the Cambrian into three divisions, namely: Lower Cambrian, Middle Cambrian, and Upper Cambrian. These three primary divisions are recognized in the Cambrian of Europe, and each of them has received local designations derived from the name of the region where the terrane is typical and well exposed. Thus, in the Cordillera, the Lower Cambrian is designated as the Prospect Mountain group, whereas in New York and New England it is best known as the Georgia shale, from the well known locality in Vermont. The Middle Cambrian has as yet no better typical locality than the slates and shales of St. John, New Brunswick. The Upper Cambrian is usually spoken of as the Potsdam so well recognized all the way from the Atlantic coast to central Nevada. At Eureka the latter epoch is represented by the Hamburg Ridge.

Wherever in the Great Basin, so far as known to the writer, the genus *Olenellus* has been discovered, the beds do not attain a development of more than 400 feet; at least they pass from shale and shaly limestone to limestone, in which as yet no organic forms have been recognized. Only at Eureka and in the Highland Range are their structural relations with both the overlying and underlying beds clearly made out. We have very little

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[1] U. S. Geographical Surveys, West of 100th Meridian, vol. IV, Paleontology, 1877, p. 47.

[2] Stratigraphic Position of the Olenellus Fauna in North America and Europe. Am. Jour. Sci., 3d ser., vol. XXXVII, May and July, 1889.

knowledge of the structure at the other localities, and in the Oquirrh Range the *Olenellus* shales are known to be cut off by a sharp fault from the Upper Cambrian.

By reference to the Eureka section it will be seen that the *Olenellus* horizon is nearly 2,500 feet below the top of the Prospect Mountain limestone, where there comes in a fauna showing a mingling of Middle and Upper Cambrian forms. At the base of the Hamburg limestone, 1,600 feet higher in the strata, the true Potsdam fauna of Wisconsin and Minnesota is abundantly represented by a characteristic grouping. By comparing these lists of fossils from the different horizons, it will be seen that in this group, at the top of the Hamburg limestone, there are found seven species, which first occur at the top of the Prospect Mountain limestone. They pass up through the beds at the base of the Hamburg limestone and, together with five additional species obtained for the first time from the latter horizon, come up to the close of the epoch, making in all twelve species common to the top and bottom of the Hamburg limestone. Three species obtained from both the base and the summit of the limestone are identical with forms from the Potsdam sandstone of Wisconsin—*Hyolithes primordialis*, *Dicellocephalus osceola*, *Ptychaspis minuta*. Another, *Lingula manticula*, first described by Dr. C. A. White,[1] from the Schell Creek Mountains, Nevada, has here at Eureka a wide range, extending from the Prospect Mountain limestone through the Hamburg limestone and shale and well up into the overlying Pogonip group of the Silurian.

SILURIAN ROCKS.

Rocks of the Silurian period at Eureka fall readily into three epochs. From our present knowledge, it would be a somewhat difficult matter to subdivide them still further, except upon fine distinctions founded upon paleontological grounds, which might not hold good over any large area of country. These three divisions correspond with the lithological character of their sediments, two heavy masses of limestone with a sharply defined intervening bed of quartzite. This quartzite is a highly altered sandstone, much purer in composition than the Cambrian quartzite below or the sili-

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[1] U. S. Geographical Surveys West of the 100th Meridian, vol. IV, Paleontology, part 1, p. 52.

ceous beds of the Carboniferous above. They have been designated as follows: first, Pogonip limestone; second, Eureka quartzite; third, Lone Mountain limestone. The division between the Cambrian and Silurian rests mainly upon paleontological evidences and is by no means a well defined line of separation. While the underlying Hamburg shales of the Cambrian present a lithological distinction, the transition beds are of varying thickness and pass gradually into the overlying limestone. Moreover, while at Eureka the argillaceous shales serve to separate the two periods, the distinction would not hold good in other regions, particularly at White Pine, where both the Upper Cambrian and Pogonip are well developed, with a great thickness of strata and an abundant fauna, but without a well recognized intermediate shale belt. Wherever in the Great Basin the Silurian is exposed, conformably overlying the Cambrian, there occur at the same horizon a commingling of species of both periods, but this condition of things presents no valid objection against the division of any two periods, for the argument holds with equal force between the limestones of the Upper Silurian and Devonian, and between the limestones of the latter and the Carboniferous.

Pogonip Limestone.—The name given to this epoch is taken from Pogonip Ridge at White Pine, and was first employed by the Geological Exploration of the Fortieth Parallel to designate the great belt of limestone at the base of the Silurian period. At White Pine this epoch is remarkably well exposed and of much greater thickness than at Eureka, although at the latter locality it covers large areas and may be equally well studied, both in its structural relations and faunal development. On the line of the Section E F (atlas sheet XIII) the transition between the Hamburg shale and Pogonip passes gradually upward from argillites and fine grained arenaceous beds with interstratified calcareous shales into purer limestones distinctly bedded. The limestone is for the most part bluish gray, but near the top is of a darker tint, in places becoming almost black. It is distinguished lithologically from both the lower belts of limestone in its more massive bedding, fineness of texture, and the smoothness of its weathered surfaces. This last feature, however, holds true only in a broad, general way, as bands of chert frequently produce roughness of texture resembling Hamburg limestone.

Chemistry shows no characteristic difference between this limestone and the older masses, the beds being more or less magnesian throughout their entire vertical range. A complete analysis was made of a siliceous variety, taken from near Wood Cone, yielding the following result:

Silica	9·345
Alumina	0·309
Ferric oxide	0·289
Ferrous oxide	.....
Manganese	.....
Lime	50·011
Magnesia	0·535
Water	0·130
Carbonic acid	39·111
Phosphoric acid	0·240
Chlorine	0·030
Organic matter	Traces.
Alkalies	Traces.
Total	100·000

To the east of Jackson Mine, where the beds are well exposed and lie inclined at a nearly uniform angle, they measure 2,700 feet across their greatest development. This thickness is probably surpassed by the beds on the long spur southwest of Wood Cone, but there they stand nearly vertical, in some places dipping eastward and in others westward, occasionally showing evidences of faulting, which prevents any reliable estimate of their thickness. It is probable they measure over 3,000 feet. An estimate of the strata at White Pine gives over 5,000 feet of limestone. At first sight it would appear as if there must have been some displacement of beds along Prospect Mountain, but the succession of a rich fauna with the same characteristic specific forms at the base and summit of the epoch at both Eureka and White Pine would preclude such a supposition and the simplicity and uniformity of structure go to show that such is not the case.

Fauna of the Pogonip Epoch.—Throughout the entire thickness of the Pogonip beds, organic remains characterize the epoch. At the base there is a decided mingling of species, a number of Potsdam forms extending upward for some distance into the limestone. Passing upward, however, these species gradually diminish and there comes in rapidly a numerous fauna representing higher and higher forms, till midway in the beds nearly all the characteristic Cambrian fauna have passed away and genera equivalent to the Chazy horizon of New York have taken their place, and near the top a grouping of fossils comes in strongly indicating the Trenton horizon. In the collections made from the Pogonip beds at Eureka, nearly eighty species have been determined, a large proportion of them forms found for the first time either at Eureka or White Pine, while many of them are common to both localities and from the same stratigraphical position in the beds. Many of them are identical with species found in New York and Canada and along the Atlantic border.

Fifteen species comprise all those forms which have been recognized as common to both the Cambrian period, and Pogonip epoch of the Silurian, and several of these present a wide vertical range extending downward to the summit of the Prospect Mountain limestone.

The list is as follows:

Lingulepis mæra.
Lingulepis minuta.
Lingula manticula.
Obolella discoidea.
Acrotreta gemma.
Leptæna melita.
Agnostus communis.
Agnostus bidens.
Agnostus neon.
Ptychoparia affinis.
Ptychoparia oweni.
Ptychoparia granulosus.
Ptychoparia haguei.
Ptychoparia unisulcatus.
Arethusina americana.

Only two species of the genus *Dicellocephalus* have been recognized as yet in the Pogonip group at Eureka, *D. finalis* and *D. inexpectans*, both new to science. They occur associated together several hundred feet above the base, at a horizon where many of the Cambrian species have already disappeared. Of the genus *Dicellocephalus* only two species are known from the corresponding beds at White Pine. Near the base of the Pogonip in a limestone northeast of Adams Hill, a decided mingling of both Cambrian and Silurian occur, as seen by the following list:

Lingulepis mæra.
Obolella discoidea.
Acrotreta gemma.
Leptæna melita.
Triplesia calcifera.
Hyolithes vanuxemi.
Asaphus caribouensis.
Agnostus neon.
Ptychoparia (Euloma) affinis.
Ptychoparia oweni.
Ptychoparia haguei.
Ptychoparia unisulcatus.
Illænurus eurekensis.

A number of localities southeast of Ruby Hill represent, in their fauna, a somewhat higher horizon, the most favorable for collecting being found on the first ridge southeast of the Jackson Mine, where the base of the Pogonip beds are wanting, having been cut off by the Jackson fault. These beds yielded the following species:

Lingulepis mæra.
Lingula manticula.
Acrotreta gemma.
Leptæna melita.
Orthis hamburgensis.
Ptychoparia (Euloma) affinis.
Arethusina americana.
Illænurus eurekensis.
Asaphus caribonensis.
Asaphus (sp. undt.).

Directly east of the Hamburg Ridge and several hundred feet above the last locality, a grouping of fossils comes in which is characteristic of a slightly higher horizon:

Lingulepis mæra.
Lingula manticula.
Discina (sp. undt.).
Acrotreta gemma.
Schizambon typicalis.
Obolella ambigua.
Orthis hamburgensis.
Orthis testudinaria.
Triplesia calcifera.
Tellinomya? hamburgensis.
Dicellocephalus finalis.
Dicellocephalus inexpectans.
Ptychoparia annectans.
Ptychoparia oweni.
Amphion (sp. undt.).

This horizon may be easily identified by collections of fossils more or less complete from numerous other localities in the district. From about this point in the limestone the older persistent forms gradually disappear, and the new species introduced in the above list become more and more abundant, as is evidenced by the increasing number of localities where they occur as higher strata are reached.

In a compact gray limestone southwest of McCoy's Ridge are the following:

Orthis perveta.
Orthis testudinaria.
Triplesia calcifera.
Maclurea annulata.
Plumulites (sp. undt.).
Ceraurus (sp. undt.).
Illænurus eurekensis.
Asaphus caribonensis.

Midway in the Pogonip, the genera *Receptaculites, Chætetes, Pleurotomaria, Maclurea, Bathyurus, Asaphus, and Cyphaspis,* make a decided change in the fauna from the Hamburg limestone. Many of these genera gradually give way and are replaced by others, until at about 800 or 1,000 feet below the summit the faunal development is shown by a grouping of fossils made at two widely separated areas, which begin to foreshadow the strongly marked fauna at the summit of the epoch. From the east slope of the ridge east of the Hamburg Ridge there were collected—

Receptaculites ellipticus.
Cystidian plates.
Orthis perveta.
Triplesia calcifera.
Raphistoma?
Pleurotomaria lonensis.
Maclurea annulata.
Bellerophon?
Orthoceras (like O. multicameratum).
Cyphaspis brevimarginatus.
Illænurus eurekensis.
Asaphus? curiosus.

And from the long, eastern slope of White Mountain, about 800 feet from the top of the mountain and probably nearly the same distance below the summit of the Pogonip, there were collected as follows:

Monticulopra.
Orthis testudinaria.
Raphistoma nasoni.
Maclurea annulata.
Maclurea subannulata.
Pleurotomaria lonensis.
Endoceras proteiforme.
Orthoceras sp.?
Bathyurus similis.
Asaphus cariboensis.

Throughout the upper 600 feet of the Pogonip, wherever organic remains have been observed, the association of genera are much the same, the horizon being well determined both by the fauna and the position of the overlying Eureka quartzite. In many areas where the Eureka quartzite forms the surface rock an underlying limestone several hundred feet in thickness is frequently exposed, which carries paleontological evidences of the upper Pogonip strata. Two localities in these upper Pogonip beds have furnished a rich and varied fauna. From a dark limestone on the summit of White Mountain the following species have been determined:

Receptaculites ellipticus.
Receptaculites elongatus.
Receptaculites mammillaris.
Cystidean plates.
Strophomena nemea.
Orthis perveta.
Orthis testudinaria.
Tellinomya contracta.
Helicotoma sp?
Orthoceras multicameratum.
Endoceras (like E. multitubulatum).
Leperditia bivia.
Leperditia sp?
Beyrichia sp?

A similar grouping of fossils was procured in the Fish Creek Mountains a short distance below the quartzite, numerous localities yielding nearly identical lists:

Receptaculites ellipticus.
Receptaculites elongatus.
Receptaculites mammillaris.
Cystidean plates.
Ptilodictya sp?
Monticulopora sp?
Orthis perveta.
Tellinomya contracta.
Modiolopsis occidens.
Modiolopsis pogonipensis.
Pleurotomaria sp?
Maclurea sp?
Orthoceras multicameratum.
Endoceras proteiforme.
Amphion nevadensis.
Ceraurus sp?

On the north slope of Surprise Peak, just below the quartzite, the limestone supplied the following:

Receptaculites mammillaris.
Cystidean plates.
Orthis perveta.
Orthis tricenaria.
Raphistoma nasoni.
Pleurotomaria ?
Maclurea annulata.
Leperditia bivia.

A convenient locality to those visiting Eureka and wishing to examine the Upper Pogonip beds may be found on the west side of Caribou Hill, which has furnished a few typical forms:

Orthis perveta.
Orthis tricenaria.
Asaphus cariboueusis.
Receptaculites mammillaris.
Maclurea annulata.

Other localities which have presented evidences of the same horizon may be found in Goodwin Canyon, at the head of Lamoureux Canyon, and in the limestones not far from the line of the general section E F, atlas sheet XIII.

This grouping of fossils from the summit of the Pogonip limestone is of special interest on account of the commingling of species and the position of the strata. Ascending in the beds it will be found that the Cambrian fauna entirely disappears, the life of the Middle Pogonip gradually passes away, and new species come in until the grouping of the fauna presents an aspect peculiarly its own. Two species of the genus *Modiolopsis*, and the characteristic fossil, *Tellinomya contracta*, foreshadow still higher strata, indicating the coming in of the Trenton horizon. The summit of the Pogonip is also marked by an increase in the number of species of

Orthis tricenaria, *O. testudinaria*, and *O. perveta*, characteristic forms in New York and Wisconsin. A marked feature of this upper horizon is the presence of the genus *Receptaculites*, three species having been identified. Immense numbers of specimens of one of them, *R. mammillaris*, are found throughout the beds with a vertical range of several hundred feet, and are abundant where all other fossils are wanting. *Graptolites*, in the Pogonip epoch at Eureka, are represented by a single undetermined species, which, according to Mr. C. D. Walcott, resembles closely *G. bifidus*.

Eureka Quartzite.—The name of the district has been employed to designate this formation, as during the progress of the survey the quartzite was determined for the first time as a distinct geological epoch and its stratigraphical position clearly defined. Up to this time the occurrence of a broad belt of quartzite lying between two massive bodies of Silurian limestone had never been recognized. Moreover, nowhere else in the Great Basin has the formation been so carefully studied. It lies superimposed directly on the Pogonip limestone, and where the upper beds of the latter epoch are exposed they are frequently capped by a greater or less thickness of the quartzite, as is well shown on Caribou Hill and McCoy's Ridge. Again, the position of the Eureka quartzite is clearly brought out by the patches of quartzite left by erosion upon the massive Pogonip beds of Fish Creek Mountains. No horizon is more marked in its physical features than the Eureka quartzite. Besides its frequent occurrence as a capping rock, its snow-white color, and its tendency to fracture in mural-like escarpments render it easily recognizable wherever it occurs.

The Eureka quartzite is made up almost entirely of siliceous grains firmly compacted together. It possesses a granular texture and a vitreous luster, and for the most part is free from partings parallel to the planes of bedding. At the base of the formation the quartzite is colored red and gray by iron, but it rapidly passes into white, with an occasional bluish or purplish tinge, frequently presenting a mottled coloring. In general it is exceptionally free from seams or patches of ferruginous material, its purity and uniformity of composition and marble-like appearance being a marked feature of the horizon. In one or two places it shows a brecciated appearance, with fine, cherty masses, notably on Hoosac Mountain. In the neighborhood of

McCoy's Ridge it has been quarried for fluxing purposes at the smelting furnaces, the rock yielding nearly two dollars in gold per ton, which paid for hauling. Whether the gold is of primary origin in the quartzite or whether it was derived from some vent carrying mineral matter in solution has never been determined. The locality where the rock was quarried is situated near the Hoosac fault, and in close proximity to ore bodies.

The ridge extending southwest from Castle Mountain shows a fine body of the Eureka quartzite, the southern escarpment of which exposes a section 300 feet in thickness. Numerous specimens collected at intervals across the quartzite were subjected to microscopic examination. All the upper portion of the rock proved to be an exceptionally pure and fine quartz, the grains averaging between 0·02 and 0·03 millimeters in size, with a granitoid structure; that is, the grains did not show rounded outlines, but instead presented irregular shapes that fitted into each other and firmly crystallized together without fine groundmass between them.

The quartzite is free from impurities but full of fluid inclusions with moving bubbles, some of them evidently liquid carbonic acid. The minute fluid cavities appear white in incident light. An examination of the quartzite indicated that the entire rockmass had undergone a recrystallization of the material and was not by any means a simple solidification and packing together of quartz grains. In other words, it is a true quartzite and not a compact sandstone, hardened by superincumbent rock. Even under the microscope the rock appears to carry but little oxide of iron. Toward the upper part of the formation the microscope detects increasing numbers of needles and grains of iron oxide, accounting for the change of color both in the unaltered rock and on the weathered surfaces of the larger detached blocks. Particles of calcite also begin to appear some distance beneath the Lone Mountain limestone, associated with the quartz grains, while at the base of the quartzite there is a very decided increase in the amount of lime present.

Although not differing materially from those observed elsewhere, the most satisfactory section across the quartzite was made just west of Castle Mountain. Here the quartzite presents a perpendicular cliff, 300 feet in thickness, resting horizontally on the Pogonip limestone. The subjoined section is numbered from the top downward, the numbers inclosed in brackets coinciding with the specimen number in the collection. Throughout the section the quartzite is for the most part vitreous without partings parallel to the bedding, the coloring, however, being in nearly horizontal planes, passing insensibly from one tint to another.

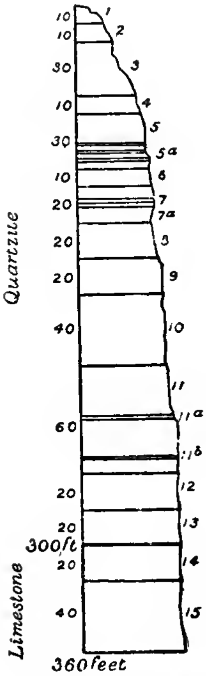

FIG. 1.—Eureka quartzite west of Castle Mountain.

No. 1	(391)	10 feet of white vitreous quartzite.	
No. 2	(390)	10 feet grayish white, with segregation of ferruginous material.	
No. 3	(389)	30 feet white and vitreous.	
No. 4	(388)	10 feet purple and white, vitreous.	
No. 5 No. 5*a*	(387) (386)	30 feet purplish white, with three narrow bands of dark gray granular quartzite.	
No. 6	(385)	10 feet dark gray quartzite.	
No. 7 No. 7*a*	(384) (383)	20 feet white, banded with steel gray; dark gray quartzite bands in No. 7.	
No. 8	(382)	20 feet dark gray and white, banded and mottled.	
No. 9	(381)	20 feet light gray, fine granular.	
No. 10	(380) (379)	40 feet white and pinkish white.	
No. 11 No. 11*a* No. 11*b*	(378) (377) (376)	60 feet dark gray passing into light gray, with bands more or less calcareous, weathering red.	
No. 12	(375)	20 feet gray, having cross bedding brought out by weathering.	
No. 13	(374)	20 feet dark steel gray quartzite, somewhat calcareous.	
No. 14	(373)	20 feet siliceous limestone.	Pogonip limestone.
No. 15	(372)	40 feet black compact limestone.	

The junction between the quartzite and the underlying limestone presents a sharp line of demarcation and indicates an abrupt change in the deposition of sediments.

Although the Eureka quartzite is probably not more than a few hundred feet in thickness, it can be estimated only approximately, as an unconformity exists between it and the next overlying group. Over the large area covered by the exposures of the quartzite, evidences of denudation prior to the deposition of the Lone Mountain limestone may be observed in the mountains connecting the Fish Creek Range with Prospect Ridge, but no satisfactory estimate of the amount seems possible. Again, not only different horizons of the Lone Mountain limestone, but even of the Devonian, are seen to repose directly upon and to overlap the quartzite. Under any circumstances the quartzite would be difficult to measure, inasmuch as over the greater part of the area stratification lines are wanting, and the beds are frequently broken up by a succession of small parallel faults not always easy to recognize, rendering the amount of displacement still more difficult to estimate. These minor displacements, when the rocks lie nearly horizontal, produce steps and mural faces wherever the quartzite occurs as the surface rock. In nearly all such instances the Pogonip beds are exposed in the more deeply eroded canyons. On the other hand, where the beds are inclined at high angles, accompanied by numerous faults, the formation frequently presents the appearance of a much greater thickness than is really the case, as is seen on Hoosac and Lookout mountains.

The best estimates place the thickness of the beds at about 500 feet, although no escarpment of the quartzite free from faulting presents quite so broad a development. No fossils have been obtained from this horizon, nor is it likely that they will be found. The microscope shows clearly how complete an alteration has taken place since the original sand deposits were laid down, so that all traces of fossils, if any existed, must have been obliterated.

Lone Mountain Limestone.—Next above the Eureka quartzite comes a body of limestone without any transition beds, the change in the character of deposits being unusually abrupt. The designation of the epoch is taken from a bold isolated mountain which rises out of the plain a few miles to the northwest of the Eureka District, where it is seen in its full development better than in the immediate area of the map. Not only is it well shown at Lone Mountain, but in a continuous section its relations are clearly made out with the other members of the Silurian period and with the overlying body of Devonian limestone. The section at Lone Mountain is given in detail at the end of this chapter.

The Lone Mountain epoch may be divided upon paleontological grounds into two horizons, which, for convenience, are provisionally designated as the Trenton and Niagara. The lowest beds resting immediately on the quartzite are a steel-gray, almost black, gritty limestone, in most places without traces of bedding, and so altered as to have obliterated all evidences of organic remains. Ascending the strata these steel-gray beds pass up into dark bluish gray limestone, which in one locality north of Wood Cone yielded a small lot of fragmentary and poorly preserved fossils, but which represent a characteristic Trenton grouping. These black and gritty beds are recognized in but few places at Eureka, mainly in the southwest corner of the district, along the southern base of the Mahogany Hills. It is quite possible that the horizon covers a larger area than has been supposed, but if such is the case the beds have undergone so great a lithological change that their recognition seems impossible without paleontological evidence, and that is wholly wanting. Moreover, the beds resting upon the quartzite in other places resemble higher strata in the Lone Mountain epoch.

This limestone appears to be magnesian throughout; a siliceous variety from the fossiliferous beds north of Wood Cone yielded 8·41 per cent silica and 2·55 per cent magnesium carbonate. The thickness of these lower beds, in which the Trenton aspect of the fauna is so strongly marked, may be taken at 300 feet, at least the black and blue limestone presents about that development before passing into the upper strata.

Above the horizon with the Trenton grouping the rocks pass gradually into light gray siliceous limestone, with a peculiar saccharoidal texture, in places becoming almost white and wholly without bedding. On the surface the limestones weather brown and buff, their light colors throughout a great vertical range standing out in strong contrast with the other massive limestone beds of the Paleozoic. It weathers in rounded outlines, breaking with an irregular fracture and presenting a monotonous appearance wearisome to the eye. Rock of this character makes up by far the greater part of the horizon, and then by slow, imperceptible changes it becomes darker in color, with more and more tendency to develop planes of stratification, and gradually passes into the overlying limestone of the Devonian.

As already mentioned, an unconformity exists between the Eureka quartzite and the Lone Mountain limestone. There is therefore no direct evidence in the district of the thickness of the limestone. The average thickness of strata exposed has been taken at 1,800 feet, but it is probable that this is under rather than over estimated, and at Lone Mountain they attain a somewhat greater development, at least 2,000 feet being exposed. In most localities at Eureka where the limestone rests upon the quartzite the upper members of the epoch are wanting, and in others they pass under the Devonian without any means of measuring their thickness. Another difficulty arises from the impossibility, on our present knowledge, of determining a line of separation between the Silurian and Devonian, as no sharp lithological distinctions exist and there is no means of telling exactly how far down in the limestone a Devonian fauna comes in. It is known, however, that Silurian corals extend up into the limestone about 1,500 feet from the base, and the dark blue limestone which characterizes the Devonian makes its appearance about 300 feet higher up in the series.

Fauna of the Lone Mountain Limestone.—The fauna obtained from the Lone Mountain limestone, although meager and most of the material too poorly preserved for specific indentification, is of special interest, as it occupies a most important position in the development of life in the geological record. Not only are organic forms poorly represented, but the beds themselves over large areas of the Great Basin have not as yet been recognized and over other areas are known to be wanting. The collection indentifying the Trenton fauna was found on a low ridge a short distance northeast of Wood Cone. The list comprises several characteristic species: *Leptæna sericea*, *Orthis subquadrata*, *O. (like O. plicatella)*, *Trinucleus concentricus*, and *Asaphus platycephalus*, and representatives of the following genera: *Streptelasma*, *Rhynchonella*, *Orthoceras*, *Cyrtoceras*, *Ceraurus*, *Dalmanites*, and *Illænus*. It is worthy of special mention that in this small but representative collection, all the more typical forms found in the beds immediately below the Eureka quartzite, which indicated the coming in of higher horizons, are wanting or at least have not as yet been found.

Above the Trenton no good grouping of fossils has as yet been discovered until the Devonian rocks are reached. The upper portion of the Silurian limestone presents a most forbidding aspect for the preservation of organic remains, and although diligent search was made throughout the horizon it was rewarded only by finding a few imperfect corals, belonging to the species *Halysites catenulatus*, which is so characteristic of the Niagara of the East, and here found in what should be its true geological position.

They have a wide range and occur nearly 1,500 feet above the summit of the Eureka quartzite. The same coral has been obtained from Lone Mountain and White Pine, and in both these latter localities associated with the genus *Zaphrentis.*

Lone Mountain.—This isolated mass rises abruptly out of the broad plain lying between the Wahweah and Piñon ranges and about 15 miles northwest of the Eureka Mountains, which shut in the plain to the southwest. Its isolation, its great altitude as compared with the length of the uplift in strong contrast with the neighboring ranges, and its steep slope to the eastward make the mountain a most conspicuous object. In its geological structure the mountain appears to be a monoclinal ridge of great simplicity and uniformity, remarkably free from any great faults and folds and presenting a block of strata about 4,000 feet in thickness and reaching an altitude nearly 2,000 feet above the plain. The beds have all the appearance of being cut off by a sharp fault at the south end of the block, evidence of which may be found in the body of Carboniferous limestone resting against the Devonian at the southeast base of the uplifted mass. The dip of the strata upon Lone Mountain is uniformly to the east at an angle of 30° to 50°, with a strike a little east of north. To the geologist a series of beds like this at Lone Mountain would at all times command attention, but in this exposure of 4,000 feet of strata is represented a section of the Paleozoic rocks rarely seen in the Great Basin and so far as known nowhere else so well shown as here. The value of the exposure consists in the simplicity with which the three divisions of the Silurian are brought out in the same continuous section. At the western base of the mountain the upper members of the Pogonip come to the surface, but with an exposure of only about 375 feet of beds. Within this belt, however, a fauna strikingly characteristic of this horizon is found and almost identical with that occurring in the corresponding Pogonip beds at Eureka. A few hours' search yielded the following:

Receptaculites mammillaris.
Monticulopora sp.?
Cystidian plates.
Acrotreta (like A. subconica).
Strophomena nemea.
Modiolopsis occidens.
Modiolopsis pogonipensis.
Hellicotoma?
Pleurotomaria lonensis.
Murchisonia sp.?

Orthis lonensis.
Orthis perveta.
Orthis testudinaria.
Streptorhynchus minor.
Coleoprion minuta.
Maclurea annulata.
Maclurea carinata.
Maclurea sp.?
Cyrtolites sinuatus.
Illænus sp.?

Resting upon the Pogonip comes the Eureka quartzite, but with less thickness than the corresponding beds at Eureka. Immediately above the quartzite, with but little development of transition beds, occur the light colored siliceous limestones, measuring at least 2,000 feet. These beds form the greater part of the western slope of the mountain, and are so characteristically shown as to make the local name of Lone Mountain an appropriate one to designate the epoch. In the lower limestones, resting directly upon the quartzite, the Trenton fauna appears to be wanting, and it is by no means certain that the beds are represented. At all events the bluish gray limestone characteristic of the Trenton at Eureka and White Pine has not been recognized. On the other hand, throughout the entire epoch evidences of organic remains are exceedingly meager and confined to silicified corals imperfectly preserved. The Niagara coral, *Halysites catenulatus*, which usually occurs several hundred feet above, is found here within 50 feet of the quartzite.

The light colored siliceous limestone passes up gradually into the distinctly bedded Nevada limestone of the Devonian, which forms the summit of the ridge, and as the strata dip eastward make up the greater part of the eastern slope. It is by no means certain, however, that a displacement of strata does not extend along the eastern face of the uplifted mass, the base of the ridge not having been examined.

Mr. C. D. Walcott made the following section across Lone Mountain (see Fig. 2):

	Feet.
1. Dark gray limestone, with brown and variegated layers interbedded. Typical Devonian fauna. (Nevada limestone.)	1,500
2. Siliceous bluish gray limestone breaking up into shaly bands carrying abundant fossils of the Lower Devonian. (Nevada limestone.)	200
3. Siliceous limestone, light brown, gray, and buff in color, with *Halysites catenulatus* near the base; passing up into beds almost white, with blue and gray tints, followed by alternating dark and light beds. (Lone Mountain limestone.)	2,000

	Feet.
4. White quartzite. (Eureka quartzite.)	200
5. Dark gray limestone, massive bedding, with intercalated shaly layers carrying a typical Silurian fauna. (Pogonip limestone.)	300
6. Siliceous cherty limestone	75
	4, 275

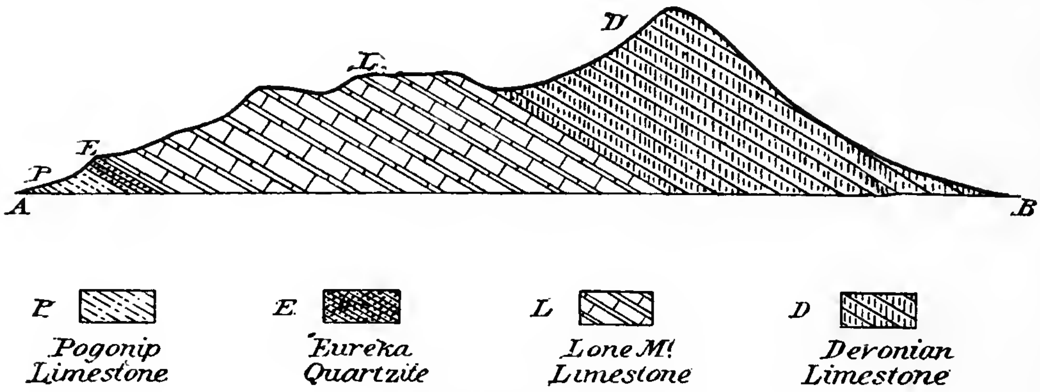

FIG. 2.—Section across Lone Mountain.

In the Nevada limestone at Lone Mountain the fauna is exceedingly rich in species. A list of the fossils occurring here, together with some remarks upon their geological significance, will be found in the following chapter in the discussion of the Devonian rocks.

CHAPTER IV.

DEVONIAN AND CARBONIFEROUS ROCKS.

DEVONIAN ROCKS.

By imperceptible gradations limestones of the Lone Mountain epoch pass upward into those of the Devonian period, and as no definite horizon separating them has as yet been determined no accurate measurements of their respective thicknesses can be given. Devonian rocks cover a far greater area in the district than those of any other period; they are much more widely distributed and present a thickness greater than either the Cambrian or Silurian. In no part of the Great Basin are they better exposed than at Eureka, and as nowhere else have they been so carefully investigated the district must long remain a typical one for the study of Devonian strata. Notwithstanding the beds present a rich fauna, only two subdivisions of the Devonian have been made—first, Nevada limestone, and second, White Pine shale—although taken together they have a thickness of about 8,000 feet. This division is based upon a marked change in both the fauna and character of the sedimentation.

Nevada limestone.—The name selected to designate this horizon is taken from the name of the state where the epoch is so well represented by a broad development of beds and the only state or territory in the Great Basin where it has been recognized as attaining any great thickness and its limits and geological relations studied. As the designation of the epoch would suggest, the beds throughout the entire series are composed mainly of limestone, although intercalated beds of shale, quartzite, and sandstone occur. The Lone Mountain and Nevada limestones taken together present an immense thickness of beds, lying between the Eureka quartzite and White Pine shale. Together they measure about 7,800 feet in their broadest development. The division into Silurian and Devonian is based mainly upon paleontological grounds. The transition in sedimentation from characteristic Silurian to unmistakable Devonian is so imperceptible that a boundary between them is impossible to establish, and, as is usually the case where beds form a continuous, conformable limestone series, a line of separation based upon faunal changes must always remain more or less arbitrary. Lithologically, in their broader features, the Silurian and Devonian limestones are quite distinct; it is only in the intermediate beds that no line can be drawn. The light gray and white siliceous beds that form the mass of the Lone Mountain present a wide vertical range, and in these beds are occasionally seen obscure impressions of Niagara corals, and in other localities, in similar rocks not much higher up in the series, occur *Atrypa reticularis* and other forms foreshadowing the Devonian. It is known that characteristic Lone Mountain beds carrying *Halysites catenulatus* extend for nearly 1,500 feet above the Eureka quartzite, and that beds easily identified by their organic remains bring the Devonian down to about 6,000 feet below the summit of the great limestone belt lying between the Eureka quartzite and White Pine shale. *Halysites* and *Atrypa reticularis* were never found associated together, although it can not be definitely stated that the former fossil does not appear as low down in the limestone as the highest occurrences of the characteristic coral.

The Nevada limestone presents broad elevated rock-masses characterized by bold escarpments and castellated summits. Profound orographic movements have broken this great body of limestone into massive blocks intersected by gorges and canyons, affording a mountain scenery both grand and picturesque, and one rarely equaled in any limestone region of the Great Basin. Although these uplifted blocks afford abundant geological exposures across the greater part of the limestone, in no one instance is there a complete or in every way satisfactory section from base to summit. In many localities the exposures extend upward from the summit of the Lone Mountain several thousand feet into the Nevada beds; in others the strata are well shown from the top down till cut off by some line of faulting which hides all the lower limestones. Frequently the lower beds of the Devonian are buried beneath the Quaternary plain. The region, however, affords many excellent and overlapping sections exposing from 4,000 to 5,000 feet of rock; one continuous series of beds being estimated at 5,400 feet, which includes nearly the entire Nevada epoch. Throughout the

Nevada limestone, the physical features of sedimentation are sufficiently characteristic to correlate the strata when comparing a large number of sections across several thousand feet, although the details across any one section are not persistent enough to determine with precision the horizons over any extended area. Modoc Peak, Combs Mountain, Atrypa Peak, Woodpeckers Peak, and Newark Mountain afford typical sections.

In general the lower limestones are indistinctly bedded, light gray in color, and highly crystalline, passing up into brown, reddish brown, and gray beds, which are distinctly stratified and finely banded and striped, presenting a somewhat variegated appearance on the weathered surfaces. This latter feature is very persistent throughout the middle portion of the limestone. In the upper members the limestones are more massive, usually well bedded, and possess a normal bluish black and bluish gray color. In broad masses it is difficult to distinguish the upper members of the Nevada limestone from the Carboniferous limestone, and they closely resemble the great bodies of the Wasatch limestone of Utah. The intercalated bands of argillaceous shale and quartzite vary greatly in width, but do not especially mark any part of the limestone, except that they occur more frequently in the middle portion than elsewhere. Calcareous shales are found throughout the epoch. The limestones are everywhere more or less magnesian, nearly pure dolomites frequently occurring in narrow layers. At the base of the section north of Modoc Peak (Fig. 3) the rock carries 40·62 per cent of magnesium carbonate, with 0·1 per cent of insoluble residue. In band 15, of the same section, the dark colored limestone carries 1·26 per cent of carbonate of magnesia, while the light colored rock holds 26 78 per cent.

The Modoc Section.—A section in detail across the strata, extending from the summit of the Nevada limestones nearly to the base, was made by Mr. J. P. Iddings. It was constructed across the high ridge lying between Signal and Modoc peaks, beginning with the lowest rocks exposed at a point northwest of the latter peak just east of the Modoc fault, and terminating at the eastern base of the hills where the uppermost beds pass beneath the valley accumulations (atlas sheet VII). The section measures 5,400 feet. The beds trend obliquely across the ridge, striking N. 50°–55° W.

Nevada limestone—Devonian.

MODOC SECTION.

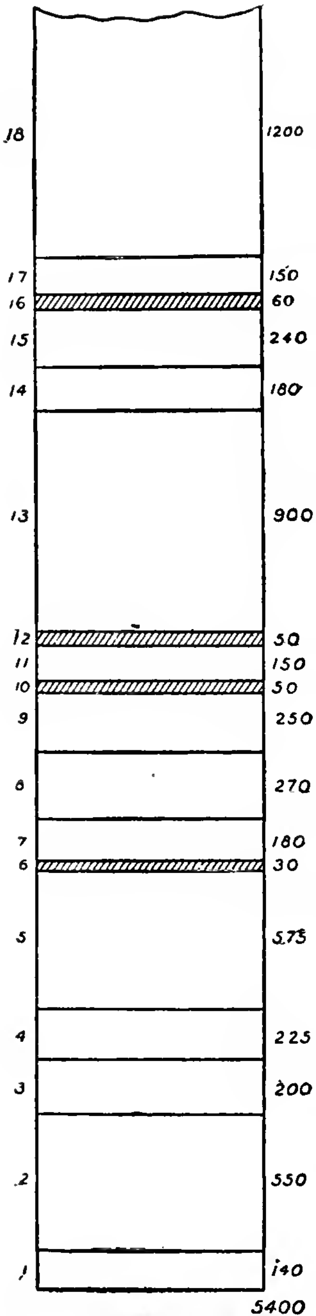

FIG. 3.—Nevada limestone—Modoc section.

18	1200	Dark gray to bluish black massive limestone poor in fossils; quite well bedded; weathering partly smooth and dark colored; partly rough and pitted and of lighter color; mostly compact and massive, also of uneven texture; with numerous calcite seams.
17	150	Light and dark colored limestone with *Stromatopora* and *Chætetes;* contains two layers thinly bedded (fissile).
16	60	Compact light yellow sandstone.
15	240	Light and dark colored limestone in layers 10 to 20 feet thick, with *Stromatopora* and *Chætetes.*
14	180	Dark colored limestone with *Stromatopora* and *Chætetes.*
13	900	Alternating layers (about 10 feet thick) of dark and light gray limestone, finely banded and lined; weathering brownish gray; in places bearing *Chætetes.*
12	50	Compact yellow sandstone.
11	150	Dark and light gray limestone; indistinct bedding.
10	50	Compact yellow sandstone.
9	250	Dark and light colored limestone interbedded in layers from 4 to 10 feet thick.
8	270	Light gray siliceous limestone; very siliceous near base.
7	180	Alternating beds of dark and light gray limestone; at base 30 feet; very siliceous limestone; with cross bedding on weathered surface.
6	30	Compact yellow sandstone.
5	575	Dark and light gray limestone in thick belts of dark, lighter, and gray colors.
4	225	Dark dense limestone; well bedded; bearing fossils.
3	200	Shaly limestone rich in fossils.
2	550	Light gray siliceous limestone, with fine lines of bedding; in upper portion weathering in almost rectangular fragments; growing less siliceous toward the bottom.
1	140	Light gray highly crystalline, saccharoid dolomite; not siliceous.
	5400	

The Lamoureux Section.—The section along the limestone ridge northeast of the head of Lamoureux Canyon (atlas sheet IX) exposes 4,300 feet of strata, the lowest members resting immediately upon the Eureka quartzite of the flat-top hill about three-quarters of a mile south of Atrypa Peak. It is impossible to say just how great a thickness of these beds should be assigned to the Lone Mountain epoch. Unquestionably the lower members of the Silurian are wanting, and if a line be drawn placing the alternating blue and light gray bedded rocks No. 6, in the Devonian, it would give about 800 feet to the lower group. About 500 feet above this line a fossiliferous belt comes in, carrying a well known Devonian fauna. This fossiliferous belt may be traced around to the east slope of Atrypa Peak, where a most abundant fauna occurs rich in generic and specific forms. Here at Atrypa Peak, however, there are nearly 2,000 feet of strata below the fossiliferous belt as against 1,300 feet in the Lamoureux Section before reaching the Eureka quartzite, but as the inclination of the beds can not well be determined no accurate measurement of the thickness can be given. Apparently the lowest horizon at Atrypa Peak is below the one shown in the section, although the character of the sedimentation is much the same.

The section is as follows:

Section East of Lamoureux Canyon—4,300 feet.

	Feet.
1. Brown and blue limestone, well bedded, with occasional mottled beds	300
2. Brownish gray, finely striped, well bedded limestone, with corals	1,000
3. Dark blue, light gray, and brownish limestone	1,000
4. Alternating dark and light limestone	500
5. Fossiliferous shaly belt	200
6. Light blue and gray bedded limestone	500
7. Light colored siliceous limestone, with indistinct bedding	800
8. { Thin layer of black siliceous limestone. Eureka quartzite.	
	4,300

County Peak Section.—On the east side of the Eureka District, in the region of County Peak, the Devonian rocks offer still another section quite similar in the character of its sedimentation to those already given. It includes a portion of the Lone Mountain rocks exposed in the bluffs on the east side of C. C. Canyon and extends eastward until the upper members of the Nevada limestone are submerged beneath the great basalt flow of Basalt Peak and the Strahlenberg.

County Peak Section—5,200 feet.

	Feet.
1. Evenly bedded, bluish gray limestone, with interbedded bands of dark limestone	600
2. Irregularly bedded, blue limestone, with intercalated seams of quartzite	1,600
3. Yellowish gray quartzite, with narrow bands of gray siliceous limestone	100
4. Massive beds of siliceous limestone alternating with beds of pure gray limestone and narrow bands of quartzite	700
5. Massive, gray vitreous sandstone	100
6. Siliceous limestone in massive beds more or less siliceous in thin bands, carrying shaly limestone belts	800
7. Grayish white, vitreous sandstone	100
8. Gray and blue limestone well bedded	500
9. Light colored, compact quartzite changing from red to white	50
10. Massive, light colored limestone without bedding, more or less siliceous	650
	5,200

In this section the lower 700 feet are assumed to belong to the Lone Mountain, giving 4,500 to the Devonian. This leaves about 1,500 feet of the Upper Devonian strata wanting as compared with the beds in the region of Modoc Peak. These upper beds are again well shown at Newark Mountain and Mahogany Hills.

White Pine Shale.—Conformably overlying the Nevada limestone occurs a heavy body of black shale, which has been designated as above, it having been first recognized as a distinct horizon in the White Pine mining district to the southeast of Eureka. It occupies a clearly defined stratigraphic position with a marked change in the character of sedimentation and a fauna distinct from both the underlying and overlying horizons.

There are only two large bodies of White Pine shale at Eureka, but they both offer excellent rock exposures, one west of Newark Mountain, the other east of Sentinel Peak. The shale is best studied west of Newark Mountain (atlas sheet VI), where it forms the entire rock mass through which

Hayes Canyon has been eroded and where its geological relations with the Nevada limestone below and the Diamond Peak quartzite above may be easily recognized. The shale attains its greatest development east of Sentinel Peak and Sugar Loaf, but as it is cut off from the Nevada limestone by a north and south fault which passes up Rescue Canyon its stratigraphical relations with the underlying strata are not as clearly shown as at the first locality, while the overlying beds are buried beneath the detritus of the plain. The thickness across the broadest part of the White Pine shale east of Sugar Loaf may be placed at 2,000 feet. A marked feature of the beds is the rapid changes which they undergo, both in their lateral and vertical extension, passing abruptly from pure, argillaceous, black shale into beds more or less arenaceous and frequently carrying intercalated beds of red, friable sandstone appearing as lenticular masses in the shale. In Hayes Canyon the beds for the most part are brownish black shale, with thin bands of red sandstone while opposite Sugar Loaf the intercalated red sandstone strata occasionally attain a thickness of 100 feet. Out in the valley the lines between the shale and sandstone may be easily followed for long distances, the former occupying shallow, trough-like depressions and the latter low intervening ridges slightly elevated above the general level. Cross sections made at no great distances apart differ widely in the character of the sediments. All evidence indicates a shallow-water deposit. The formations at Eureka and White Pine are identical in every way except in thickness of deposits, at the latter locality measuring not more than 600 feet.

Plant Remains in White Pine shale.—Impressions of plants which are exceedingly rare in Paleozoic rocks of the Great Basin are very abundant and form a distinctive feature of this epoch, notwithstanding that everything which has been collected is of fragmentary nature. The most promising specimens for identification were submitted to Sir J. William Dawson, who, in his report, called attention to the poor state of preservation of the plants. Under date of Montreal, June 11, 1889, he writes:

> One slab contains a small ribbed stem referable to Goeppert's *Anarthrocanna*, a doubtful Calamitean plant. The specimen is not unlike those found at Perry, in Maine, and Bay de Chaleur. On the large slab is also a slender branch stem which I suppose may be the stipe of a fern, and from its character and angle of ramification

probably belongs to the genus *Aneimites*, but no trace of the pinnæ can be seen. The evidence, so far as it goes, would indicate the Upper Devonian (or Erian, as I prefer to call it,) rather than the Middle Devonian or the Lower Carboniferous.

It will be seen that this determination as to the age of the plants is quite in accord with the geological position of the beds above the Nevada limestone of the Devonian and directly below the Diamond Peak quartzite of the Carboniferous.

Notwithstanding the great development of the black shales they have as yet been recognized only in the two localities already mentioned, Eureka and White Pine. On the east side of the Eureka District, if they are represented at all, it is only by 100 feet more or less of dark shaly beds, highly arenaceous, and passing into sandstones and quartzites of the Diamond Peak beds. There seems to be no doubt that the Diamond Peak formation in the Piñon Range rests conformably upon the Nevada limestone, without the interposition of any great thickness of White Pine shales, although there are a few black sandstones and narrow chert bands which apparently represent the intervening argillaceous epoch. The evidence in favor of this correlation is strengthened by the presence of poorly preserved fragments of vegetable life wherever the black belt comes in. These intervening beds have yielded one single species, *Discina minuta*, which, according to Mr. C. D. Walcott, corresponds closely with typical specimens from the Marcellus shale of New York. The fact that the White Pine shales are wanting over large areas, where both the Devonian and Carboniferous are found together, renders it highly probable that these shallow water deposits, although developed to a great thickness, form exceptional occurrences, and that the Nevada limestone passes over abruptly into sandstones of Carboniferous age. On the map (atlas sheet v) these intervening beds on both sides of The Gate are included in the Nevada limestone.

Fauna of the Devonian.—As already mentioned, no subdivisions in the Nevada limestone have been made. Geology as yet fails to furnish sufficient evidence for drawing any sharp demarcation, sedimentation having gone on too uniformly under similar conditions to form any marked change in the character of the beds. From the sections already given it will be seen that this epoch was essentially a limestone-making one, the amount of sandstone deposited being relatively small. Paleontology fails equally with geology to point out any strong reasons for subdivisions; moreover, it would be impossible, from our present knowledge, to subdivide the epoch into horizons as recognized in the Mississippi Valley and the Appalachians of the Atlantic coast. The groupings of fossils at the base and those at the top show very considerable difference in the fauna, but the mingling of species throughout the beds has rendered it difficult to draw any line of separation. Many of the species characteristic of a restricted horizon elsewhere have been identified in the Nevada limestone, but with a wide vertical range, and in some instances have reversed their relative positions, as recognized in New York state. At no distant day, when the epoch becomes still better known and comparative studies have been made with other localities in the Great Basin, it may be quite possible and even desirable that such divisions should be drawn. At present, however, it will be quite sufficient to speak in general terms of an upper and a lower horizon.

The Nevada limestone has yielded an exceedingly rich and well preserved fauna; certainly no epoch in the Great Basin can surpass it in general interest, either in the variety of its organic forms, in the number of species determined, or in the commingling of species found elsewhere in widely separated localities. This terrane alone has yielded more species than the Cambrian and Silurian periods together, and surpasses the entire Carboniferous, with its great thickness and wide areas, by more than one hundred specific forms. From Eureka and White Pine together it has furnished over two hundred species, of which one-third have been described for the first time in the report of Mr. C. D. Walcott;[1] while, a fact of great interest as regards geographical distribution, one hundred and nineteen of them are specifically identical with previously described forms from other well known Devonian localities, and no less than seventy-nine of them have been identified with species occurring in New York. The Upper Helderberg, Hamilton, and Chemung are all well represented so far as species are concerned, although the vertical range of certain species by no means agrees with the limits assigned to them in New York. In comparing the Nevada limestone of the Great Basin with the Devonian of New York state, Mr. Walcott says:

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[1] Paleontology of the Eureka District, Monograph VIII. Washington, 1884.

The Upper Helderberg horizon of the New York series is represented by thirty-eight species common to it and the lower portion of the Devonian of the Eureka district; the Chemung group of the same by sixteen species; of the Hamilton species of New York twenty-three are distributed through the lower portion of the Eureka Devonian limestone and eighteen species in the middle and upper portions, but not in such a manner as to distinguish a middle division corresponding to the Hamilton formation of New York. Of strictly Hamilton species in New York, twenty-three are found, of which eleven are in beds a little below the summit, and twelve just above the base of the formation.

Eleven species not known in New York are common to both the Great Basin and Iowa, thus emphasizing the faunal relations between the corresponding horizons in the Cordillera, the Mississippi Valley and the Appalachians.

While the fauna at Eureka is rich and varied, both in genera and species, remains of Devonian fishes appear to be restricted to a single ctenacanthus-like tooth. Mr. S. F. Emmons, while engaged on the Fortieth Parallel Exploration, brought in a small tooth of the genus *Cladodus* from the western entrance to Emigrant Canyon, in the Tucubit Mountains north of Humboldt River. These two single specimens, collected at widely separated points, are all that is known of Devonian fishes from Central Nevada, although from Northern Arizona, in the Kanab Canyon, Mr. C. D. Walcott[1] obtained abundant evidence of the presence of placoganoid fishes from Devonian beds, which were represented by only 100 feet of strata as against 8,000 feet in Nevada.

Corals occur throughout the Nevada limestone and certain species present a wide vertical range. Among these *Stromatopora* are known from base to summit, and in one or two horizons they are found in such profusion as to characterize the strata by the peculiar weathering-out of the imbedded silicified corals. In the siliceous limestone of the Upper Devonian, fragments of *Syringopora* associated with *Stromatopora* are occasionally abundant when all other species are wanting. The bedded limestone on both sides of the Yahoo Canyon offer favorable conditions for the preservation of these forms. Prior to the survey of the Eureka District the *Lamellibranchiates* were poorly represented from the Great Basin. To a meager list almost

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[1] Am. Jour. Sci. Sept., 1880.

wholly collected by the Geological Exploration of the Fortieth Parallel, Eureka has now furnished no less than twenty-three genera and thirty-five species.

In the collections from Eureka, occur two species, first described by Mr. F. B. Meek,[1] *Orthis macfarleni* and *Rhynchonella castanea*, from the Mackenzie River. Both of these important species were brought to this country by the late Mr. Robert Kinnicut, and were found associated together on the Lockhart River, a tributary of the Mackenzie, in latitude 67° 15′ north, longitude 126° west, while the *Orthis* was also obtained in a very similar limestone 40 miles below Fort Good Hope, on the Mackenzie. According to Mr. A. K. Isbister,[2] who traveled extensively in Northern British America, along the base of the Rocky Mountains, and who published a sketch map of its geology, the Devonian extends through the valley of the Mackenzie from its mouth southward for 15° of latitude, nearly, if not quite, to the headwaters of the Saskatchewan River. It certainly is of considerable interest to find these two species, which occur together in the Arctic regions, associated at Eureka in the upper members of the Lower Devonian They are found near Woodpeckers Peak, about 3,000 feet above the base of the limestone, while *R. castanea* was also obtained from the upper horizon at Rescue Hill.

Within the area covered by the Nevada limestone collections of fossils were made more or less complete from nearly forty localities. For the purpose of this volume it seems hardly desirable to publish the lists in full, and such only are made use of as may be necesesary to elucidate for geological purposes the faunal development and also to point out clearly upon what evidence the division into two groups is based. Of the 6,000 feet included within the epoch, 4,000 are provisionally assigned to the lower and 2,000 to the upper horizon. About two-thirds of the species belong to the lower and one-third to the upper, corresponding roughly to the relative thicknesses of the two horizons. The upper portion of the limestone, however, represents a fauna equally varied, although not so complete, as the lower. So far as they have been studied the upper and lower horizons furnish quite characteristic faunas, with only seventeen species which may

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[1] Trans. Chi. Acad. Sci., vol. I, pt. 1, 1867-'69, p. 88.

[2] Quarterly Journal, Geological Society, vol. XI, London, 1855, p. 497.

be considered as common throughout the epoch. The following list comprises the species common to both upper and lower horizons:

Stromatopora, ?
Syringopora perelegans.
Streptorhynchus chemungensis var. pandora.
Orthis tulliensis.
Strophodonta perplana.
Chonetes deflecta.
Productus hallanus.
Productus shumardianus.
Productus shumardianus, var. pyxidatus.
Productus subaculeatus.
Spirifera piñonensis.
Spirifera (M.) maia.
Atrypa recticularis.
Rhynchonella castanea.
Nyassa parva.
Paracyclas occidentalis.
Styliola fissurella.

A complete systematic list of all the genera and species known from the Nevada limestone at Eureka and White Pine tabulated into an upper and lower group, will be found as an appendix at the end of this volume.

At Eureka, above the light gray, crystalline strata carrying the *Halysites*, and somewhere near the base of the Nevada limestone, the beds begin to yield *Atrypa reticularis*, *Spirifera*, *Stromatopora*, and *Edmondia*, which have a wide vertical range, all but the latter extending well up nearly to the top of the limestone. The lowest well defined fossiliferous belt carrying a decided Devonian fauna is found at Lone Mountain not far above the Silurian line. The fauna is uncommonly rich in species, no one locality having furnished quite as many forms. They occur in shaly strata in belt No. 2 of the Lone Mountain section. No less than fifty-two species were obtained from this horizon. The list of fossils is as follows:

Lingula læna.
Lingula lonensis.
Discina, sp.?.
Pholidops bellula.
Pholidops quadrangularis.
Orthis impressa.
Skenidium devonicum.
Streptorhynchus chemungensis, var. perversa.
Strophomena rhomboidalis.
Strophodonta arcuata.
Strophodonta calvini.
Strophodonta pattersoni.
Strophodonta perplana.
Strophodonta punctulifera.
Chonetes filistriata.
Chonetes hemispherica.
Chonetes macrostriata.
Productus shumardianus.
Productus subaculeatus.
Productus navicella.
Spirifera piñonensis.
Spirifera raricosta.
Spirifera varicosa.
Nucleospira concinna.
Trematospira infrequens.

Atrypa desquamata.
Atrypa reticularis.
Meristella nasuta.
Rhynchonella tethys.
Cryptonella circula.
Pentamerus comis.
Pterinea flabella.
Mytilarca dubia.
Plethomytillis oviforme.
Modiomorpha altiforme.
Modiomorpha obtusa.
Goniophora perangulata.
Megambonia occidualis.
Edmondia piñonensis.
Paracyclas occidentalis.
Microdon macrostriata.
Anadontopsis amygdalæformis.
Schizodus orbicularis.
Platyceras nodosum.
Loxonema nobile.
Bellerophon pelops.
Tentaculites gracilistriatus.
Orthoceras (2 sp.?).
Beyrichia occidentalis.
Phacops rana.
Dalmanites mecki.
Prœtus marginalis.

About 500 feet above this belt, in the dark gray limestone, occurs a group of fossils, mainly silicified corals, as follows:

Paleomanon roemeri.
Stromatopora.
Favosites basaltica.
Favosites hemispherica.
Favosites, n. sp.
Syringopora perelegans.
Cyathophyllum davidsoni.
Cyathophyllum rugosum.
Diphyphyllum simcoense.
Cystiphyllum americanum.
Zaphrentis, sp.?.
Atrypa reticularis.

Above this latter grouping only a few fossils were found, mainly species like *Atrypa reticularis* and *Styliola fissurella*, which occur all through the epoch. In this long list of species from the base of the Devonian at Lone Mountain, only seven forms occur which are known in the Upper Devonian, the list as a group being decidedly Lower Devonian in character. *Skenidium devonicum* is the only species of this genera which is known above the Silurian, while *Atrypa desquamata*, here associated with *A. reticularis*, occurs only in the lower beds. The Devonian trilobites in this list occur in nearly all the other fossil-bearing beds at the base of the Nevada limestone—namely, Combs Peak, Atrypa Peak, Brush Peak—but are not found in the middle or upper horizons. It will be noticed that the list includes quite a number of species usually regarded as characteristic types of the Upper Helderberg.

At Combs Mountain, Atrypa Peak, Brush Peak, Modoc Peak, and several other localities occur fossiliferous calcareous shale bands well defined lithologically, which present much the same aspect at each place, with a similar Lower Devonian fauna, many of the forms being specifically identical. The evidence goes to show that they belong essentially to the same horizon, although the estimated vertical distance of the beds above the Eureka quartzite varies considerably in the different localities. This difference is undoubtedly due in part to the varying thickness of the underlying Lone Mountain beds resting on the quartzite and partly to the more rapid changes in some places than in others in the nature of the sedimentation. In certain localities, under favorable conditions, the calcareous shale seems to have been deposited earlier than elsewhere. In other words, the shale belts are not absolutely synchronous; in some places they are known to be wanting. They may be taken as representing characteristic horizons in the Lower Devonian without at the same time occupying a sufficiently definite position to be made a datum point in determining the thickness of the strata between the shale belt and the basal member of the epoch.

The following list includes all species obtained from the calcareous shale belts of Brush Peak, Atrypa Peak, and Combs Mountain. The numerals affixed opposite the name of each species indicate from which of the three localities they have been obtained. In this way it will be seen at a glance which forms are common to more than one of these typical localities.

– – 3	Stromatopora.
– 2 –	Favosites basaltica.
1 – 3	Favosites n. sp.
– – 3	Pachyphyllum woodmani.
– 2 3	Zaphrentis.
– 2 –	Lingula whitei.
1 2 –	Orthis impressa.
1 2 3	Streptorhynchus chemungensis.
– 2 3	Streptorhynchus chemungensis, var. pandora.
– 2 –	Streptorhynchus chemungensis, var. perversa.
1 – 3	Strophodonta calvini.
– 2 –	Strophodonta demissa.
– 2 3	Strophodonta inequiradiata.
– 2 3	Strophodonta perplana.
– 2 –	Strophodonta punctilifera.
1 2 –	Chonetes deflecta.
– 2 3	Chonetes filistriata.
1 – –	Chonetes granulifera.
1 – –	Chonetes hemispherica.
1 2 –	Chonetes macrostriata.
– 2 –	Productus navicellus.
– 2 –	Productus subaculeatus.
– 2 –	Productus truncata.
1 2 3	Spirifera piñonensis.
– 2 –	Spirifera undifera.

– – 3 Spirifera sp.?.
– 2 – Atrypa desquamata.
1 2 3 Atrypa reticularis.
1 2 – Rhynchonella horsfordi.
– – 3 Rhynchonella occidens.
– – 3 Rhynchonella tethys.
– – 3 Pentamerus comis.
– 2 – Leipteria rafinesqui.
– 2 – Limoptera sarmentica.
– 2 – Mytilarca sp.?.
– 2 – Modiomorpha oblonga.
1 – – Modiomorpha obtusa.
– 2 – Goniophora perangulata.
– 2 3 Edmondia piñonensis.
– – 3 Sanguinolites combensis.
1 – – Sanguinolites gracilis.
– 2 – Sanguinolites sanduskyensis.
– – 3 Conocardium nevadensis.
– 2 – Posidomya devonica.
– 2 – Posidomya lævis.
– 2 – Microdon macrostriata.
– 2 – Schizodus orbicularis.
– 2 – Cypricardinia indenta.
– 2 3 Platyceras carinatum.
1 – 3 Platyceras conradi.
– 2 – Platyceras dentalium.
1 – – Platyceras thetiforme.
– – 3 Platyceras thetis.
1 – – Platyceras undulatum.
1 – 3 Platyostoma lineata.
– 2 – Ecculiomphalus devonicus.
– 2 3 Euomphalus eurekensis.
– – 3 Calonema occidentalis.
– 2 – Cyclonema (like C. multilera).
– 2 – Loxonema approximatum.
– 2 3 Loxonema nobile.
– – 3 Loxonema subattenuata.
– 2 – Bellerophon neleus.
1 2 3 Bellerophon perplexa.
– 2 – Scoliostoma americana.
1 – – Tentaculites attenuatus.
– – 3 Tentaculites scalariformis.
– 2 – Hyolithes sp.?.
– 2 – Orthoceras sp.?.
– – 3 Goniatites desideratus.
1 2 3 Phacops rana.
1 2 3 Dalmanites meeki.
– – 3 Proetus marginalis.

[No. 1, from the south slope of Brush Peak. No. 2, from the shale belt of Atrypa Peak. No. 3, from the west spur of Combs Mountain.]

The shale belt of Brush Peak promises to the collector a most varied fauna of Lower Devonian species. It measures about 150 feet in thickness and may be traced along the west side of both Brush and Modoc peaks; thence still farther northward, where its connection is clearly made out with shale belt No. 3, of the Devonian section, south of Signal Peak. On the southeast slope of Atrypa Peak the shale belt crosses the spur striking N. 30° E., dipping 40° W. The beds are of a light bluish gray color about 150 feet in thickness. The horizon corresponds to the fossiliferous shale belt in the section east of Lamoureux Canyon (p. 67).

Combs Mountain presents upon its south side a fine display of massive limestone beds dipping northward into the mountain. There is exposed here between the base of the mountain and the summit of the ridge nearly 5,000 feet of strata. No line of demarcation can be drawn here between the Lone Mountain and Nevada epochs. Fossils were rarely met with except in well defined strata, separated by long vertical intervals. The Trenton horizon, which is well represented, is estimated at 300 feet in thickness, resting immediately upon the Eureka beds. From the top of the Trenton the section across the beds is strikingly similar to those observed at Atrypa and Brush peaks. Careful estimates place the fossiliferous shale at 1,700 feet above the Trenton or 2,000 feet above the Eureka quartzite. This is the same vertical distance above the quartzite assigned to the shale belt at Atrypa Peak, although at the latter locality the Trenton limestone is not recognized either by its physical features or its organic forms. From the shale belt to the top of the ridge the only species secured were corals having a wide vertical range or else fragments too imperfect for specific description. A comparison of the species obtained in the three shale belts, taken together with the stratigraphy of the beds, proves without much doubt the equivalency of the Combs Mountain shale with those at Atrypa and Brush peaks.

In the County Peak body of limestone the lowest organic remains obtained occur midway in the siliceous limestone beds of No. 6, of the County Peak section (p. 68). Here the gray and blue limestone of No. 8 is assigned to the base of the Devonian, which places the fossil-bearing bed about 1,000 feet above the Silurian. The species recognized are *Edmondia piñonensis*, *Atrypa reticularis*, *Spirifera* sp. ?. and *Cladopora* sp. ?.

Passing upward for 2,000 feet above this last bed, or 3,000 feet above the base, and in about the middle of the great limestone belt (No. 2), there occurs in a thinly bedded bluish gray limestone an interesting grouping of species characteristic of the middle Devonian, or rather a mingling of species from both upper and lower horizons. The bed, owing to its marked lithological features, may be traced by the eye for long distances along the slope of the mountains. At Woodpeckers Peak, where the collection was made, the fauna is by no means as large or as varied as that found in the lower shale belt. While many species are identical with those found at the lower horizon, and present a decided Lower Devonian aspect, the greater part of them are common to both Upper and Lower beds. It is at this locality that the two Mackenzie River species are seen associated together in the same matrix. The following is the list of species collected at Woodpeckers Peak:

Orthis macfarleni.
Streptorhynchus chemungensis, var. pandora.
Streptorhynchus chemungensis, var. perversa.
Rhynchonella castanea.
Strophomena rhomboidalis.
Chonetes deflecta.
Productus hallanus.
Productus subaculeatus.
Productus truncatus.
Spirifera (M.) maia.
Atrypa reticularis.
Nyassa parva.
Edmondia piñonensis.
Paracyclas occidentalis.
Metoptoma devonica.

On the south slope of Sentinel Peak, southeast of the last locality, at about the same horizon as the grouping of fossils, a small collection was obtained, all but two of them being identical with those observed at Woodpeckers Peak, and all of them, without exception, forms recognized from the Upper, as well as the Lower, horizon. The two species not known at Woodpeckers Peak are *Styliola fissurella* and *Lingula ligea*, var. *nevadensis*, the former common throughout the Nevada limestone, and the latter a Hamilton species of New York state, collected also from Rescue Hill, of the Upper Devonian.

Another 1,000 feet of limestone reaches the dark blue massive beds in the upper part of No. 1 of the County Peak section. If the somewhat arbitrary line, provisionally drawn between the Upper and Lower Nevada limestones, is correctly placed about 4,000 feet above the base of the Devonian, these beds would lie at the base of the upper series. In all probability they belong to the Upper Nevada limestone, although there is nothing sufficiently distinct in the meager fauna obtained to determine the question definitely. The only species observed which is at all restricted in its range is *Spirifera engelmanni*, a form common to the highest members of the epoch, but nowhere as yet found lower down than these intermediate strata. Somewhat higher beds give much the same grouping of fossils, and in several localities *Spirifera engelmanni* has been recognized. The highest horizon in this great mass of limestone from which fossils have been obtained is in a well stratified blue bed near the mouth of Packer Basin, where the fauna has a decidedly Upper Devonian aspect. Among the species collected here are

Spirifera engelmanni and the two *Chemung* forms, *Rhynchonella duplicata* and *R. sinuata,* both found at several localities in the Upper Nevada limestone.

Rescue Hill, on the east side of Rescue Canyon, is a faulted block of Devonian limestone. Along the abrupt east slope of the hill the north and south Rescue Canyon fault cuts off the limestone from that found on the opposite side of the canyon, while an east and west fault, approximately coinciding with the course of Silverado Canyon, intersects the Rescue Canyon fault, and separates the hill from the limestone body to the north. The beds forming the summit of Rescue Hill belong to strata somewhat higher in the series than those found on the summit of Sentinel Peak and Island Mountain, but the lower limestones of the three localities may be easily correlated. In a light bluish gray limestone just below the top of Rescue Hill the following grouping of fossils occurs:

Lingula ligea, var. nevadensis.
Productus hallanus.
Productus shumardianus.
Productus stigmatus.
Productus subaculeatus.
Spirifera (M.) maia.
Atrypa reticularis.
Rhynchonella castanea.
Rhynchonella duplicata.
Rhynchonella (L.) laura.
Rhynchonella nevadensis.
Rhynchonella sinuatus.
Cryptonella piñonensis.
Mytilarca chemungensis.
Leptodesma transversa.
Nucula rescuensis.
Nucula (like N. niotica, Hall).
Grammysia minor.
Sanguinolites ventricosus.
Paracyclas occidentalis.
Platyceras carinatus.
Bellerophon pelops.
Naticopsis, sp.? (like N. æquistriata, Meek).
Tentaculites gracilistriatus.
Styliola fissurella.
Prœtus haldermanni.

The Rescue Canyon fault, as already described, is a profound displacement. After crossing Silverado Canyon at the head of Rescue Canyon, it extends northward until concealed beneath the great basalt flow. By reference to the map (atlas sheets VIII and X) the course of the fault will be seen along the base of Sugar Loaf and Sentinel Peak. In the faulted block to the eastward there occurs a wedge-shaped mass of Devonian limestone lying north of Silverado Canyon and east of Island Mountain and Sugar Loaf. It conformably underlies the great body of White Pine shale and admirably shows the relation between the Nevada limestone and the overlying shale. These beds directly underlying the shale are of course the uppermost members of the Nevada limestone. The following section gives the sequence of beds from the Quaternary plain westward across the White Pine shale and the underlying limestone until the beds are cut off by the fault.

	Feet.
1. Shaly sandstone followed by 50 feet of dark argillaceous shale and a great thickness of arenaceous shale and thinly bedded sandstone; occasional beds of fine siliceous conglomerate; constant changes from shale to sandstone	1,000
2. Black argillaceous shale passing into arenaceous shale and shaly sandstone becoming distinctly bedded and passing up into a fine siliceous conglomerate. Throughout the series are occasional thin belts of argillaceous shale	400
3. Gray crinoidal limestone in layers of varying thickness and more or less sandy; carries *Chonetes*	50
4. Dark bluish black argillaceous and calcareous shale weathering yellow on the surface; fossiliferous	300
5. Blue limestone with alternating thin massive layers; fossiliferous	250
6. Siliceous limestone passing into gray limestone with irregular seams and nodules of calcite	150

The lower gray limestone carries no fossils.

In the massive blue limestone (No. 5) occur the following Upper Devonian species:

Productus shumardianus.
Spirifera engelmanni.
Atrypa reticularis.
Rhynchonella duplicata.
Leperditia rotundatus.
Styliola fissurella.

In the overlying 300 feet of clay shales (No. 4) the more calcareous portions carry *Spirifera engelmanni* and *Productus shumardianus*, while in the more argillaceous strata are numerous imperfect plant remains.

The gray limestone (No. 3) overlying the black shale is characterized by typical Devonian forms: *Chonetes mucronata*, *Spirifera engelmanni* and *Beyrichia occidentalis*. Above this latter limestone in the clayey and sandy strata (Nos. 1 and 2) no invertebrate forms have as yet been obtained, but numerous fragments of plant remains, some of which would doubtless admit of generic determination, are abundant. A careful search for a Devonian flora would yield important results. The evidence of the Devonian age of the upper 1,400 feet of shales and sands is apparent, from the identity of the plants with those obtained from the black shale below the gray limestone as well as from the character of the sediments.

Another locality where the Nevada limestone and White Pine shale are structurally well shown with a typical fauna in both horizons is found at Newark Mountain. The mountain presents a bold impressive mass of bluish gray limestone with the physical features of the Upper Devonian strata. The section here is as follows:

	Feet.
1. Black argillaceous shale more or less arenaceous and similar to the lower black shale	1,000
2. Compact fine grained sandstone with minute dark siliceous pebbles scattered through the beds	100
3. Black argillaceous shale with fine intercalated beds of arenaceous shale. These shales crumble on exposure to atmospheric influence	500
4. Reddish gray shaly calcareous beds	100
5. Dark gray heavily bedded siliceous limestone passing into bluish gray limestone in places finely banded	3,500

Several hundred feet below the top of the Nevada limestone and calcareous shale the limestone yielded a small group of fossils, some of them common to both the upper and lower horizons, but none of them characteristic of the Lower Devonian.

Stromatopora.
Strophodonta perplana.
Productus shumardianus.
Spirifera disjuncta.
Spirifera piñonensis.
Atrypa reticularis.
Pterinea newarkensis.
Platyschisma maccoyi.

Immediately below the black shales, near the eastern end of Newark Mountain, the following species occur:

Orthis tulliensis.
Spirifera disjuncta.
Spirifera engelmanni.
Athyris angelica.
Atrypa reticularis.
Nyassa parva.
Straparollus newarkensis.
Beyrichia occidentalis.

Reddish gray calcareous shales pass rapidly into the argillaceous beds. Invertebrate remains wherever found in the black shale are imperfectly preserved so that specific determinations are in most instances out of the question. From the lower beds were obtained *Aviculopecten* and a species of *Goniatites*, while the upper and rather more sandy beds have furnished a more varied material in which, according to Mr. C. D. Walcott, the facies is Devonian with a foreshadowing of the Carboniferous period. Among the genera found here are *Fenestella*, *Chonetes*, *Modiomorpha*, sp.?, *Cypricardinia*, sp.?, *Palaeoneilo*, sp.?, *Cardiomorpha*, sp.?, *Conocardium*, sp.?, and *Goniatites*. In only two cases were specific determinations possible:

Productus hirsutiforme and *Coleolus lævis.* Plant remains occur here similar to those found east of Sugar Loaf, but still less perfectly preserved. The identification of the flora from the former locality places the age of these beds without doubt at the top of the Devonian, in accordance with their stratigraphical position. The corresponding horizon at White Pine Mountain presents still stronger evidence of the Devonian age of the shale; but here, as well as at Eureka, little has been accomplished by investigating this ancient flora.

Passing to the Piñon Range and the Mahogany Hills in the northwest corner of the district, the Upper Devonian limestone is well exposed in massive beds lying beneath the Diamond Peak quartzite. It is easily determined by its lithological habit and fauna, as well as by its geological position beneath the Carboniferous quartzite. Fossils are known in a number of places, but the localities which have furnished the largest and most varied fauna and offer the most promising return are found on the east side of Yahoo Canyon and north side of The Gate. Near the entrance to Yahoo Canyon the beds have yielded a rich fauna characterized by silicified corals. The grouping here is as follows:

Stromatopora.
Alveolites rockfordensis.
Cladopora pulchra.
Syringopora hisingeri.
Syringopora perelegans.
Cyathophyllum corniculum.?
Pachyphyllum woodmani.
Spirifera glabra, var. nevadensis.
Spirifera disjuncta.
Atrypa recticularis.
Rhynchonella castanea.
Styliola fissurella.

On the north side of The Gate, at a little higher horizon and directly beneath the quartzite, there is exposed a fine section, 500 feet in thickness, of massive blue limestone, passing into shaly beds, in places almost fissile. Fossils characteristic of the Upper Devonian are abundant throughout the beds. The limestone yielded the following species:

Stromatopora.
Syringopora hisingeri.
Syringopora perelegans.
Cyathophyllum corniculum.
Discina minuta.
Orthis impressa.
Orthis tulliensis.
Productus lachrymosa, var. lima.
Productus schumardianus.
Productus speciosus.
Productus stigmatus.
Productus subaculeatus.

Spirifera disjuncta.
Spirifera engelmanni.
Athyris angelica.
Atrypa reticularis.
Rhynchonella pugnus.
Rhynchonella (L.) laura.
Rhynchonella (L.) nevadensis.
Rhynchonella (L.) sinuata.
Grammysia minor.
Sanguinolites rigidus.
Paracyclas occidentalis.
Euomphalus (P.) laxus.
Euomphalus, sp.?
Platyschisma ? ambigua.
Naticopsis, sp.?
Styliola fissurella.
Cytoceras nevadensis.
Orthoceras, sp.?

It is immediately overlying the limestone holding this fauna that the argillaceous, cherty beds occur which carry poorly preserved fragments of plant remains and the single species, *Discina minuta.* They probably represent the great development of the White Pine shale found upon the east slope of Newark Mountain, but they are not represented on the map, as they are recognized only in a few localities lying between the Nevada limestone and Diamond Peak quartzite.

CARBONIFEROUS ROCKS.

Although rocks of this period cover large areas and make up the greater part of many mountain ridges in the Great Basin, few localities offer better exposures of all the epochs into which they have been divided than that portion of the Diamond Range which lies within the limits of the Eureka survey. To the northeast and east of Eureka, Carboniferous rocks, more especially the limestones, present a greater thickness of strata than is shown here, but in most cases the single, narrow ridges fail to expose in any continuous section the entire series of rocks from base to summit. At Eureka the Carboniferous rocks have been estimated to measure 9,300 feet in thickness, which, however, does not represent the full development of the Carboniferous period, the Upper Coal-measures, the top of the Paleozoic system having suffered a very considerable amount of erosion. This upper limestone is by no means as thick as that found elsewhere.

The Carboniferous rocks have been subdivided into four epochs: First, Diamond Peak quartzite; second, Lower Coal-measure limestone; third, Weber conglomerate; fourth, Upper Coal-measure limestone.

Diamond Peak Quartzite.—This epoch, the base of the series, takes its name from Diamond Peak, where it is exposed on both flanks of the peak, dipping into the range with a synclinal structure. On the west side of the peak, where it attains its greatest exposure, it measures about 3,000 feet in thickness. Beds of this epoch are found only at Diamond Peak and on the opposite side of the valley in the region of The Gate. At the base of the horizon fine conglomerates firmly cemented together lie next the argillaceous shale of the White Pine epoch, but quickly give place to a more massive, usually vitreous, quartzite with a characteristic grayish brown color and breaking irregularly with a flinty fracture. Intercalated black cherty bands, carrying a more or less ferruginous matter, occur near the middle portion of the horizon. Near the summit the beds pass into thinly laminated green, brown and chocolate-colored schists and clay shales. The Carboniferous age of the epoch is determined by a narrow belt of blue limestone, which occurs interstratified in the quartzite about 200 feet above its base, in which the widespread species *Productus semireticulatus* occurs associated with an undetermined species of *Athyris*. As the fauna at the top of the black shales foreshadows the coming in of the Carboniferous, the presence of this characteristic *Productus*, with only a Carboniferous fauna higher up in the series, determines without question the geological position of the quartzite between the black shale and Coal-measure limestone.

Lower Coal-measure Limestone.—Beds of this epoch are found in a great number of ranges in Utah and Nevada, stretching all the way from the Wasatch to Battle Mountain, and the horizon has probably been better studied than any other in the Great Basin. The beds cover large areas at Eureka and offer better exposures than any other division of the Carboniferous. In the Diamond Range they overlie conformably the Diamond Peak quartzite, the transition beds passing rapidly from siliceous to calcareous sediments. In their lithological character and physical habit they do not differ essentially from the same beds elsewhere, except, perhaps, at their base, where they carry intercalated beds of chert, argillite, and gritty, pebbly limestone, with evidences of shallow water deposition. They pass rapidly, however, into purer gray and blue limestone, for the most part heavily bedded and distinctly stratified at varying intervals. In broad masses they resemble the Upper Nevada limestone, but are rather lighter in color in distinction from the dark blue and black of the latter horizon. No true dolomite beds of any considerable thickness have been recognized, 9·21 per cent being the largest amount of magnesium carbonate obtained in any of the rocks subjected to chemical analysis. Across their broadest development they measure about 3,800 feet in thickness, which is much less than has usually been assigned to this horizon in other mountain uplifts, more especially those lying eastward.

As the term Lower Coal-measure has been employed by most geologists to designate this epoch throughout the Great Basin, it has been thought best to retain the name provisionally, although not exactly applicable, as the epoch includes such a commingling of species from both the Upper and Lower Coal-measures that a separation of the beds seems quite impossible. Moreover, those distinctions which hold good in the Mississippi Valley are by no means always applicable to the Cordillera. In the present state of our knowledge of the Carboniferous limestone, it is impossible to establish subdivisions in either of the Coal-measure epochs, based upon faunal differences, owing to the fact that so many species extend through a wide vertical range, and so few characteristic species occur within restricted limits.

Lower Coal-measure Fauna.—As the limestones are in general favorable to the preservation of organic remains, fossil-bearing strata are found throughout the beds, and geologists are not so dependent upon definite horizons as among Lower Paleozoic rocks. About 100 species have been collected from this epoch, but most of those obtained from the upper and middle portions have already been recognized as occurring elsewhere in the Lower Coal-measures of the Great Basin. In comparison with the new species obtained from the Cambrian, Silurian and Devonian, the Carboniferous of Eureka offer singularly few forms new to science, but this, of course, may be accounted for by the thorough researches which have been made in this period elsewhere. At the base of the limestone the life is more varied and presents certain facts that are of both geological and biological interest.

Three salient features in the life of the Lower Coal-measures at Eureka call for special mention, and each is worthy of still further investigation: First, the occurrence near the base of the limestone of a fresh-water fauna; second, the varied development of the *Lamellibranchiates*, a class which has heretofore been but sparingly represented in the collection of Carboniferous fossils from the Cordillera; third, the mingling near the base of the horizon of Devonian, Lower Carboniferous and Coal-measure species in gray limestone directly overlying beds characterized by a purely Coal-measure fauna.

Fresh-water Life.—The lowest strata from which we have any record of organic life from this epoch are found at the extreme northeast corner of New York Mountain, and also near the railway cut immediately south of the Richmond furnaces. Both localities lie just east of the Hoosac fault, which brings up Carboniferous beds against the Silurian. But for the alluvial deposits, which occupy the valley, the beds of the two localities would probably be found to be continuous; the rocks in both are similar. There occur here 100 feet or more of fine clays and grits, interstratified with arenaceous and argillaceous limestones passing up into pure limestone, showing abrupt changes and rapid deposition. In these transition beds were found abundant evidence of a varied fresh-water life, it being possible to determine several distinct species. The shells indicate a shallow water fauna, as is also clearly established by the mode of deposition of the sediments. Mingled with these shells are a few fragmentary bits of twigs and stems of plant life, for the most part referable to a coniferous growth, and showing signs of having been washed down from a land surface that could not have been very far away. Mr. Walcott has briefly described three species: one belonging to the genus *Physa*, named by him *P. prisca;* another form is a pulmonate shell, allied to the genus *Auricula*, and to which he has given the name *Zaptychius carbonaria;* a third shell is related to, if not identical with, *Ampullaria*, and is provisionally named after the Director of the Geological Survey, *A. powelli.* The discovery of fresh or brackish water shells so low down in the Paleozoic and so remote from any known locality of similar beds renders their mode of occurrence one of peculiar interest.

Lamellibranchiate Fauna.—From the horizon of the Lower Coal-measures there have been collected over forty species of Lamellibranchiate shells, a class which heretofore has been but sparingly represented in the collections of Carboniferous fossils from Utah and Nevada. Indeed, all told, there have been but few species recognized from the Paleozoic of the Great Basin. Most of those collected at Eureka are new species, described for the first time, but allied to forms found in the Mississippi Valley and Atlantic States, while others appear to be identical with well known species A complete catalogue of the *Lamellibranchiates* will be found under the lists of Devonian and Carboniferous species in an appendix at the end of this volume.

Commingling of Carboniferous Species.—Prof. R. P. Whitfield and Dr. C. A. White have frequently called attention to the commingling of Lower Carboniferous and Coal-measure species in New Mexico, Colorado and Utah which, in the Mississippi Valley, are quite distinct and regarded as characteristic of one or the other of the two horizons. So far as known to the writer nowhere is this commingling of types more strikingly brought out than at Eureka. Moreover, here they are associated with species which, in New York and Ohio, are regarded as typical of the Devonian, several of them being restricted within a very limited vertical range. This grouping of fossils is found on a low hill on the west base of Spring Hill, a long monotonous ridge lying just to the east of the Hoosac fault and made up wholly of Lower Coal-measure strata. The beds of Spring Hill Ridge, along the fault, for the most part dip toward the east. On a small but prominent outlying hill on the western slope of the ridge they lie inclined toward the west, the result of an anticlinal fold within the main body of limestone. In this outlying hill occurs a well marked bed of arenaceous limestone dipping about 50° to the west towards the Hoosac fault and cropping out both on the east and west slopes of the hill; the same bed being recognized in the main ridge on the opposite side of the anticline. This limestone, which has been traced for short distances, both north and south, has furnished a most varied fauna. Owing to its paleontological importance, Mr. Walcott has given especial attention to the group and has distinguished over fifty forms, most of which he has specifically determined. About one-third of them he regards as identical with species found in the Mississippi Valley in Lower Carboniferous rocks, while many of them have usually been considered as restricted to that horizon. Associated with them, in sufficient force to show a commingling of types, occur characteristic Coal-measure fossils like *Athyris subtilita* and *Euomphalus subrugosus*. Mingled with these fossils, in the same strata, are the *Lamellibranchiates*, which present so striking a feature of the Carboniferous fauna. Notwithstanding the fact that the Devonian, at Eureka, furnishes an exceptionally rich fauna in *Lamellibranchiates*, nearly all the species found in the Carboniferous occur for the first time at this horizon, and but few, if any, specifically agree with the Devonian forms. This is all the more noticeable because species, which are identical with those found in New York and Ohio, are in the latter localities only recognized in restricted areas and in most instances from horizons low down in the Devonian. This is well shown by the species *Grammysia arcuata* and *Macrodon hamiltonæ*, both regarded as typical of the Hamilton group, while others like *Sanguinolites æolus* is referred to the Chemung and to the Waverly sandstone of Ohio.

The complete list of species from these strata is as follows:

Archæocidaris, sp. ?
Fenestella (3 sp. ?)
Discina newberryi.
Streptorhynchus crenistria.
Orthis resupinata.
Chonetes granulifera.
Chonetes verneuiliana.
Productus prattenianus.
Productus semireticulatus.
Spirifera camerata.
Spirifera neglecta.
Spiriferina kentuckiensis.
Athyris subtilita ?
Rhynchonella eurekensis.
Rhynchonella (Leiorhynchus type).
Aviculopecten affinis.
Aviculopecten eurekensis.
Aviculopecten haguei.
Aviculopecten peroccidens.
Aviculopecten, sp. ?
Myalina nessus.
Pterinopecten hoosacensis.
Pterinopecten spio.
Crenipecten hallanus.
Ptychopteria protoformis.
Pinna consimilis.
Pinna inexpectans.
Modiomorpha ambigua.
Modiomorpha ? desiderata.
Nucula insularis.
Nucula, sp. ?
Solenomya curta.
Macrodon truncatus.
Grammysia arcuata.
Grammysia hannibalensis.
Edmondia medon.
Sanguinolites æolus.
Sanguinolites æolus, var.

Sanguinolites næuia.
Sanguinolites retusus.
Sanguinolites salteri.
Sanguinolites simplex.
Sanguinolites striata.
Microdon connatus.
Schizodus cuneatus.
Schizodus deparcus.
Cardiola filicostata.
Euomphalus subrugosus.
Pleurotomaria nodomarginata.
Bellerophon textilis.
Naticopsis, sp. ?
Dentalium, sp. ?
Orthoceras randolphensis.
Orthoceras, sp. ?
Gomphoceras, sp. ?
Griffithides portlocki.

Below this horizon there is a bed of bluish gray limestone interesting on account of its grouping of Lower Coal-measure fossils without the presence of any of those species which might be regarded as indicating a lower stratigraphical position, but which are here found in the overlying strata. The list is small, but characteristic of the Coal-measures. It is as follows:

Fenestella, sp. ?
Streptorhynchus crenistria.
Chonetes granulifera.
Productus prattenianus.
Productus semireticulatus.
Spirifera camerata.
Rhynchonella eurekensis.
Griffithides portlocki.

Richmond Mountain Fauna.—There is some reason to believe that the intercalated arenaceous and calcareous strata lying at the base of the great limestone belt all the way from Richmond Mountain southward to Fish Creek Valley represents a portion of the chocolate-colored clay shales underlying the limestone of Diamond Peak, and referred to the upper members of the Diamond Peak quartzite. From the base of the Lower Coal-measure limestone along the Hoosac fault up to the capping of andesite lavas of Richmond Mountain the highly inclined strata measure about 1,800 feet. Fossils occur scattered throughout the limestones. From highly fossiliferous strata favorable for their preservation, a grouping of species was found which may be taken as typical of the entire epoch, although only in a few localities is the life so full and well represented. This list from the southwest base of Richmond Mountain is as follows:

Zaphrentis.
Fenestella, sp. ?
Lingula mytaloides.
Discina newberryi.
Streptorhynchus crenistria.
Chonetes granulifera.
Productus longispinus.
Productus nebrascensis.

Productus prattenianus.
Productus semireticulatus.
Spirifera annectans.
Spirifera camerata.
Spirifera leidyi.
Spirifera neglecta.
Spirifera rockymontana.
Spirifera striata.
Spirifera (M.) setigera.
Syringothyris cuspidatus.
Athyris hirsuta.
Rhynchonella eurekensis.
Camarophoria cooperensis.
Terebratula hastata.
Aviculopecten affinis.
Streblopteria similis.
Myalina congeneris.
Bellerophon, sp. ?
Metoptoma peroccidens.
Griffithides portlocki.

Along Carbon Ridge the limestones are well developed but have as yet yielded little calling for special comment as regards the life of the period. The limestone forming the top of Diamond Peak and the long Alpha ridge west of Hayes Canyon carry several fossiliferous strata at different horizons, but all of them present much of the same grouping of species. Near the summit of Diamond Peak a shaly limestone was found to contain

Polypora (like P. stragula).
Orthis resupinata.
Productus nebrascensis.
Productus semireticulatus.
Spirifera trigonalis.
Spirifera (M.) setigera.
Athyris roissyi.
Athyris hirsuta.
Griffithides portlocki ?
Camarophoria cooperensis.

It seems hardly necessary to repeat nearly similar lists from neighboring localities so long as there appears to be no marked change of fauna with the development of the limestones. Most of the species obtained proved to be specifically identical with those from the limestone body of Richmond Mountain and Carbon Ridge east of the Hoosac fault. The region of Diamond Peak does not offer as many species, but on the other hand it has not been as diligently searched. The Lamellibranchiate fauna was nowhere recognized in the region of Diamond Peak.

Weber Conglomerate.—Conformably overlying the Lower Coal-measures comes the Weber conglomerate, one of the most persistent and well defined horizons over wide areas of the Cordillera, stretching westward all the way from the Front Range in Colorado to the Eureka Mountains. It varies in the nature of the sediment with every changing condition, but it is nearly everywhere easily recognized as a siliceous formation between two great masses of Carboniferous limestone. In places it is made up of an admixture of calcareous and sandy beds; in others, of fine grits and shales; and, again, of nearly pure siliceous sediment, varying from fine to coarse grained, dependent largely upon the distance from any land area and depth of water in which it was deposited. Here at Eureka the material is exceptionally coarse with abundant evidence of shallow water deposition and the existence of a land surface not very far removed at the time the beds were laid down.

Two large bodies represent the Weber conglomerate at Eureka, one directly east of Carbon Ridge and the other overlying the Alpha Ridge west of Hayes Canyon. The former is not shown in its full development, the upper members being cut off by the Pinto fault, but the geological position of the latter is admirably brought out by the underlying and overlying limestones. Across their broadest development the beds have a thickness estimated at about 2,000 feet. They are well shown in long parallel ridges inclined at high angles, with a synclinal followed by an anticlinal fold. For the most part the formation is made up of coarse material of both angular and rounded fragments of red, brown and white grits, together with jasper, brown hornstone, and green cherty pebbles firmly held together by a siliceous cement. Interstratified in the coarse material are occasional beds of fine, yellow white sandstone, which has been used as a lining for the large smelting furnaces at Eureka. In certain beds the angular pebbles predominate, and in others the rounded, but in general there is a fair admixture of both varieties. Near the summit of the horizon a single belt of blue limestone comes in, which, however, in its lateral extension, may not be persistent. Considering the thickness and nature of these conglomerates, they present an exceptionally uniform appearance throughout, with almost no shale and but little limestone. No subdivisions need be drawn. Although the formation has yielded no fossils, its structural relations permit of its being easily correlated with the Weber conglomerate of northern and eastern Nevada. With the coarse conglomerates of the Weber at Agate Pass[1], in the Cortez Range, there is the closest resemblance; both areas must have been near the shore line of the Paleozoic sea, in central Nevada.

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[1] U. S. Geological Exploration of the Fortieth Parallel, vol. 2, Descriptive Geology, p. 574.

Upper Coal-measures.—Beds of this epoch are found conformably overlying the Weber conglomerate, their true geological position being admirably shown at the head of Hunters Creek (atlas sheet VIII) in a belt of limestone about one mile in length, west of the Weber conglomerate horizon. Both series of rocks dip to the west at high angles, the limestones, however, being cut off by a body of basalt which forms the mass of Basalt Peak and the Strahlenberg. A much larger body of this limestone is found forming the long uniform slope of Diamond Peak, although there its true position is obscured by longitudinal faults, which in places bring it in direct contact with the Lower Coal-measures and in others it abuts unconformably against the Weber conglomerate.

The thickness attained by the rocks of this epoch is nowhere exposed in the district, the overlying beds having either suffered removal by denudation or else been concealed beneath flows of igneous rocks. West of Diamond Peak a number of narrow valleys cross the limestone, but, as the inclination of the ridge coincides closely with the dip of the beds, they nowhere reveal any considerable thickness. The beds are estimated at 500 feet. In the northern and central portions of the state of Nevada the Upper Coal-measure limestones attain a development of nearly 2,000 feet. At Moleen Peak,[1] just south of the Humboldt River, they are estimated at 1,800 feet in thickness where they conformably overlie a heavy deposit of conglomerates in their essential features quite like the Weber conglomerate of Eureka. In the field the Upper Coal-measures may be distinguished readily from the Lower Coal-measures by their lighter color and greater prevalence of fine grained beds. These colors are light bluish gray and drab, the latter possessing a conchoidal fracture and compact texture. These compact limestones frequently present forms of erosion quite different from the coarse grained and granular limestones of the Lower Coal-measures. Throughout the horizon the limestones are interstratified with belts of grit and siliceous pebbles, held together by a calcareous cement, in which are intercalated thin beds of purer limestone. One or two prominent beds are apparently made up of quartz pebbles and fragments of an older limestone, carrying such fossils as *Fusilina cylindrica* and *Productus semireticulatus*,

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[1] U. S. Geological Exploration of the Fortieth Parallel, vol. 2, Descriptive Geology, p. 600.

as if indicating that they had been derived from the underlying Carboniferous rocks. The fossils, however, which are all Coal-measure species, might be derived quite as well from the Upper as from the Lower beds. A chemical examination failed to detect any beds of dolomite in the limestones, the highest amount of magnesium carbonate obtained being 1·33 per cent. This is not without interest, as it is the only limestone horizon in the Paleozoic series at Eureka free from dolomitic strata.

Upper Coal-measure Fauna.—This epoch has not yielded as large a number of species as the Lower Coal-measures and many of those found in the middle and upper beds of the latter are known to occur in both divisions of the Carboniferous limestone throughout the Great Basin. The following list comprises all those species obtained from the Upper Coal-measures which were not observed in the Lower Coal-measures:

Zaphrentis, sp. ?
Polypora, sp. ?
Orthis pecosi.
Retzia mormoni.
Terebratula bovidens.
Myalina subquadrata.
Ptilodictya carbonaria.
Ptilodictya serrata.
Productus punctatus.
Macrodon tenuistriata.
Pleurotomaria, sp. ?

A further search of the Lower Coal-measures might show several of these species, and in other localities outside the District it is by no means certain that they have not been found lower down. *Terebratula bovidens* is known to range throughout the Coal-measures; on the other hand *Productus punctatus*, a common form, seems to be restricted to the Upper Coal-measures in the Great Basin.

A narrow belt of yellowish gray, somewhat shaly, limestone, near the head of Hunter Creek, carries the following grouping of fossils:

Fusilina cylindrica.
Fusilina robusta.
Chaetetes, sp. ?
Orthis pecosi.
Productus longispinus.
Productus nebrascensis.
Productus prattenianus.
Productus punctatus.
Productus semireticulatus.
Spirifera camerata.
Spirifera rockymontana.
Spiriferina cristata.
Athyris subtilita.
Terebratula bovidens.
Myalina subquadrata.
Pleurotomaria (like P. turbiniformis).

At the extreme northern end of the district, on the west slope of Diamond Peak and north of Garden Creek, in a very similar limestone, the beds yielded as follows:

Fusilina cylindrica.
Chaetctes, sp. ?
Zaphrentis (fragments).
Ptilodictya (Stenopera) carbonaria, ?
Ptilodictya (Stenopera) serrata, ?
Productus pratteniaus.
Productus semireticulatus.
Spiriferina cristata.
Athyris subtilita.
Retzia mormoni.

A complete list of fossils from the somewhat restricted fauna of the Upper Coal-measures will be found at the end of this volume.

Carboniferous Coal.—In the first range to the east of the Eureka District, Carboniferous formations extend for miles along the edge of the valley which in a study of Paleozoic rocks present some points of more than ordinary interest. It is the only range in the Great Basin where coal of Carboniferous age has been discovered in anything like a well defined seam of sufficient thickness to encourage exploration, although beds carrying small amounts of carbonaceous matter are known in one or two other localities in central Nevada. Two outcrops of this coal are known and considerable exploration has been undertaken in order to determine the value of the coal seams; one is situated on a low flat hill known as Pancake Ridge, and the other on Bald Mountain, which stands out prominently at the southern end of the Humboldt Range. Pancake lies about eight miles to the westward of the Eureka District in a mass of low ridges connecting the Humboldt Range with the White Pine Mountains. Rising above the plain occurs a body of rhyolite, beyond which is a low ridge of coarse conglomerate followed by a second ridge somewhat higher than the first with an intervening valley or shallow depression. Along the western base of this second ridge an exposure of drab clay shales crops out only a few feet in thickness, striking approximately north and south with a low dip to the east rarely exceeding 10°. This clay carries a seam of lignite varying from 10 to 18 inches in width which may be readily traced for nearly 150 feet along the line of outcrop. Both above and below this coal seam are alternating layers of bituminous shale and purer clay shale conformably resting upon a bed of coarse conglomerate. Above the clay shales comes a bed of conglomerate about 25 feet in thickness made up mainly of rounded quartz pebbles followed by another belt of shale quite like the one below, 40 feet in thickness. In both series of shale occur beds of carbonaceous material and thin seams of impure coal, but nowhere on the surface are the exposures more than three inches in width. Still higher up is another belt of conglomerate carrying more or less lime and followed by buff colored massive limestone changing to brownish gray limestone followed by a cherty limestone, the latter extending to the top of the mountain. This series of limestones has an estimated thickness of nearly 1,000 feet. Fossils characteristic of the Coal-measures are common throughout the limestone, but are more abundant in the lower beds, more especially in those immediately above the coal, although no horizon presents any special faunal peculiarities. Scattered throughout the limestone occur the following species:

Zaphrentis centralis, ?.
Diphyphyllum, sp. ?.
Chaetetes, n. sp.
Discina, sp. ?.
Orthis pecosi.
Orthis resupinata.
Streptorhynchus crenistria.
Chonetes granulifera.
Productus cora.
Productus costatus
Productus semireticulatus.
Spirifera camerata.
Spirifera rockymontana.
Spiriferina kentuckiensis.
Retzia mormoni.
Athyris roissyi.
Athyris subtilita.
Terebratula bovidens.

This grouping may be said to present some distinctive features containing forms regarded as belonging to the Lower Carboniferous, mingled with others typical of the Coal-measures. *Zaphrentis centralis, Diphyphyllum* and *Athyris roissyi* give to the horizon a Lower Carboniferous aspect, while the relatively large number of Coal-measure species would ordinarily determine the position of the beds. Not only do the Coal-measure species outnumber the others, but several of them happen to be those forms like *Orthis pecosi* and *Retzia mormoni*, which have as yet been recognized only in the Upper Coal-measures. Nevertheless, the evidence of the fauna is strongly in favor of the lower horizon for these coal beds, as certain species are elsewhere unknown higher up in the Carboniferous, whereas it is a feature of the Coal-measure fauna of the Great Basin that it presents a wide vertical range.

Lithologically the evidence is not specially decisive. The series of beds at Pancake bear some resemblance to the section found at the base of Richmond Mountain, which, of course, indicates the base of the Carboniferous limestone. Such evidence, however, is not conclusive, as the beds also resemble and may be synchronous with the interstratified grits and limestones of the Upper Coal-measures, with which by far the greater number of the observed species are identical.

In exploring these coal seams for marketable coal considerable work has been done, although all operations had been abandoned three years previous to our visit. In places the vein was reported as 5 feet in width, although much broken up and displaced. A vertical shaft, said to be 180 feet in depth, had been sunk before the project was abandoned and several tunnels and inclines run along the line of the coal. Examinations could be made only in one tunnel, owing to the caving-in of the clay beds. Sixty feet from the entrance, where the seam measures 20 inches, samples of coal were collected. It closely resembles the lignites of the Green River basin. On exposure the coal crumbles readily.

Bald Mountain lies to the north of Pancake and is situated in the main ridge of the Humboldt Range. The coal or lignite outcrops are exposed near the base of the range in clay shales inclined at low angles toward the mountain. The mode of occurrence bears the closest resemblance to the strata at Pancake—interstratified conglomerates and shales followed by massive, distinctly bedded yellowish brown and buff limestones. At the time of our visit, in the autumn of 1880, the Bald Mountain Coal Company had run a tunnel from the outcrop for 160 feet into the mountain following the coal seam. At the head of this tunnel the coal strata measured only from 2 to 7 inches in width, passing into black carbonaceous clays. At this point there was more or less displacement of the strata, and this thin seam of coal was apparently cut off by a line of faulting, which put an end to further explorations, the poor quality and limited quantity of the coal discouraging any further outlay of money. A search of the black shale beneath the coal was rewarded by the finding of a number of fossils all belonging to the species *Athyris subtilita.* In the buff limestones, immediately above the coal, a small number of fossils were found:

Orthis pecosi.
Streptorhynchus crenistria.
Productus cora.
Productus semireticulatus.
Spirifera rockymontana.
Athyris subtilita.
Retzia mormoni.

They represent a distinctively Coal-measure fauna and are identical with forms collected from beds at Pancake. On the other hand, none of the species obtained at Pancake, indicating the horizon at the base of the Lower Coal-measures, have as yet been found at Bald Mountain. In this grouping at Bald Mountain there is nothing to prevent the horizon from being considered as belonging to the Upper Coal-measures, but it is hardly possible to suppose that the geological position of these beds differs from the position of the coal at Pancake. The geological mode of occurrence at both places and the sections across the beds indicate that the coal comes from near the same horizon, and was deposited under similar conditions, with the probabilities in favor of their having at one time formed a continuous coal area.

The following analyses of samples of these coals, collected at the time of our visit, are given here for the purpose of showing the character of the deposits. They were made by Dr. W. F. Hillebrand, of the U. S. Geological Survey.

	No. 1, Pancake.	No. 2, Bald Mountain.
Moisture	6·17	2·60
Volatile matter	31·88	30·97
Fixed carbon	55·59	44·60
Ash	6·36	21·83
Total	100·00	100·00
Sulphur in pyrites	0·73	5·44
Sulphur in soluble sulphates	0·79	0·14

The coals do not cake or sinter.

These coals, while they are of no commercial value, are of geological importance from their exceptional mode of occurrence in the Carboniferous rocks of the Great Basin. A further search would doubtless indicate whether they belong to the base of the Lower Coal-measures or to the middle of the Upper Coal-measures.

CHAPTER V.

DESCRIPTIVE GEOLOGY.

In the following pages will be found a detailed description of the sedimentary rocks in the Eureka District, the order followed being for the most part the same as that adopted in the chapter devoted to the general geological sketch. Each orographic block is described by itself, beginning with Prospect Ridge, where the oldest rocks occur, followed by the other blocks according to the geological succession of strata; the only changes made in the order of treatment being for the purpose of bringing out more forcibly the structural relations of the individual blocks to each other. This chapter necessarily contains a repetition of many facts stated in other portions of the volume, but at the same time there is an omission of many details that, if not presented elsewhere, would properly find a place here.

The principal object of this chapter is to give a connected description of the country and to place numerous details in permanent form for the use of those who may wish to study the field in person, or who may desire to investigate more fully the facts upon which the generalizations are based. Certain portions of the country are described more fully than others, and in a few instances the descriptions follow closely those given elsewhere in the volume.

PROSPECT RIDGE REGION.

This region includes all the country lying between the Hoosac fault on the east side and the Spring Valley, Prospect Mountain, and Sierra faults on the west. These lines of faulting sharply outline a mountain block which, in its geological structure, stands out on all sides clearly defined from the adjacent country.

Along the east side of the Hoosac fault no sedimentary rocks are known other than those belonging to the Lower Coal-measures, while on the west side of the other three faults only Silurian and Devonian beds are brought up against the fault line. In this uplifted mountain mass lying between these great lines of faulting occur all the Cambrian rocks exposed in the district, with the exception of two small patches of limestone, one of Prospect Mountain limestone and one of Hamburg limestone, found on the west side of Surprise Peak, one-half mile to the westward of the line of the Sierra fault. They occur in a region of much local disturbance, not far from the body of hornblende-andesite which occupies the bottom of Sierra Valley, and are of no special geological interest otherwise than indicating great displacement of strata. This uplifted mass of Prospect Ridge measures 10 miles in length by about 2¼ miles in width across its broadest expansion, in the region of Prospect Peak, in places narrowing to one-half that distance. Within this block, evidence of minor fractures and dislocations are everywhere to be seen, influencing in a greater or less degree the geological structure of the country.

Jackson Fault.—Two faults, designated as the Jackson and the Ruby Hill, profound in their displacement and of great economic importance, deserve special mention; both of them, however, lie within the limits of the Prospect Ridge uplift. The Jackson fault starts in just north of the Eureka tunnel, in Goodwin Canyon, on the east side of the ridge, and may be traced northward along the line of contact between Prospect quartzite and the Hamburg limestone (atlas sheet VIII). It follows down the narrow ravine past the Jackson mine to the east of Ruby Hill and Adams Hill, and is lost near the body of quartz-porphyry just beyond the Wide West ravine. This fault brings up the Pogonip limestone of the Silurian against the entire series of Cambrian strata of Ruby Hill, from the lower quartzite to the Hamburg shales inclusive. On the east side of this fault exploration has failed to bring to light any large and permanent bodies of ore, if we except that of the Williamsburg mine; the more valuable mining properties in the immediate neighborhood of Ruby Hill being, for the most part, on the west side of the fault in the Cambrian rocks.

Ruby Hill Fault.—This fault starts in near the reservoir in New York Canyon, branching out from the Hoosac fault and running in a northwest direction. It cuts diagonally across the Pogonip limestone, and abruptly terminates the Hamburg limestone and Hamburg shale, which form such persistent topographic features of the country to the southward, and intersects the Jackson fault near the American shaft, just south of the Jackson mine (atlas sheet VIII). For a short distance this fault apparently coincides with the Jackson fault, then crosses it, following a northwesterly direction—the same course it held before the intersection with the great north and south fault. On Ruby Hill the fault may be traced in the underground workings of all the principal mines through to the Albion. It has exerted a most powerful influence upon the structure of Ruby Hill, and from its relations to the ore bodies its importance from a mining point of view can not be overestimated. Reference will be made to this fault in the discussion on the geology of Ruby Hill.

From Spring Valley eastward across Prospect Ridge and Hamburg Ridge to the Hoosac fault, the highly inclined strata offer an unbroken geological section from the lowest beds of the Cambrian to the Eureka quartzite of the Silurian. It offers the best section to be found in Nevada of the Cambrian rocks, with all the epochs into which it has been divided clearly defined. Sections across Prospect Mountain limestone may vary greatly in details within a few hundred feet in the relative thickness of compact limestone and calcareous shaly beds, but in general the sections across the entire thickness of the horizon coincide fairly well.

Section CD-EF (atlas sheet XIII), constructed across the central portion of the Eureka Mountains, intersects Prospect Ridge about 3,000 feet to the north of the peak, at a point selected to bring out the anticlinal structure of the mountains. The underlying quartzite is overlain on both sides of the fold by the Prospect Mountain limestone, which on the west side extends down to Spring Valley, while on the opposite side it forms not only the summit, but the entire east wall of the main ridge. This is in turn overlain by the remaining subdivisions of the Cambrian, all of which stand inclined at a uniformly high angle to the east. As the section is drawn across a high saddle at the head of New York Canyon, connecting Prospect Peak and Hamburg Ridge, the erosion of the Secret Canyon shale is not so well shown as it would be if the section had been drawn either to the north or south of this point, but it is quite sufficient to bring out the prominence of the Hamburg Ridge, which is everywhere parallel to the main ridge. Overlying the Hamburg shale occurs the Pogonip limestone, in turn followed by the Eureka quartzite, which occupy the long slope down to the Hoosac fault. The entire series of beds dips to the east, with angles varying from 75° to 85°. The section across these beds from the axis of the fold is as follows:

Prospect Ridge Section.

	Feet.		Feet.
Eureka quartzite	500	Compact vitreous white quartzite, indistinct bedding	500
Pogonip limestone	2,150	Massive siliceous dark gray limestone, occasionally black limestone, and a narrow band of quartzite midway	550
		Fine grained, evenly bedded, ash gray limestone, with more massive layers near the summit	1,250
		Calcareous shales, passing into thin-bedded limestones; bands of arenaceous sandstones and siliceous limestones	350
Hamburg shale	350	Yellow argillaceous shale, with thin layers of gray limestone; layers of chert nodules throughout the bed; cherty siliceous bands near the top	350
Hamburg limestone	1,200	Dark gray granular limestone; only slight traces of bedding; in places highly siliceous; beds brecciated in the upper portion.	1,200
Secret Canyon shale	1,600	Argillaceous shales, yellow and brown in color	750
		Massive-bedded gray limestone	100
		Argillaceous shales, yellow and brown in color	750
Prospect Mountain limestone	3,050	Massive, light gray limestones, passing into bluish gray and bluish black beds, with occasional bands of black limestone and light gray on top	1,250
		Fissile calcareous shales, with a thin band of green and drab-colored argillaceous shale, and bands of shaly limestone	350
		Massive gray limestones	700
		Argillaceous shales, ash gray in color; weathering red and yellow; layers of more compact limestone	350
		Light gray compact limestone, with thin seams of calcite through the massive layers	300
		Red and brown arenaceous shales	100
Prospect Mountain quartzite	1,000	Bedded vitreous quartzite; weathering dark brown; intercalated thin layers of arenaceous shales; beds whiter near the summit and more uniform in texture	1,000
Total thickness	9,850		

Along the line of this section there has been less faulting, crushing and local displacement than anywhere else on the ridge. Such local disturbance as has taken place in the uplifted mass is more apparent in the Prospect Mountain limestone than in the other horizons, partly owing to frequent changes in the physical conditions of the alternating beds of shale and limestone and partly to the fact that this series of beds forms the summit of the ridge and, lying nearer the axis of the fold, has been subjected to much greater pressure and strain. The shales, yielding easily to pressure, have folded and flexed under excessive strain, while the more compact limestones, under the same force, were faulted and fissured. Evidence of this is seen in the Mountain shale belt and the overlying limestone, the former exhibiting a tendency to flatten out and the latter to recover the normal dip by a sharp break, causing numerous fissures and faults. Since the first uplifting of the mountain, intrusive dikes of rhyolite have filled preexisting fissures and broadened lines of weakness, besides causing additional faulting and displacement. These intrusive masses, however, are for the most part narrow and have produced no fundamental structural changes, but much of the secondary alterations, such as local metamorphism of beds, the cementation of brecciated limestone, and similar phenomena, are easily explained by their action.

Numerous tunnels, run for the purpose of mining exploration, varying from 50 feet to several hundred feet in length, penetrate the Prospect Mountain limestone all along the ridge, at different elevations. Among them may be mentioned the Fourth of July, Maryland, Lemon, and Golden Era tunnels. Most of them, however, extend only for short distances, and, while they offer fair sections of portions of the great limestone belt and may have subserved the purposes of the miner, are of but little value for purposes of geological structure. Two tunnels, the Eureka and Prospect Mountain, running at right angles to the strike of the beds and from opposite sides of the ridge, give admirable sections across nearly the entire thickness of the limestone belt.

Eureka Tunnel.—The entrance to the Eureka tunnel is situated near the head of Goodwin Canyon, to the west of the Hamburg Ridge (atlas sheet VIII). The tunnel starts in near the base of the Hamburg limestone and is driven in a nearly due west direction for 2,000 feet, passing several hundred feet beyond the crest of the ridge and about 800 feet below. The following is the series of beds encountered in the Eureka tunnel, beginning at the entrance:

	Feet.
Black crystalline limestone (Hamburg limestone)	85
Argillaceous shale (Secret Canyon shale)	300
(Prospect Mountain limestone):	
Limestone	935
Calcareous shale	30
Brecciated limestone	51
Mountain shale	460
Stratified limestone	90
Brecciated limestone	50

The body of limestone near the entrance to the tunnel belongs to the base of the Hamburg limestone and is a small mass left by erosion upon the west side of Goodwin Canyon, the canyon for the most part having been eroded along the line of contact between the Hamburg limestone and the Secret Canyon shale. Where the tunnel enters the mountain the Secret Canyon shale pinches out to a few hundred feet, and, a short distance to the north, it is entirely cut off by the Prospect Mountain quartzite. At the tunnel the shales are only 300 feet in thickness. Through the Prospect Mountain limestone nearly all signs of stratification and bedding are wanting, the rocks everywhere showing evidence of crushing and local faulting. Evidence of movement is seen in the brecciated appearance of the limestone, which has been recemented by calcite. Fissures and seams nearly vertical are common, dipping slightly both to the east and west; the larger number of them being inclined toward the east. Dynamic action has caused such frequent changes throughout the limestone that it is difficult to recognize any belt by lithological distinctions. The narrow bed of shale, 30 feet in thickness, is a well defined belt, calcareous, and more or less argillaceous, but of little importance, simply foreshadowing the coming in of the broad belt of Mountain shale beyond. Whether it would be found to be continuous on further exploration, either to the north or south, is questionable. Beyond this narrow shale band occurs another limestone belt, similar to the main body, in turn followed by the Mountain shale, which, unlike the Secret Canyon shale, is characterized by intercalated limestone. It resembles the clay shale found on the surface, but is less pure than the Secret Canyon body. It bears a close resemblance to the shale belt found in the Prospect Mountain limestone of Ruby Hill, but there is no direct evidence of their ever having formed a continuous bed. Nowhere else on the ridge do the Mountain shales appear so broadly developed, 300 feet being the greatest thickness observed on the surface. Beyond this shale belt the limestone is occasionally stratified and then again occurs crushed and broken, showing that it has undergone much pressure; the stratified rock in general lying next the shale.

From a geological point of view the value of the tunnel lies in the evidence of the crushing, faulting and fissuring which the entire series of beds have undergone since the first uplift of the mountain, the changes in the character of the limestone being far better studied in the tunnel than on the surface. A marked fissure, slightly inclined to the east, occurs about 840 feet from the mouth of the tunnel. Stringers of ore, or rather indications of ore, are encountered all through the limestone, but few of them are of economic value, being mainly filled with calcite, oxide of iron and manganese and carrying but little lead and silver. At one point a nearly perpendicular pipe connects with the surface, but carries no ore. A small amount of ore was discovered near by, however, just north of the tunnel. The largest body of ore opened by the tunnel occurs nearly 1,200 feet from the entrance, the metal-bearing fissure running approximately north and south and standing nearly vertical. At the time of our visit this was the only ore body encountered which was of sufficient economic value to be profitably worked; but since then a fair amount of good ore has been extracted.

Prospect Mountain Tunnel.—This mining tunnel starts in at the west base of Prospect ridge at an elevation of about 7,200 feet above sea level (atlas sheet VII). It has been driven about 2,350 feet into the mountain, with a course a little north of west, but does not penetrate quite to the center of the ridge, the slope of the mountain being more gradual on the west than on the east side; if prolonged it would pass the crest of the mountain only a few hundred feet south of the Eureka tunnel. It lies wholly in the Prospect Mountain limestone, which, being less fractured and brecciated than the limestone toward the east, offers a more typical cross section, although there is but little well defined bedding. For the first 100 feet from the entrance the tunnel passes through a dark gray rock, beyond which it becomes much lighter in color and apparently uniform in texture for 500 feet. From this point frequent belts of crystalline white marble occur, alternating with compact light gray limestone. Specimens in the collection show a very fair quality of marble. A marked change in the limestone comes in about 1,500 feet from the entrance, where a fissure is met at right angles to the tunnel, inclined a few degrees to the west from the vertical; beyond this point the character of the limestone more closely resembles the brecciated rock found on the east side of the ridge, as shown in the Eureka tunnel. This resemblance is borne out by the appearance of a belt of stratified limestone, followed by argillaceous shale like the Mountain shale, but, as the latter occurs at the head of the tunnel and has not been fully explored, its true position is unknown; it may simply be one of the many lenticular shale bodies observed elsewhere in the Prospect Mountain limestone. One or two fissures were cut by the tunnel, but little ore was found, the most promising indication of an ore body being worked for a short time without any profitable return. At 475 feet from the entrance there is a well defined fissure connecting with the surface, sufficiently large to admit light and air. It evidently at one time formed a drainage channel for surface waters, as is shown by the smoothly rounded, water-worn sides. The Eureka and Prospect Mountain tunnels nearly pierce the ridge, the two taken together being over four-fifths of a mile in length.

Charter Tunnel.—The Charter tunnel lies mainly in the Prospect Mountain quartzite. The entrance is situated in the drift deposits of Spring Valley, just west of Mineral Hill, but soon after enters the quartzite, which here forms the western base of the ridge as it rises above the valley. In 1882 it had a total length of 700 feet, with a trend of N. 64° W., affording a good exposure across the beds. This tunnel, where it cuts the quartzite south of Ruby Hill, exposes narrow bands of highly altered rock, composed of fine siliceous material associated with monoclinic pyroxene and pyrites. On the ridge above the tunnel, and not far below the overlying limestones, occurs a band of exceedingly fine-grained rock, light green in color and made up of an aggregation of quartz, monoclinic pyroxene, white in thin section, probably diopside, and glossularite, a lime garnet. In the ravine immediately south of Ruby Hill is a small body of iron ore, which analysis shows to be magnetite. It possesses some interest from its position in the lower Cambrian rocks, but on account of the limited amount is of no economic value. Material dried at 104° C. yielded Mr. J. E. Whitfield the following result:

	Per cent.
Silica	5·29
Titanic acid	None
Sulphuric acid	·56
Alumina	·18
Ferric oxide	64·69
Ferrous oxide	18·96
Manganous oxide	1·16
Lime	·88
Magnesia	5·85
Water	2·68
Total	100·25

Prospect Ridge.—North of the Prospect and Eureka tunnels the main ridge loses its simple anticlinal structure and a synclinal fold, much distorted and broken, takes its place. From about the line of these tunnels to the northern end of Mineral Hill it is difficult to make out the structural features. The Prospect quartzite, which is obscured for some distance by the overlying limestone, reappears again along the west base of the ridge, curves around on the north side of the small body of granite exposed at the north end of Mineral Hill, and may be traced southward on the east side of Prospect Ridge in a continuous body until terminating abruptly near the Eureka tunnel, where it is cut off by a fault; its eastern extension is determined by the sharp line of the Jackson fault. Overlying the quartzite comes the Prospect limestone, forming the summit of Mineral Hill, with lines of bedding, although much obscured, dipping into the ridge on both sides of the hill. By reference to atlas sheet VII, the synclinal structure of Mineral Hill may be readily understood, the quartzite coming in along the base of the hill on both sides, with the limestone crushed and broken occupying the crest of the ridge.

That the small granite body at the northern end of Mineral Hill, directly opposite Ruby Hill, exerted an influence in determining the structure of Prospect Ridge, seems evident; but in just what manner it is difficult to say. The relation of this granite to the Prospect Mountain uplift will be more fully considered in discussing the geology of Ruby Hill.

South of Prospect Peak the limestone maintains a fairly persistent north and south strike and easterly dip, the angle of which seldom falls below 60°. These highly inclined beds occur for a long distance north of the Geddes and Bertrand mine. In the Irish Ambassador the beds lie inclined at 40°. In general, lines of bedding have been obliterated, but are found in sufficient number of instances to establish the structure, while a meager fauna affords ample evidence of the age of the beds. Near the Geddes and Bertrand mine in a compact limestone, the upper horizons of the Prospect Mountain limestone are identified by the occurrence of several species found also in the Richmond Mine on Ruby Hill, as well as by other forms found in the same belt just below the Secret Canyon shale. These beds yielded *Kutorgina whitfieldi*, *Ptychoparia oweni*, and *Agnostus bidens.* Lenticular beds of argillaceous shale are by no means as broadly developed as to the northward, but are of frequent occurrence and indicate the same alternating conditions of deposition. On the other hand cherty beds and highly siliceous dark limestones are very characteristic of the region. Occasionally thin siliceous beds, from their superior hardness, withstanding erosion better than the purer beds, rise like walls above the surrounding hill slopes. This latter feature frequently gives the limestone body quite a different aspect from that observed to the north and at the same time aids in determining the strike of the beds.

As already mentioned the Eureka quartzite on the west side of the Sierra fault lies unconformably against the Prospect Mountain limestone from Prospect Peak nearly to Surprise Peak. At this latter locality a body of Pogonip limestone abuts against the Cambrian limestone; the fault line, which has maintained a persistent direction, swerves suddenly eastward and then again turns and with a north and south course strikes across an easterly spur of Surprise Peak. On a broad shoulder of this spur the Prospect Mountain limestone again comes in contact with the Eureka quartzite of Surprise Peak, the line of faulting passing about 200 feet below the summit. Structurally the position of the Pogonip limestone is shown by its passing conformably beneath the Eureka quartzite. Paleontological evidence confirms this fact by the finding of a group of Silurian fossils which are characteristic of the upper beds of the horizon. Among the species found here on the north base of the Peak are *Orthis perveta*, *O. tricenaria*, *Raphistoma nasoni*, and *Receptaculites mammillaris*. The Prospect Mountain limestone follows around on the south side of Surprise Peak, thence southward until lost beneath the extravasated lavas, which encircle the ridge where it falls away toward Fish Creek valley. From Surprise Peak southward these limestones lie unconformably against Pogonip beds, the former standing at the usual high angles of 60° or more, and the latter also dipping eastward, but at angles varying from 35° to 45°.

Secret Canyon.—This canyon forms one of the most prominent physical features of the district, a deeply eroded valley lying between two parallel ridges, one of Prospect Mountain limestone and the other of Hamburg limestone. The canyon lends its name to the intermediate body of argillaceous shales which are better exposed here than elsewhere. For more than 2 miles in length the narrow valley is cut out of these easily eroded beds, the harder limestones rising upon each side in abrupt walls several hundred feet in height. There are few finer instances to be found anywhere of a valley carved out of soft friable material, the beds of which lie highly inclined and conformable with overlying and underlying strata of superior hardness, withstanding erosion better. No one overlooking Secret Canyon from any high point in the country would understand the appropriateness of the appellation; its true significance is recognized only when approached from the south. The course of the present drainage channel follows the trend of the shales until nearly opposite the southern end of Roundtop Peak, when, instead of maintaining its direction along the line of the shales for a short distance further and thence out through the Quaternary covered slopes to Fish Creek valley, it turns suddenly, follows a narrow defile obliquely through the ridge of Hamburg limestone and shale, carves its way through the Pogonip and Eureka quartzite, crosses the Hoosac fault, and is again deflected to the south only by Carbon Ridge. The reason for its leaving the valley of Secret Canyon is to be found in the rhyolite mass which probably underlies the hills of detritus near the entrance to the canyon, blocking the former drainage channel. This is, however, only a partial explanation, as it is difficult to understand why the stream should not continue on its course, cutting its way through the low rhyolite barrier, rather than turn to the east and follow the present course, which it finally took across the uplifted sedimentary beds. There seems no doubt that, before the rhyolite eruption, the stream bed followed the canyon and emptied directly into Fish Creek Valley.

Of the shale formation, little need be said in addition to the descriptions already given of the beds. They show great uniformity of deposition and physical character, monotonous in outline and color, and, so far as recognized, carry no organic remains. The sandy, limy transition strata into the Hamburg limestone generally offers better lines of stratification than either the shales below or the limestones above, and the dip and strike may be determined at a number of points along the base of the overlying horizon.

Hamburg Ridge.—Along the east side of Secret Canyon the Hamburg limestone and shale and the Pogonip limestone horizons form a single ridge, which, although of less elevation and of less rugged aspect, is singularly like Prospect Ridge in its salient topographical features. With the exception of the summit of Roundtop, all the more elevated portions are found in the Hamburg limestone. Although evidences of bedding are for the most part obliterated in the Hamburg limestone, they are by no means so exceptional as to leave any doubt that the ridge dips easterly with great uniformity. Occasional beds are found with a dip and strike not in accordance with this general structure, but in such instances they can be shown to be the results of local disturbance produced by the action of intrusive rhyolites. In studying the district, care has been taken to discriminate between such local disturbances, which may be very considerable within limited areas, and the structure due to the primary upheaval and the blocking out of the great mountain masses. At the southern end of the ridge the Hamburg limestone has been a good deal broken up under the influence of the rhyolites of Gray Fox and the numerous small dikes of the same intrusive rock. Here the beds are seen standing nearly vertical, sometimes inclined westerly, and again resuming the normal dip to the east. The limestone beds throughout are highly siliceous.

Black cherty bands and beds of black quartzite form a characteristic feature of the horizon. One of these siliceous beds on the crest of the ridge may be followed for a long distance without any break in the continuity and is sufficiently well marked to form a characteristic feature of the ridge.

Evidence of the age of these beds, based upon their organic remains, rests mainly upon the material obtained from the limestone immediately overlying the Secret Canyon shale. Fossils are known to occur, more or less well preserved, in a number of places, but the most satisfactory localities are found just north of the Geddes and Bertrand dike and immediately west of the divide separating Secret Canyon from New York Canyon. All the species obtained are identical with those collected from the same horizon north of Ruby Hill. Midway up the west slope of Hamburg Ridge, and nearly due west from Roundtop, several species with much the same grouping occur in a dark, compact limestone—a locality which, if thoroughly examined, might possibly yield a rich fauna. The Hamburg shale forms a well marked horizon, but, being harder and more compact, yields less readily to erosion, and, in consequence, is less easily determined by topographical features than the same horizon northward. It may be traced from the extreme southern end of the ridge northward across the broad west spur of Roundtop, until abruptly cut off by the rhyolite body which occupies Glendale Valley. The Pogonip limestone has much the same north and south limits, rising gradually out of the rhyolitic tuffs at the base of Gray Fox Peak on the south, and terminating in a high wall which forms the west side of the upper Glendale Valley.

Roundtop Mountain.—Roundtop Mountain is almost wholly made up of Pogonip limestone, and offers the best exposure of the series of beds characteristic of this horizon to be found in the southern part of the Eureka District. On the spur running out to the west from the top of the mountain, and in an arenaceous limestone immediately above the Hamburg shale, a few organic remains were obtained, belonging to a characteristic grouping which marks the transition from Cambrian to Silurian, found in several other localities at the base of the Pogonip. On the southern spur of Roundtop, in beds dipping from 65° to 70° eastward, a small but characteristic fauna occurs, in which were found *Lingula manticula; Orthis hamburgensis, O. testudinaria, Tiplesia calcifera,* and *Ptychoparia haguei.* To the north of Roundtop the beds are much broken up by volcanic masses, the structure being most difficult to make out and the beds impossible to follow, but beyond this again the beds recover their normal position, striking north and south and dipping at a high angle to the east, until the entire series of beds is lost beneath the rhyolite. Along the east slope of Roundtop the Eureka quartzite dips generally eastward, an exception being the block lying between Glendale Valley and the ravine coming down from the north slope of Roundtop. Here it has been thrust violently forward toward the south and dips with a high angle to the southwest, in marked contrast to the main body.

Along the west slope of Hoosac Mountain both the Hamburg shale and the Pogonip limestone again come to the surface, the latter rising within 200 feet of the top of the mountain, the line between the two limestones being defined as elsewhere by the occurrence, although poorly preserved, of a grouping of species characteristic of the border line between the Cambrian and the Silurian.

Hoosac Mountain.—This bold mountain mass, situated to the east of the Hamburg Ridge, attains an elevation several hundred feet higher than any point along the ridge, rising prominently above the immediate country with an altitude of over 8,500 feet above sea level. The broad summit for nearly one-half mile in length maintains approximately the same elevation, a few points here and there rising slightly above the general level. With the exception of the narrow strip of Pogonip limestone upon the west slope, the Eureka quartzite forms the entire mountain. The mountain falls off gradually to the north and south, but more or less abruptly to the east, where the quartzite, broken down by a series of small parallel faults, presents numerous low walls and cliffs toward the Hoosac fault. The quartzite body, where it is possible to determine any structure, trends invariably north and south and dips easterly, but nothing can be made out as to its thickness, owing to the great amount of local displacement. The quartzite resembles the horizon as seen elsewhere, except that it is more or less altered by solfataric action and by the intrusive rocks, which penetrate it as narrow dikes. There occur here some curious bands of a dark brecciated quartzite made up of chert and jasper, in fragments firmly cemented together and brilliantly colored by secondary alteration. The cementation probably followed the infiltration of silica, which took place during the volcanic period. Both hornblende-andesite and rhyolite penetrate the mountain, but mainly in narrow dikes, the surface exposures of which are much decomposed and in most instances so altered as to render a study of them impossible; no dikes of perfectly fresh rock were observed. Miners searching for ore bodies along the outcrops of these decomposed rocks have explored them in a way to permit of their general course and mode of occurence being made out. From underground exploration there is reason to believe that but a small part of the andesite dikes reach the surface, and these only in stringers and offshoots from some parent body. Mapping the hornblende-andesite exposures along the mountain, they are seen to follow a common course approximately north and south, coincident with the lines of faulting and the trend of the mountain uplift, following the direction of the main Hoosac fault. Although much decomposed, the andesitic character of these rocks can be readily made out from a study of their hornblendes and glassy feldspars; the latter under the microscope are found to be all triclinic. The rhyolite exposure just east of the Hoosac mine appears to be a remnant left by erosion from the main body of the Hoosac fault outburst.

The Hoosac mine, situated on the east slope of the mountain, is one of the oldest mining properties in the district, having been located in 1869 and opened early the succeeding year. As it is the only mine in the district found in the Eureka quartzite, it has much geological interest, and its development has served at least to furnish data bearing upon the structure of a singular mountain. A vertical shaft 200 feet in depth has been sunk through the quartzite, from the bottom of which a level 300 feet in length runs westward into the mountain. All the mine workings lie in quartzite, the ore bodies encountered being found in connection with the intrusive rocks. It is reported that the owners of the property took out in a short time precious metals to the value of $500,000. Continued exploration failed to maintain the high hopes first entertained of the mine.

Northward of Hoosac Mountain the Pogonip limestone maintains, as far as New York Canyon, its uniform and simple structure, while the Eureka quartzite, on the other hand, occurs only here and there in irregular patches cropping out from beneath heavy flows of hornblende-andesite, which come to the surface along the line of the Hoosac fault. This profound fault coming up from the south may be said to bifurcate at New York Canyon, the main branch swerving off to the northeast, retaining the name of Hoosac fault, the other, trending to the northwest, being designated as the Ruby Hill fault. Between these two lines of faulting lies a block of uplifted beds, which in structure is in some respects quite independent of the Prospect Mountain Ridge, a result probably brought about by the dynamic forces which produced both the Ruby Hill and Jackson faults and the rhyolite outbursts of Purple Mountain. This block is wholly made up of Silurian strata, all three periods being represented. The Ruby Hill fault may be traced on the surface from New York Canyon to its junction with the Jackson fault by the numerous outbursts of rhyolite, whereas northward along the Jackson fault no rhyolite has anywhere been observed. As far north as Shadow Canyon the strata incline southwest toward McCoy's Ridge, but beyond this canyon the dip and strike of the beds is most irregular, in general dipping away from the Jackson fault and under Purple Mountain and Caribou Hill. The greatest thickness of limestones anywhere represented in this belt is about 2,700 feet, measured across the strata from Shadow Canyon to McCoy's Ridge. The age of the limestone underlying the quartzite of McCoy's Ridge is determined by the presence of a Pogonip fauna characteristic of the upper horizons, serving also to identify the quartzite which here forms such a persistent ridge along the north side of New York Canyon. The trend of the ridge is determined in part by the direction of the Hoosac fault and in part by the outbursts of the lavas of Purple Mountain. The limestones overlying the quartzites can be no other than the Lone Mountain beds. Although they carry no organic remains, their geological position and lithological habit, quite like the Lone Mountain strata immediately over the Eureka quartzite elsewhere, leave no doubt as to their true correlation. It is the only exposure of Lone Mountain limestone found in the uplift of Prospect Mountain Ridge, but owing to the want of well defined lines of stratification no reliable estimate can be made of the thickness. There are, however, only 200 or 300 feet of beds before the horizon is sharply cut off by the Hoosac fault bringing in the Carboniferous in juxtaposition with it.

Caribou Hill, separated from McCoy's Ridge by Purple Mountain, stands out as a prominent topographical feature. It is capped by the same Eureka quartzite. There are only 200 feet of beds and consequently the Lone Mountain limestones are wholly wanting. It is this cap of quartzite which has protected from erosion the underlying limestones. Here, again, in a narrow ravine at the west base of the hill, in the underlying limestone immediately beneath the quartzite, the *Receptaculites* beds occur, with several characteristic species, offering additional proof, if any was needed, as to their geological position. From Caribou Hill northward no outcrops of the Eureka quartzite were recognized. The Pogonip limestones present low, flat-topped ridges inclined northward, gradually passing beneath the recent deposits of Diamond Valley.

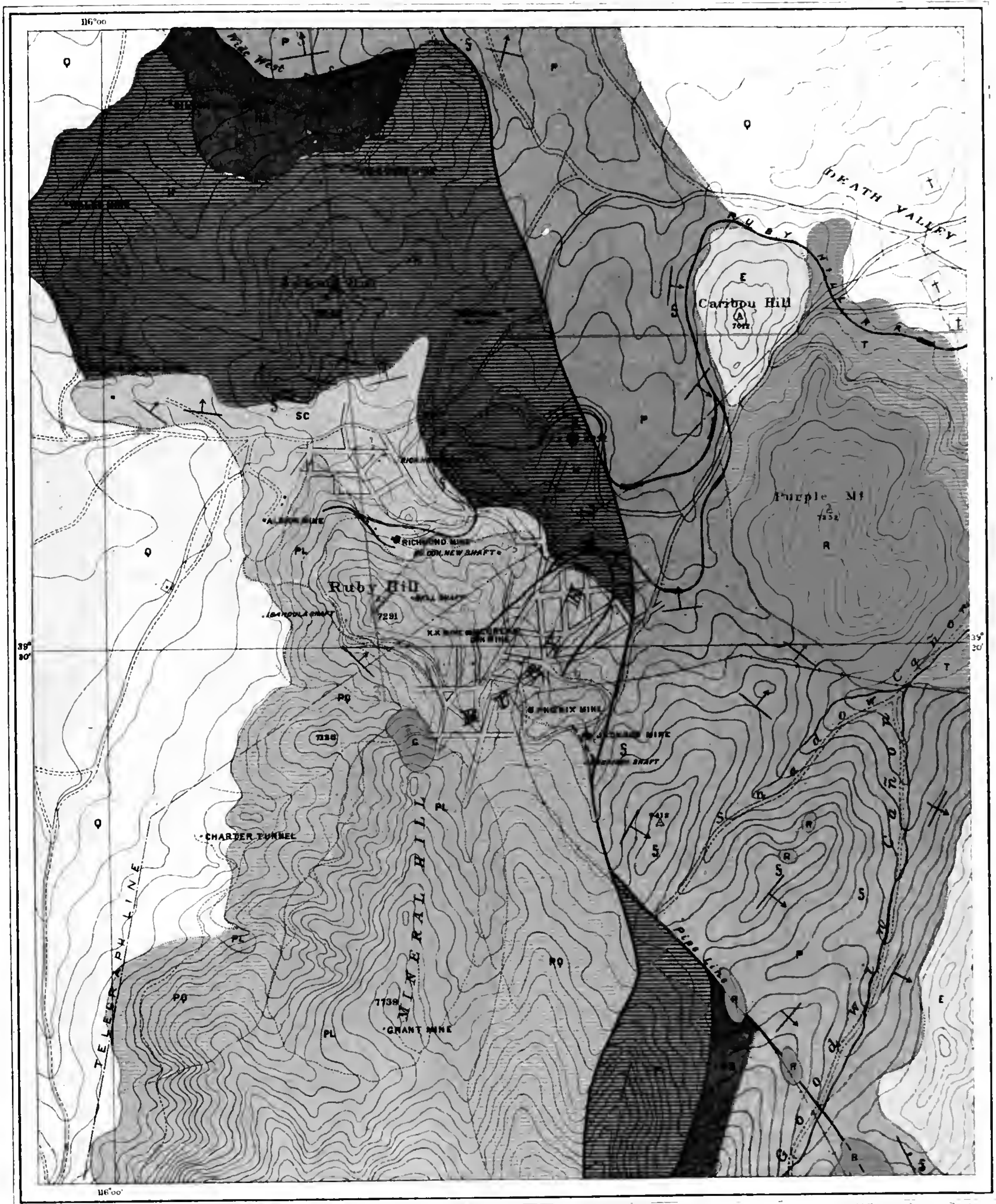
RUBY HILL REGION.

Ruby Hill and Adams Hill together occupy a small but clearly defined area which may be considered simply the northern extension of Prospect Ridge. The Jackson fault sharply outlines this area on the east side, while the recent accumulations along the line of the Spring Valley fault limit it on the west side. The geological importance of the region is mainly derived from the enormous ore deposits found in the limestones of Ruby Hill, which had yielded, up to the time of this investigation, over $60,000,000 in precious metals. In general the orographic structure is simple, and only in detail in the immediate neighborhood of Ruby Hill is it in any way complex.

On Plate I will be found a geological map of Ruby Hill and the adjacent country, prepared from the large atlas sheets for more easy reference to the text. Unfortunately the line between atlas sheets VII and VIII runs directly across this area, interfering greatly with the clear understanding of the structural relations of the beds of Prospect Ridge with those of the Ruby Hill as well as with those lying east of the Jackson fault. By referring to the map it will be readily seen that the Jackson fault cuts off the Cambrian strata and brings the Pogonip up against the entire series.

Granite.—North of the granite exposure at the end of Mineral Hill the strata all dip northward, curving gently around the crystalline rock which apparently has acted as a center of upheaving forces. The beds present a broad anticlinal arch, less and less disturbed as they recede from the granite and with a slightly decreasing angle of dip. The granite body occupies but a small area on the steep slope of Mineral Hill. It is quite obscure in its surface exposure, and might readily be overlooked but for its probable influence in producing the present geological features of the country. Fortunately, it gives some clue to the peculiarities of structure. The age of this granite is by no means easily determined, but the evidence seems to show that it was a portion of an Archean island, around which the sediments were deposited. At some later period there was a movement of the entire region, and the beds were uplifted and arched into their present position around the granite. The exposure of the granite is wholly due to erosion, and up to quite a recent date was covered with quartzite. There is reason to believe that at the time the quartzite was deposited, a land surface existed at no great distance, and this granite may have been connected with it. Evidence in favor of such a supposition was found near the bottom of the Richmond shaft, 1,200 feet below the surface. The vertical shaft, after passing through limestone as far as the seventh level of the mine, penetrates the quartzite for 500 feet. In a white, fine grained quartzite, small pieces of rock were obtained, closely resembling granite. Although somewhat decomposed, the rock was found to be made up of quartz, mica, and an altered highly kaolinized mineral, probably feldspar.

Encircling the granite and resting directly upon it, occurs the Prospect Mountain quartzite, followed in turn by the Prospect Mountain limestone, Secret Canyon shale, Hamburg limestone, Hamburg shale, and Pogonip limestone, the entire series of sedimentary beds exposed on Prospect Ridge. That the Ruby Hill series of beds were once continuous with those of Prospect Ridge there is no reason to doubt, ample evidence being found in the character of their sedimentation and the sequence of strata. The continuity was broken only by profound faulting in much later times. As the quartzite lies next the granite it is much broken up in the sharp turns which it is compelled to make as the underlying rock of the arch. No dips or strikes can be



F. A. Clark Topographer
Julius Bien & Co. lith.
Arnold Hague Geologist in Charge

GEOLOGICAL MAP OF RUBY HILL.

EUREKA MINING DISTRICT, NEV.

QUATERNARY

- Q

SILURIAN

- Eureka Quartzite: E
- Pogonip Limestone: P

CAMBRIAN

- Hamburg Shale: HS
- Hamburg Limestone: H
- Secret Cn. Shale: SC
- Prospect Mt. Limestone: PL
- Prospect Mt. Quartzite: PQ

IGNEOUS

- Rhyolite Pumice: T
- Rhyolite: R
- Granite: G

showing Strike and approximate angle of Dip

made out except on the slopes of Ruby Hill, where the beds are distinctly seen to pass beneath the limestone which caps the hill. Owing to this abrupt curve, and the consequent breaking up of the strata, erosion has cut a deep ravine in the quartzite. It is this ravine which separates Ruby Hill from the main ridge. Overlying the quartzite comes the Prospect Mountain limestone forming the summit, the isolation of the hill being made complete by the erosion of a broad, shallow ravine in the Secret Canyon shale on the north side.

Adams Hill, a flat topped mass of Hamburg limestone, lies between two nearly parallel ravines, one of which is eroded in the Secret Canyon or underlying shale, and the other in the overlying Hamburg shale. On the south side the Secret Canyon shale passes beneath the limestone, the line of contact being well determined at the base of the hill, the dip and strike of the beds agreeing closely with those found on Ruby Hill. On the north side of Adams Hill the Hamburg shales appear and are sharply defined by the limits of the Wide West ravine. Beyond this latter ravine the Pogonip limestone comes in, gradually falling away beneath the deposits of Diamond Valley. On Pl. II, Sec. 3, will be found a geological section drawn across the strata from the Prospect Mountain quartzite on the south slope of Ruby Hill to the Silurian limestone, the two Cambrian limestones forming the summits of the two hills, the underlying one capping Ruby Hill and the overlying one forming the mass of Adams Hill. The section is drawn across a body of quartz-porphyry which breaks through the Pogonip limestone. It is quite unlike any other crystalline body known in the district, but it is of no special value as it has exerted little influence upon the limestone, the latter being very little disturbed and showing but few signs of alteration. The age of the quartz-porphyry is unknown, as it penetrates Silurian rocks only, but it is probably older than the rhyolites, which it in no way resembles except in mineral composition.

A comparison of the section referred to with the one across Prospect Ridge (atlas sheet XIII) brings out the complete correlation between the two series of beds, and the great similarity in the configuration of the two areas, Ruby Hill and Adams Hill to the north corresponding with Prospect Ridge and Hamburg Ridge of the east and west section of the main mountain.

On Pl. II, Sec. 4, there is shown for comparative purposes a section across the highest point of Prospect Peak where the quartzite reaches the very summit of the ridge. On Prospect Peak the strata stand at an angle of nearly 70°, whereas on Ruby Hill and Adams Hill they lie inclined at about 40°.

Paleontological evidence that the Ruby Hill series of beds are the precise equivalent of those found on the east side of Prospect Ridge is ample for all purposes of identification. Three well defined horizons are recognized yielding the same organic forms which characterize identical strata elsewhere. The lowest of these three horizons is found not far below the summit of the Prospect limestone, the middle one near the base of the Hamburg limestone and the upper one near the base of the Pogonip.

Fossils in Richmond Mine.—In a compact stratified limestone on the seventh level of the Richmond Mine a sufficient number of organic forms were found to identify the beds with the upper members of the Prospect Mountain limestone, and locating beyond all question the geological position of the ore bodies. The species collected were:

Lingula manticula.
Agnostus communis.
Agnostus bidens.
Agnostus neon.
Agnostus richmondensis.
Ptychoparia oweni.

At the base of the Hamburg limestone opposite the Richmond dump, and again north of the Albion mine, species have been identified corresponding to those obtained in New York Canyon and Secret Canyon just above the great shale body. North of the Wide West ravine a small grouping of forms correlates the limestone just above the shales as the base of the Pogonip, showing the mingling of the Cambrian fauna with a grouping of fossils which higher up in the beds becomes characteristic of the Pogonip. The two species *Obolella discoidea* and *Dicellocephalus marica*, occurring in the Pogonip elsewhere, have been collected from the limestones north of the Wide West ravine.

FISH CREEK MOUNTAINS.

Fish Creek Mountains.—These somewhat isolated mountains lie to the southwest of Prospect Ridge. They are surrounded on three sides by the ever-present sagebrush valleys of Nevada, but to the northward maintain their connection with the Eureka Mountains by a complicated system of ridges which closely unites them with both Prospect Ridge and the Mahogany Hills. Although their northern limit is very ill defined, they stretch in a north and south direction for 10 or 12 miles and measure about 5 miles in width, with an elevation above the surrounding valleys of over 2,000 feet. Bellevue and White Cloud Peaks are the two most prominent points in the mountains, the former with an altitude of 8,883 feet, the latter of 8,850 feet above sea level, while between them is a still higher table-topped summit, having an elevation of 8,951 feet above the sea.

In structure the main body of Fish Creek Mountains consists of an anticlinal fold, whose axis lies along the eastern edge of the broad, slightly inclined table which forms the top of the range. A north and south line of faulting coincides with this axial plane and is accompanied by an escarpment, nearly 600 feet in height, showing a downthrow at least equal to that amount. The displacement may be traced readily for a considerable distance along the mountain. The fault is not laid down on the map, but the escarpment itself is indicated by the contour lines being thrown close together. At the base of this cliff the rocks are much broken up, as there appears to be a series of small faults rather than one sharp displacement. The anticline is nevertheless sharply brought out by the limestone dipping in opposite directions with a marked difference in the angle of inclination. The beds of the cliff incline at low angles into the mountains, whereas the slopes upon the east side, with an average dip of 15°, fall away abruptly for about 1,500 feet or until buried beneath the Quaternary deposits of Fish Creek Valley. On the west side of the main axis the limestones assume a gentle synclinal roll, followed by a low, broad anticline, the westerly dipping beds of which extend for nearly two miles, with a monotonous uniform dip, rarely exceeding 5° or 6°, till lost beneath the detrital accumulations of Antelope Valley. The geological structure is that of a faulted anticline, gentle on one side and relatively steep on the other, a structure typical of many ranges in the Great Basin. Besides the north and south anticlinal fold there is a gentle quaquaversal dip from the central mass about Bellevue Peak, the beds to the northward, however, dipping away steeper than in the other directions.

All three divisions of the Silurian are found here—the Pogonip limestone, Eureka quartzite, and Lone Mountain limestone. This orographic block is one of the few mountain ranges made up wholly of Silurian rocks. Nearly all the more elevated portions are formed of Pogonip beds, which gradually pass under the overlying Eureka quartzite, which forms continuous bodies to the west and north. The drainage channels running out from the summit are narrow ravines, and, although cutting hundreds of feet into the Pogonip, never, so far as is known, expose the underlying Cambrian strata. It is probable that only the higher Pogonip beds are represented. Abrupt walls of nearly black limestone, characteristic of the upper members of this horizon, form the sides of these ravines, in many instances the dark rock being capped by overlying beds of white Eureka quartzite, showing that these upper beds were in place. This is especially noticeable to the northwest of White Cloud where the heads of nearly all the ravines occur in the quartzites. Near the summit of the range they cut through nearly vertical walls of quartzite from 200 to 400 feet in thickness. Outlying patches of quartzite, remnants of erosion, are still to be seen capping the ends of the ridges on both slopes of the mountains. These isolated patches are seldom more than 50 feet in thickness; they lie scattered all over the slopes, many of them being so small and obscure as to be unrepresented on the map. Over the long western slopes detached blocks of quartzite may be found resting on the limestone, showing that while the quartzite has, for the most part, been carried away, the uppermost beds of limestone still remain in place. The *Receptaculites* beds extend in all directions under the quartzite, paleontology confirming structural evidence of their geological position. All three species of the genus *Receptaculites* known in the Great Basin have been recognized here, associated with a varied fauna typical of this horizon elsewhere, with the same foreshadowing of Trenton species. The same specific forms occur here that are found underlying McCoy's Ridge and Caribou Hill. A list of the species obtained at Bellevue and White Cloud Peaks will be found on page 53.

Bellevue Peak is capped with Eureka quartzite which, from here northward, stretches in a continuous body to Reese and Berry Canyon. Over this intermediate country it presents much the same general features, a white vitreous rock inclined at angles seldom exceeding 10° and frequently horizontal. The country offers, in places, broad table-topped masses, and again in others is roughly accidented, caused by numerous minor faults and small displacements, producing picturesque mural-like cliffs that serve to break the otherwise monotonous scenery. A measurement of the thickness of the quartzite is impossible. These displacements, although frequent, are seldom sufficient to bring the underlying limestones to the surface. The greatest thickness observed in any vertical wall is about 300 feet, which, however, fails to take into account the amount carried off from the surface by denudation. A section across the vertical cliff just west of Castle Mountain will be found on page 56. Near the base of the quartzite cross-bedding has been detected in one or two localities, indicating shallow water deposits; it appears, however, to be wanting in all the higher beds that present a singularly uniform body of quartz grains free from impurities.

Castle Mountain is capped by 200 feet of Lone Mountain limestone overlying the quartzite, and from here extends in a narrow belt in a southeast direction for over 2 miles. Here, as in many other localities, the Lone Mountain limestone is devoid of fossils, and not until *Stromatopora*, *Chætetes*, and *Atrypa reticularis* appear in beds generally regarded as Devonian, have organic forms been recognized. The country is monotonous in the extreme, dazzling to the eyes, waterless, and for the most part treeless. The limestone shows no lines of stratification.

Granite-porphyry.—To the northwest of Bellevue and White Cloud Peak, in the region of the granite-porphyry dikes, the simple structural features of the Fish Creek Mountains are lost by the intrusion of large bodies of granite-porphyry. It occurs in two distinct masses with a few outlying smaller dikes and knolls, the two principal bodies being separated by a belt of limestone scarcely 300 feet in width.

The largest exposure of granite-porphyry presents an irregular body lying between Fish Creek Mountain and Mahogany Hills on the extreme western edge of the District. The smaller body occurs as a prominent north and south dike, which, breaking through Pogonip limestone, appears at the surface as an offshoot from the larger mass. From this massive dike several lesser ones branch off, nearly all of them lying approximately parallel with the same northeast trend.

On the summit of the Fish Creek Mountains, midway between Bellevue and White Cloud Peaks, occurs a vertical dike of granite-porphyry only a few feet in width. It is made up of feldspar, hornblende and mica, imbedded in a groundmass of quartz and feldspar, possessing typical microgranitic structure. Apparently this dike itself exerted little, if any, influence on the adjoining country, and the only geological interest attached to the occurrence consists in its being closely allied to the larger bodies of coarse granite-porphyry, from which it is most likely an offshoot. It is quite possible that the quaquaversal dip of the strata from White Cloud Peak, of which mention has already been made, may be due to an underlying mass of intruded crystalline rock, of which the dike is the only evidence upon the surface.

Coinciding in direction with the secondary off-shoots from the main dike occur narrow dikes of granite-porphyry penetrating the Lone Mountain limestone of Castle Mountain. They are exceptionally fine grained, with a characteristic microgranitic groundmass. In their mode of occurrence they resemble the dike near Bellevue Peak, and doubtless have the same common origin.

As the geological and petrographical features of the granite-porphyry are discussed with some detail in chapter VII, devoted to the discussion of the pre-Tertiary crystalline rocks, it is needless to enter more at length into the subject here. By reference to the map (atlas sheet XI) the position of the main body of granite-porphyry and its relations to the primary and secondary offshoots from the parent mass may be readily seen.

Ridge West of Wood Cone.—In many respects the best locality to study the Pogonip of the Eureka District is the long, narrow, monotonous ridge which stretches westward from Wood Cone. Here the beds abut against the southern end of the main granite-porphyry body, standing invariably at high angles, in most places nearly vertical, but sometimes inclined westerly and again easterly. Just west of the limestone saddle, which separates the two bodies of porphyry, there is a fault in the limestone which brings up the lower beds. There is apparently a synclinal fold, to the west of which comes in a sharp anticline, beyond which the beds dip uniformly to the west. At the western end of this ridge occurs a small knoll or hill of Eureka quartzite, its geological position being determined by the *Receptaculites* fauna immediately underlying it.

At the eastern end of this ridge, just west of Wood Cone, a fauna was obtained which indicated a horizon not far above the base of the Pogonip, being largely made up of species found near the summit of the Cambrian, associated with others never as yet recognized below the Pogonip. It is a fauna characteristic of the lower portions of the epoch and quite like a grouping found on the east side of Hamburg Ridge. In other words, they may be correlated with the transition beds just above the Hamburg shale. Many of the species also characterize the Pogonip of White Pine. Among the species identified were the following:

Lingulepis mæra.
Lingula manticula.
Leptæna melita.
Illænurus eurekensis.
Orthis hamburgensis.
Triplesia calcifera.
Bathyurus congeneris.
Bathyurus tuberculatus.

No accurate measurements of the Pogonip along this ridge can be made, owing to the great irregularities of dip and strike, but it is probable that the beds exceed 3,000 feet in thickness. From the fauna obtained just below the Eureka quartzite, and that from the base of the limestone west of Wood Cone, it is evident that the entire development of Pogonip is represented in this ridge. This gives a somewhat greater development for the epoch than has been recognized east of the Prospect Ridge, but, on the other hand, it does not reach the very great thickness found on Pogonip Mountain at White Pine, estimated at 5,000 feet.

REGION BETWEEN FISH CREEK MOUNTAINS AND PROSPECT RIDGE.

This region possesses some distinctive features unlike either of the mountain blocks that adjoin it, yet at the same time it shows the influence of the forces that uplifted Prospect Ridge on the northeast and Fish Creek Mountains on the southwest. It is sharply defined from Prospect Ridge in geological structure by the Sierra fault, which brings the Silurian up against the lower Cambrian of Prospect Ridge. The anticlinal structure of the latter ridge has disappeared, in place of which there is a complicated and confused mass of mountains without any well defined characters. The same dynamic forces that produced the great longitudinal faults extending across the Eureka Mountains, on both sides of Prospect Ridge, may still be seen westward of the Sierra fault in a series of north and south fractures, approximately parallel with the more powerful displacements. Such lesser faults as the Lookout Mountain, Pinnacle Peak, and Lamoureux Canyon faults, are by no means as persistent as the Hoosac and Pinto, and nowhere indicate such profound displacements. The forces that caused these displacements died out gradually to the west of the Sierra fault.

From Fish Creek Mountains the line of demarcation is by no means as easily defined, being unaccompanied by great physical breaks of any kind or abrupt changes in geological structure. The simplicity of the Fish Creek Mountains as they approach Prospect Ridge gradually gives way to a more intricate structure, the north and south displacements being complicated by numerous minor cross-fractures and faults. North of Castle Mountain, the configuration of the country gradually assumes new forms, and from here to Prospect Peak it suggests little in common with the ordinary type of Great Basin ranges. This intermediate region is the resultant of varying forces not always easy to define.

The Eureka quartzite forms the surface rock over the greater part of this area, stretching in an almost unbroken line from Spring Valley to the Sierra fault, although faulting or erosion has exposed the underlying Pogonip limestone in a number of places. Overlying the Eureka quartzite comes the Lone Mountain, usually passing into the Nevada limestone of the Devonian, the latter in the neighborhood of Atrypa Peak offering an exposure several thousand feet in thickness. Everywhere the Eureka quartzite serves readily as a datum point to determine the position of the faulted strata, and in most instances the age of the underlying beds may be identified by the *Receptaculites* fauna. Where the thickness of overlying limestone admits of it, the Devonian age is shown by characteristic organic forms. By these two groupings of fossils and the intermediate broad belt of quartzite, the stratigraphical position of beds in this highly disturbed region may generally be determined without difficulty.

Castle Mountain may, for sake of convenience, be taken as the northern limit of the Fish Creek Mountains. From Castle Mountain to Reese and Berry Canyon no beds come to the surface other than the quartzites. Here, however, a sudden change takes place, the canyon occupying a line of southeast and northwest faulting with the quartzite on one side dipping at a low angle to the west, and the Lone Mountain limestone on the opposite side, but without any distinct line of bedding. From the head of Reese and Berry Canyon the limestone crosses over a low saddle to the head of Lamoureux Canyon, following the latter ravine until it makes an abrupt bend to the south. The limestone may be traced eastward around the base of Atrypa Peak, thence westward again with an irregular course as far as Spring Valley. In this area the underlying limestone belongs, for the most part, to the Silurian, but in one or two places the beds assigned to the Devonian on lithological grounds rest directly upon the quartzites abutting against them almost at right angles. The division between the Silurian and Devonian in this region is an arbitrary one, but in most instances the passage from the white saccharoidal limestone of the former into the stratified gray beds of the latter is the same here as elsewhere in the District.

Atrypa Peak.—Nowhere in this area is there any place which permits of a measurement of the Silurian rocks, but the region of Atrypa Peak, the culminating point, affords excellent sections across the Nevada limestone, the beds presenting nearly uniform dips and strikes. This imposing mountain is formed almost wholly of Devonian limestone, the name of the peak being derived from the abundance of *Atrypa reticularis* found on its slopes. Two sections for comparative purposes were made: one, directly across the strata on the southeast slope of the peak, the other on the high ridge extending westward lying between the peak and the head of Lamoureux Canyon. The latter section will be found on page 67.

Where the sections include the same geological horizons they agree closely in details, but the one taken across the slope of the peak gives a much greater thickness of Silurian rocks, whereas the ridge section extends higher up into Devonian strata. The fossiliferous shaly belt (No. 5), in the section east of Lamoureux Canyon, is easily traceable across the ravine to Atrypa Peak and may be taken as a base for comparing the two sections. In the ridge section there are 1,300 feet of strata below this shale belt before reaching the quartzite, and about 3,000 feet above the shale. The Atrypa Peak section gives 2,000 feet from the shale to the quartzite at the base, and nearly the same thickness from the shale upward. This shale carries an abundance of characteristic species and, although a larger number were obtained on the slope of Atrypa Peak, there is no question that the fauna is identical in both.

At the head of Lamoureux Canyon there is a ridge of limestone, striking northwest and southeast, which rests unconformably against the quartzite. Not far above the quartzite a small collection of typical fossils was made, amply sufficient to prove that the beds belong to the Devonian. On the summit of the high peak east of Jones Canyon is another excellent locality for the collection of Devonian species, but no specific forms were found here not recognized elsewhere. Owing to local faulting, the exact position of these latter beds could not be determined other than that they belonged to the lower Nevada limestone. They are well bedded, strike across the ridge and dip westerly.

Jones Canyon lies wholly in the Devonian limestone and offers some good exposures of rock, but no continuous section at all comparable to those described in the region of Atrypa Peak.

White Mountain.—The country between Atrypa Peak, and the Prospect Peak fault culminates in White Mountain (9,941), the highest point west of Prospect Ridge, with which it is connected on the northeast by a high ridge of quartzite. From Spring Valley a fairly uniform slope of 1,500 feet extends to the summit of White Mountain, made up wholly of Pogonip limestone, which stretches eastward and falls away gradually for about 800 feet to a high saddle in the range, beyond which it descends in a narrow belt for another 300 feet to Mountain Valley. Here it is cut off by a fault bringing up a narrow strip of Nevada limestone lying between the Pogonip on the one side and the Eureka quartzite on the other. It is possible that this fault may be only an extension northward of the Pinnacle Peak fault. In the neighborhood of the saddle the quartzite encroaches on the limestone. The structure of the mountain is difficult to make out, but the limestone is everywhere surrounded by the quartzite, long belts of the latter rock stretching down on both the north and south sides of the mountain to Spring Valley. Patches of quartzite resting upon the limestone on the summit give stratigraphical evidence of the age of the beds. It is probable that the quartzite passed over the top of the limestone, east of the mountain, and that the patches of the former, found near the summit, are mere relics of erosion. As regards stratigraphic position of beds, we have here conditions nearly identical to those in the Fish Creek Mountains. Characteristic Pogonip fossils, sufficient to determine the position of the beds, have been secured from a number of localities, proving the age of the limestone, while the beds forming the summit have furnished a typical fauna of the upper portions of this horizon. About 800 feet below the top of the mountain and not far from the same distance below the quartzite bodies an interesting grouping of fossils occurs, and immediately beneath the quartzite on the summit the *Receptaculites* beds are well shown. The student of structural geology in this region owes much to the genus *Receptaculites*, which is very abundant within a restricted vertical range. A list of the principal groupings of fossils collected on White Mountain will be found on page 52.

South of White Mountain, and separated from it by a belt of Eureka quartzite not over 1,000 feet in width, an irregular shaped body of limestone is exposed from beneath the quartzite. If any evidence of its age is needed beyond its stratigraphical position, it will be found in the typical Pogonip fossils which occur scattered throughout the beds which, like the corresponding beds on the east slope of White Mountain, possess a southeast dip and a northeast and southwest strike. This limestone, like the main body, is nearly everywhere encircled by the quartzite, the only exception being on the south side, where it abuts against the Nevada limestone, which forms a part of the east ridge of Atrypa Peak. The two limestone bodies are unconformable, of different lithological character, and dip in opposite direction.

North of White Mountain the Eureka quartzite terminates abruptly against the Prospect Peak fault, the Cambrian and Silurian quartzites being placed in juxtaposition. These quartzites resemble each other closely in their upper strata, being simply indurated sandstones, and it is only after long study of them that they can be readily distinguished; along the line of contact it is by no means easy to separate them. Evidences of geological position come in, however, and the limestone, both above and below the Eureka horizon, usually determines the age of the beds. As the country is much broken up by profound faults, and the Eureka quartzite is not over 500 feet in thickness, either the Pogonip below or Lone Mountain horizon above, frequently both, are apt to come to the surface near the exposures of the Silurian quartzite. Wherever the Cambrian quartzite is found it is overlain by Cambrian limestone.

On the summit of the ridge along the line of the Prospect Peak fault occurs a small patch of highly altered limestone, without any structural indications of its relationship to either of the quartzite bodies. Its position is difficult to explain satisfactorily, but it has been referred to the Pogonip, since it more closely resembles the limestone of White Mountain than that of Prospect Ridge.

From Prospect Peak southward the Eureka quartzite forms the west side of Prospect Ridge, following the line of the Sierra fault. The ridge falls away steadily to the south for 1¾ miles, with a descent of over 1,500 feet to Sierra Valley. A series of minor longitudinal faults presents a much more abrupt slope on the west side and prevents the underlying formations from coming to the surface, notwithstanding that a narrow ravine is eroded in the quartzites for nearly 700 feet in depth. Not till descending the slope for nearly 1,000 feet do the Pogonip beds come to the surface, and then only a small patch of this underlying rock is exposed. This interesting body of limestone crops out to the northeast of Lookout Mountain, where it presents an obscure exposure of slight area and thickness. The fauna obtained here is strikingly Pogonip in aspect, and resembles the fauna found on the face of White Mountain for 500 to 1,000 feet below the summit. Associated with other more common forms are *Raphistoma nasoni*, *Maclurea annulata*, and *Leperditia bivia*, all recognized as belonging to the Pogonip of White Pine. The interest in this identification lies in the fact that only a few hundred feet to the southward the Cambrian limestone comes to the surface in Sierra Valley, while just to the westward the Devonian limestone is exposed in Mountain Valley, the three horizons being determined by characteristic species.

Lookout Mountain.—This isolated mountain stands out prominently from the surrounding country, cut off on three sides by faults. On the east runs the Lookout fault, and along the west base the persistent and profound Pinnacle Peak fault brings up the Nevada limestone against the Eureka quartzite. The mountain is wholly made up of quartzite, inclined eastward at low angles, the beds of which are for the most part darker in color and more ferruginous than those of the same horizon found elsewhere. At the east base of the mountain occurs a small patch of limestone, in part obscured by surface accumulations of Sierra Valley and in part by andesitic lavas. As this limestone lies on the east side of the Lookout fault its age can be determined only by its fauna, but fortunately this is sufficiently typical to admit of its reference to the Cambrian.

Northward of this last exposure and separated from it by only 300 feet of acidic lavas, occurs a larger body of limestone, which forms a narrow ridge, cut by the stream bed which comes down along the north side of Lookout Mountain. The ravine affords a fair exposure of the beds. This second body of limestone presents no structural evidence of its position, the fauna alone determining its age, but fortunately it yielded a small number of fossils. These two groupings are not quite identical, but the beds from which they were obtained can not be wide apart. The outcrop east of Lone Mountain indicates clearly the horizon of the Hamburg limestone, carrying certain species which extend downward into the Prospect Mountain beds, mingled with others occurring as high as the middle portion of the Pogonip. The larger exposure at the northeast base of the mountain has been assigned to the Prospect Mountain limestone, without any decided evidence as to the correctness of the reference otherwise than that it belongs to the Cambrian.

Pinnacle Peak.—This summit lies about one and one-quarter miles due south of Lookout Mountain and presents much the same general features in the character of the beds and mode of occurrence, the two mountains being connected by a continuous mass of quartzite. The beds strike invariably north and south and incline eastward at angles seldom exceeding 20°, forming the entire slope as far as the Lookout fault. There is little doubt that this quartzite is correctly referred to the Silurian, although no direct evidence exists. Nearly everywhere else the Eureka quartzite may be determined upon structural grounds alone, but here the entire body from Lookout Mountain to Pinnacle Peak has been uplifted between two longitudinal faults, with limestones of different age brought to the surface on opposite sides of the displacements and lying unconformably against the quartzite. In contrast with the quartzite on the west side of the Lookout fault, limestones form the east wall stretching southward until beds on both sides of the fault are buried beneath volcanic lavas. This body of limestone extends eastward until cut off by the fault, bringing up the basal members of the Cambrian limestone of Prospect Ridge. Between these two faults the beds are broken by irregular outbursts of andesites and in places have undergone considerable alteration, due to solfataric action, the beds being frequently intersected by calcite and quartz in narrow seams and veins. So much disturbed are the beds that structural features are of little value, although it may be well to add that the general dip is eastward. These limestones have been referred to the Pogonip, although evidence of their position is not in all respects satisfactory. Obscure fragments of fossils may be obtained in a number of places, but only in one was anything like a grouping of forms observed. This fauna was collected on the west side of Sierra Canyon, nearly due south from Surprise Peak and just west of the Prospect Mountain limestone, in distinctly bedded strata inclined at an angle of about 40° eastward. All the species obtained have been found in the Pogonip limestones elsewhere, but singularly enough they are all known in the Hamburg limestone, every species having a wide vertical range. They probably represent beds not far from the base of the Pogonip and possibly should be referred to the same horizon as the beds east of Lookout Mountain, although at the latter locality the fauna distinctly indicates the Hamburg period. This reference to the Pogonip, however, is justified by the occurrence of undoubted Silurian beds underlying Surprise Peak; a further search would certainly determine the question.

Surprise Peak.—No mountain in this part of the district affords a more commanding view than Surprise Peak. It is situated between the Sierra fault on the east side and Sierra Valley on the west. It is capped by Eureka quartzite, which is underlain by the Pogonip, the limestone being distinctly seen to pass beneath the quartzite. On the north side of the peak, and on the opposite side of the fault, in beds unconformable with the Prospect Mountain limestone, was found a small but characteristic Pogonip fauna. Its occurrence here is so important that it is given in full, as follows:

Receptaculites mammillaris.
Cystidean plates.
Orthis perveta.
Orthis tricenaria.
Raphistoma nasoni.
Pleurotomaria?
Leperditia bivia.

Sierra Valley, along the west base of Surprise Peak, has been the center for the eruption of considerable masses of andesitic pearlites and hornblende andesites, which, in the form of small irregular knolls and dikes, have penetrated the limestone on the south side of the peak. Associated with these dikes are others of rhyolite, while still farther southward, where the sedimentary rocks pass beneath the valley, occur large accumulations of pearlites, pumices, and tuffs. Details in regard to these igneous rocks will be found on page 234 et seq.

Grays Canyon.—The Pinnacle Peak fault lies on the west side of the peak of the same name, at the southern end of the mountains. The line of the fault is obscured by broad lava flows, but where these give out it is easily traceable northward nearly to Prospect Peak with the Eureka quartzite on one side and the Nevada limestone on the other.

West of the Pinnacle Peak fault the Nevada limestone extends from Mountain Valley southward till the sedimentary beds pass beneath Fish Creek Valley. Through these limestones Grays Canyon cuts a narrow ravine, which offers a few good exposures, but nowhere exhibits a continuous section across any great thickness of beds. Only the lower portions of the Nevada limestone are exposed, and over the greater part of this area bedding planes are wanting. The best locality observed for the collection of fossils was found on the low, flat-topped ridge west of Grays Canyon and southwest of Pinnacle Peak, the beds dipping to the southeast at a low angle and striking northeast and southwest. These beds yielded the following forms:

Thecia ramosa.
Aulopora serpens.
Chonetes deflecta.
Spirifera piñonensis.
Atrypa reticularis.
Rhynchonella occidens.
Dystactella insularis.
Conocardium nevadensis.
Loxonema subattenuata.
Bellerophon perplexa.
Tentaculites scalariformis.

Nearly all these species occur in the shale belts of Atrypa Peak, Brush Peak, and Combs Mountain, the exceptions being the three species, *Thecia ramosa*, *Aulopora serpens*, and *Dystactella insularis*, which are, however, characteristic of the upper Helderberg in New York and Ohio; *Thecia ramosa* and *Dystactella insularis* have only as yet been found at this one locality at Eureka. A smaller but somewhat similar grouping of fossils occurs in the limestone just west of Lookout Mountain, where they are associated with *Strophodonta canace*, a species found by the writer in the limestone at Treasure Hill, White Pine.

On the west slope of Pinnacle Peak the beds dip toward the fault at an angle of 10°, reaching to within 150 feet of the summit and lying unconformably against the Eureka quartzite of the peak. Following the line of the fault the beds trend off to the southeast, the quartzite belt gradually narrowing until lost beneath the pumices, the Nevada limestone, on the other hand, continuing southward in a low ridge bounded on the east and west sides by igneous rocks. The beds exhibit much the same habit as those to the northward, usually light in color and highly siliceous, but showing more distinct lines of bedding. By reference to the map (atlas sheet XI) the structure will be seen indicated by strikes and dips. South Hill, the most prominent point on this southern extension, has a marked anticlinal fold, the axis of the fold striking N. 40° to 45° east, with a dip of 15°. The brownish gray limestones are distinctly bedded and probably belong to a somewhat higher horizon than any of those exposed in Grays Canyon. South of the road, which traverses the ridge near its southern extremity, a well defined but gentle synclinal fold may be seen crossing the ridge obliquely, with approximately the same strike as the strata on South Hill. In this southern extension the only fossils obtained were *Chaetetes* and associated corals so abundant in the Lower Nevada limestone.

Grays Peak.—This name has been given to the flat topped summit which forms the eastern limit of the broad quartzite plateau. It offers a commanding view, as the country falls off rapidly to the south and east. On the summit the beds lie nearly horizontal, but break away abruptly and dip off in every direction accompanied by mural-like escarpments produced by a series of small parallel faults lying wholly within the quartzite. On the eastern side the slope descends for nearly 1,000 feet, with an average dip of 20°, the angle of the slope and the inclination of the beds coinciding within 1° or 2°. South and east the quartzites are overlain by the Nevada limestones which dip away from the peak with varying angles. On the east side the line of contact between the two formations is strongly marked by a deeply eroded ravine draining into Grays Canyon. While these limestones have been referred to the Nevada period, it is by no means definitely ascertained that beds which in other places have been assigned to the Lone Mountain series may not here, in some instances, rest upon the quartzite. In many instances there is an entire absence of bedding, and in others the strata rest unconformably upon the quartzite. Apparently the underlying limestones belong to the transition series between well recognized Silurian and Devonian, but pass rapidly into limestone which has everywhere else in the district been assigned to the Nevada epoch. These limestones stretch away to the south in insignificant monotonous hills and ridges of lower Devonian age and have as yet yielded only a few obscure corals of wide vertical range. North of Grays Peak on the plateau where the beds lie either horizontally or at low angles, there are several patches of limestone still left in place as remnants of erosion. These exposures resemble the beds of the Lone Mountain series and serve to show by their geological position that the quartzites on the ridge belong to the upper members of the Eureka epoch. To the westward of these Silurian limestone patches the quartzites break down in abrupt walls and cliffs toward Lamoureux Canyon much in the same way as seen on the east side of Grays Peak. Along Lamoureux Canyon, however, the wall is most persistent, continuing northward nearly to Atrypa Peak, and is an excellent locality for studying the Eureka quartzite. A longitudinal fault line follows up Lamoureux Canyon, but the amount of movement is by no means as great as along the Sierra and Lookout faults; the orographic movements apparently displaying less and less force to the westward of Prospect Ridge. Passing up to the head of Lamoureux Canyon, there is an interesting occurrence of an exposure of the underlying limestones brought up by faulting. Here the Pogonip beds are surrounded on all sides unconformably by the quartzite. The hill in the middle of the canyon formed of these limestones is capped by about 100 feet of quartzite resting conformably upon the underlying beds. A careful search in this locality reveals the *Receptaculites* fauna, associated with *Orthis* and *Maclurea*, immediately beneath the quartzite.

Between Lamoureux Canyon and Castle Mountain the country presents the appearance of a shallow trough or basin with a northwest and southeast trend. This basin is for the most part filled with Nevada limestone, between which and the Eureka quartzite the Lone Mountain beds generally come to the surface, forming a narrow belt around the edge of the basin and in places extending up on to the top of the quartzite rim. Over this area the beds dip east and southeast except immediately next the quartzite of Lamoureux Canyon, where, conforming with it, they show a westerly dip. But few fossils have been recognized in this area other than an occasional *Atrypa reticularis* and corals characteristic of the Devonian, but without indicating any special horizon.

MAHOGANY HILLS.

Spring Valley extends the entire length of the Eureka Mountains and sharply distinguished Prospect Ridge and the Fish Creek Mountains from Mahogany Hills, all that region lying on the west side of this valley being included within the Mahogany Hills. Strictly speaking, it is not one continuous valley, but rather two valleys, with a low dividing grassy ridge between them, the water draining both to the north and to the south. From the broad plain of Diamond Valley, Spring Valley, only a few hundred yards in width, rises gradually for 1,200 feet to the divide, following the course of a remarkable fault, which brings both the Lone

Mountain and the Nevada limestones in juxtaposition with the Prospect Mountain quartzite, recent accumulations, however, obscuring the precise line of the displacement. The water-shed lies nearly opposite Prospect Peak. Southward from this dividing ridge the valley becomes a more important physical feature, in places opening out to more than a mile in width, finally draining into Antelope Valley southwest of the mountains. The southern end of the valley is arid and covered with sage-brush, closely resembling the broader longitudinal valleys of the Great Basin.

Mahogany Hills occupy by far the largest area of any mountain block in the Eureka District, measuring 12 miles in length by 8 miles in width. Nevada limestones constitute by far the greater part of this orographic block, four epochs of the geological section—Eureka quartzite, Lone Mountain limestone, Nevada limestone, and Diamond Peak quartzite—are all represented and their structural relations well shown. In presenting some of the more important details of the region, it will be well to begin at the southern end, where both in geological and topographical structure Mahogany Hills are closely connected with the Fish Creek Mountains through Wood Cone and the granite-porphyry region.

Combs Peak.—On the north side of Wood Cone, resting uncomformably upon the Eureka quartzite, lies a body of bluish black and dark gray limestones dipping beneath the limestones of Combs Peak. These dark limestones everywhere form the southern slopes of the Peak, and westward of the quartzite rest directly upon the granite-porphyry body. The hillsides are scored by frequent ravines and water-courses showing the inclination of the strata northward into the mountain, but lines of stratification are exceedingly rare, nowhere affording, for any considerable distance, continuous dips and strikes. The best locality for observing these beds was found just north of Wood Cone, on the end of the long spur coming down from Combs Peak. From their dark steel-gray color and their uniformly fine grained appearance, it is easy to see that they differ essentially from the characteristic Lone Mountain beds observed elsewhere. This is all the more noticeable, as they are found to pass into beds possessing the peculiar habit of the latter horizon. This striking contrast in the limestones led to a diligent search for paleontological evidence of their geological position, a search which was rewarded by finding a limited and imperfect fauna, characteristic of the Trenton period. The finding of this grouping of fossils is important, as it carries the comformable Silurian limestones overlying the Eureka quartzite down into beds generally regarded as lower Silurian, whereas, elsewhere in the district there is no paleontological evidence of strata older than the Niagara or *Halysites* beds above the quartzite. Some description of this fauna will be found on page 59.

The dark limestones which have been referred to the Trenton at this point measure, according to the best estimates that can be made, about 300 feet; that is to say, this is approximately the thickness from the Eureka quartzite on Wood Cone to the strata having the characteristics of the horizon found elsewhere and regarded as of Lone Mountain age. These dark limestones extend northward to the low saddle over which the wagon road passes, beyond which the light colored, pearly limestones come in. Westward and northward of the granite-porphyry a second locality was found yielding a similar fauna, proving the extension of the horizon in that direction. Here the Trenton beds, or those assigned to that epoch upon lithological grounds, appear somewhat thicker than those obtained near the first mentioned locality. Passing up the slope of the peak over the Lone Mountain beds, north of Wood Cone, the strata generally referred to the Nevada limestone make their appearance at the base of the first abrupt slope of the long spur from Combs Peak, and from here to the top of the prominent hill south of the peak the ridge offers an excellent section across the limestones. The beds strike across the ridge and dip toward the peak, with varying angles. A number of the observed strikes and dips will be found recorded on atlas sheet IX. On the top of the hill a few fossils may be found, indicating that the beds at the top of the northerly dipping rocks still belong to the Lower Nevada limestone. Between this hill and the summit of Combs Peak occurs a sharp syncline, the axis of the fold lying in the saddle at the base of the steep slope of the peak. The limestones on both summits strike about N. 55° west; those on the peak dipping 25° southwesterly, and those on the spur 35° northeasterly. The amphitheater of Combs Canyon has been eroded out of the beds lying within the synclinal fold.

On the west spur of Combs Peak, in beds dipping to the northeast, occurs a belt of calcareous shales about 150 feet in width, carrying a rich and varied fauna quite similar to the fossil-bearing shale belts of Atrypa and Brush peaks and with a nearly identical fauna. On page 76 will be found a list of the Combs Peak fauna, together with those of the other peaks, showing the strong parallelism in the life from the three localities. The precise locality from which this fauna was obtained is designated on the map. All the beds on the north slope of Combs Peak belong to the east side of the synclinal fold, dipping into the mountain and passing beneath the beds which form the summit.

Browns Canyon, at the base of the mountain, lies in the axis of an anticlinal fold, the beds on the north side dipping to the northeast at angles seldom exceeding 20°. At the head of this canyon, along the axis of the fold, occurs a body of compact rhyolite, which has for the most part been extravasated on the south side of a local line of faulting. It forms a hill about 250 feet in height, whose outlines are sharply defined by drainage channels which almost completely surround it on all sides. The slopes of the hill are strewn with fissile, sherdy fragments of rock characteristic of the entire mass. The rhyolite has a microcrystalline groundmass, with but few microscopic crystals of gray quartz, brilliant biotite flakes, and occasional dull orthoclases. In the middle of this rhyolite is an irregular exposure of Nevada limestone about 100 feet in thickness, indicating that the greater part of the lava is only a thin flow over underlying limestones. It is the single instance of a rhyolite exposure observed in Mahogany Hills east of Yahoo Canyon.

Temple Peak.—From this rhyolite body the limestone hills rise gradually to the northeast in gentle, flat topped spurs, culminating in Temple Peak (8,398 feet), the highest point between Browns and Denio canyons. Across this limestone body, from Browns Canyon to Dry Lake, the strata dip persistently to the northeast, with a northwest and southeast strike. The limestones at the summit lie inclined at angles seldom exceeding 5°, but are distinctly bedded, and in physical habit and sequence of strata resemble those about midway in the Nevada limestone epoch. The same limestones cross Denio Canyon and continue northward to Burlingame Canyon, invariably dipping slightly to the northeast.

About 150 feet above the bottom of Browns Canyon, in beds near the base of the Nevada limestone, a small number of fossils were procured, most of them like *Atrypa reticularis*, common forms having a wide vertical range. Associated with them was the coral *Acervularia pentagona*. This was found also by the writer in the Nevada limestone of Treasure Hill,[1] White Pine, the only other locality where it has been observed in the Great Basin.

Table Mountain.—South of Browns Canyon the beds of Combs Peak continuing westward gradually curve around until the limestones of Table Mountain strike north and south and lie nearly horizontal, but with a slight dip to the east. Table Mountain is made up of dark massive beds, the upper strata occupying about the same geological position as the summit of Temple Peak. From Table Mountain westward to Antelope Valley, the long spurs afford a fair opportunity to study the beds of the lower and middle portions of the Nevada epoch, which is here represented by 2,500 to 3,000 feet of limestones.

Devon Peak.—The culminating point of the northwest part of Mahogany Hills is known as Devon Peak (8,537 feet), although it is simply the highest point in a broad, plateau-like body of nearly horizontal limestones. To the west and north the beds incline gently toward the sage brush plain of Antelope Valley and the broad plain west of the Piñon Range. One or two of the more deeply eroded canyons offer partial exposures of the beds, but nowhere any continuous sections more than 500 to 700 feet in thickness; yet they serve to show similar conditions of sedimentation over a widespread area. All over this area, at several horizons, a few scattering fossils may be found, such as *Atrypa reticularis*, *Strophomena rhomboidalis*, *Spirifera piñonensis*, *Stromatopora*, and *Chætetes*. In the first ravine running up to Mahogany Hills from Hay Ranch Valley, the limestones afford such large numbers of corals, partially weathered out, that the locality would well repay a visit by anyone specially interested in the study of Devonian fauna.

Yahoo Canyon.—This canyon has its source at the northern end of Dry

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[1] U. S. Geol. Explor. 40th Par., vol. ii, Descriptive Geology, p. 544.

Lake and is the only one of the principal drainage channels of the Mahogany Hills that follows a north and south course. At one time it drained the depressed basin of Dry Lake. At the head of Yahoo Canyon a small outburst of rhyolite forms a low obscure hill, around which the wagon road passes on the west side. A few hundred feet to the south of the hill is a dike of similar rock about 100 feet long by 25 feet wide. This rhyolite is a light gray rock, weathering brown, and carrying a few macroscopic secretions of biotite, sanadin, and quartz; it closely resembles the rhyolite of Browns Canyon. Yahoo Canyon presents some interest as being the dividing line between two quite different types of orographic structure; on the west side the plateau-like body of limestones in the neighborhood of Devon and Temple Peaks lies gently inclined to the westward, while on the east side the limestones have been uplifted into longitudinal ridges with the structural peculiarities of the Piñon Range. In general the canyon may be said to have been eroded along the axis of an anticlinal fold, although this is not strictly correct, as on the east side near its lower end a sharp anticlinal ridge exists, which, however, dies out toward the head of the canyon. The structural details are rather intricate and were by no means carefully worked out, but the dips and strikes indicated on the map (atlas sheet v.) show this anticlinal structure with the trend of the ridges agreeing with the course of the canyon. The main ridge of limestones east of Yahoo Canyon inclines invariably to the eastward with an average dip of about 35° and with a strike a little west of north, maintaining this position till passing beneath the Carboniferous rocks which everywhere seem to overlie them conformably. The ridge is made up of monotonous blue massive limestones characteristic of the Upper Nevada epoch as seen elsewhere, especially in the neighborhood of Signal Peak on the west side and Newark Mountain on the east side of the district. On the east side of Yahoo Canyon a most interesting collection of characteristic species was made, consisting largely of Upper Devonian corals. Associated with them occurs such distinctive species as *Spirifera disjuncta* and the widely distributed *Spirifera glabra*; a fauna indicating a higher horizon than any of the examined beds in the Mahogany Hills to the west. A list of the fauna obtained is given on page 83. Between this locality and the Diamond

Peak quartzites, paleontology again supports structural evidence, the organic forms being such as are only found in the upper horizons or mingled with those having a wide vertical range.

Spanish Mountain.—This broad, elevated mass of Eureka quartzite, nearly two and one-half miles in width, lies due west of Prospect Peak. Its structural features differ from those of any other area of the Eureka Mountains, but at the same time bear some resemblance to those of Grays Peak, both being formed of strata of the same geological age, with the Lone Mountain beds resting upon their slopes. On Spanish Mountain the quartzites dip away in every direction from the summit, but without any clearly defined lines of bedding, presenting the appearance of a great dome-shaped body falling away on all sides. This quartzite is fractured by local displacements, but they fail to bring to the surface any underlying Pogonip beds, and the few drainage channels, which have cut one or two narrow gorges, still lie wholly within the quartzite. Over this dome-shaped body the Lone Mountain beds undoubtedly passed at one time; erosion, however, has worn them off the summit, with the exception of two small patches, which are sufficient to establish the fact that the upper members of the quartzite are still in place on the top of the mountain. Surrounding the quartzite on all sides occurs the Lone Mountain limestone, except along Spring Valley, where it is probably obscured by recent accumulations.

Isolated patches of limestone in the valley confirm the opinion that the Lone Mountain beds extend down to the Spring Valley fault. These limestones cross the divide connecting Spanish Mountain with Swiss Mountain and come within 200 feet of the summit of the former. Wherever observed, the limestones rest unconformably upon the quartzite, but, as they are for the most part devoid of bedding plane, no determination can be made of their thickness. Moreover, the line between the Silurian and Devonian is arbitrarily drawn and rests, as elsewhere in the district, on lithological distinctions and the absence of evidence of life in the lower rocks. As shown on the map, the thickness ascribed to the Lone Mountain beds varies greatly at different localities, but there is no doubt that the vertical distance between Eureka quartzite and limestone characterized by a Devonian fauna actually does exhibit great variations in thickness.

The hornblende-andesite body on the edge of Dry Lake Valley, at the southwest base of Spanish Mountain, will be discussed in the chapter devoted to igneous rocks, which form a most important group, not only in themselves, but in connection with similar outbursts in Sierra Valley and elsewhere. Here at Dry Lake they present a marvelous variety in color, density and texture, but on careful study they are shown to be closely related, with a marked similarity in mineral and chemical composition. The small body designated on the map as dacite is simply an extreme form of the larger mass, being characterized by considerable free quartz and biotite, and has much the nature of a pumice, while the main body might be designated more concisely as an andesitic pearlite.

North of Spanish Mountain, as elsewhere, the Lone Mountain limestones pass gradually into those of the Nevada epoch, and with this change the structural features of the region assume new aspects, quite different from the rest of Mahogany Hills or Fish Creek Mountains. From Brush Creek northward the structure is that of a simple monoclinal ridge, trending about north 40° west, with a dip invariably to the east. Rising above the Quaternary accumulations along the east base of the ridge in Spring Valley, at sufficiently frequent intervals to prove the continuity of strata, occur exposures of quartzite beds, conformably overlying the limestones. As the latter beds bear ample testimony of their Devonian age to the very summit, the siliceous strata have been referred to the Diamond Peak horizon of the Carboniferous. Brush, Modoc, and Signal peaks are the culminating elevations along this limestone ridge, which stretches northward all the way to The Gate. Along the west base of these peaks runs the Modoc fault, extending southward from Hay Ranch Valley, near The Gate, till lost in the Lone Mountain limestones west of Brush Peak. This fault brings up the Diamond Peak horizon in juxtaposition with the Devonian, leaving the limestone ridge between two nearly parallel belts of quartzite of the same age, conformable on the east side, but unconformable on the west. As the line of the fault follows the contact between two dissimilar rocks it is easily traced. North of Signal Peak erosion has worn out a deep ravine along the contact, and still farther southward the east drainage of Reilley Creek also owes its origin to erosion along the same fault line. The Diamond Peak beds may be represented in their full development near The Gate, but they gradually die out to the southward in a wedge-shaped body and finally disappear altogether, beyond which the fault may be followed for a considerable distance, with Nevada limestone walls upon both sides. This long body of Diamond Peak quartzite rests conformably upon the Nevada limestone to the westward, both series of strata dipping uniformly to the east. We have here, then, a duplication of strata made up of the Upper Nevada limestone, overlain by the Diamond Peak quartzite. Small drainage channels, branches of Reilley Creek traverse the quartzite, affording fair cross sections. Numerous minor dislocations, at right angles to the Modoc fault, trend easterly across the ridge, dying out in the plain beyond, but, while they tend to break up the uniformity of structure, do not cause any very decided dislocation in the Nevada limestones.

Perhaps the best section, the one showing the greatest vertical thickness across the Nevada limestone, may be found on the ridge north of Modoc Peak. This section is given on page 66. Starting in at the Modoc fault in Reilley Canyon, nearly due west of Modoc Peak, it crosses the strata nearly at right angles and terminates at the base of the hills in Diamond Valley. The beds strike N. 50° to 55° W., measuring about 5,400 feet in thickness. Just north of Modoc Peak a fossiliferous shaly limestone, 200 feet in thickness, crosses the ridge. It is the belt designated No. 3 of the section, and is the equivalent of the rich fossiliferous shale which has yielded such an abundant Devonian fauna at several localities in the District, notably, at Brush Peak, about 2 miles southward. Higher up in the strata, corals of the middle and upper horizons were obtained, but nowhere immediately along the line of the section was any special fossiliferous zone recognized.

Both north and south of the line of the section the strata are easily traceable, striking obliquely across the ridge, the upper horizons being developed on Signal Peak and the lower on Modoc and Brush Peaks. Just below the summit of Brush Peak the fossiliferous shale belt, which is here about 150 feet in width, determines the position of the beds without question. It is at this locality that the shales have furnished such an excellent opportunity for the collection of a Devonian fauna. The few hours spent here gave promise of an abundant harvest if time would permit of a diligent search. From this shale belt the limestones pass down into the Lone Mountain series, the hill lying between Brush Peak and Spanish Mountain being formed of the latter beds.

Metamorphosed sandstones.—Interstratified in the Nevada limestone of this ridge occur numerous bands of fine grained sandstones with their bedding planes parallel to the inclosing rock. Some of them may be traced for over a mile without interruption, rarely exceeding 50 feet in thickness, but most of them only a few feet in width. They are shown in the section north of Modoc Peak occurring at varying intervals throughout nearly 1,000 feet of limestones.

Instances of sandstones in limestones are common enough and would call for no special comment but for the fact that here they have undergone considerable alteration, and as the original material was more or less impure, they have developed under dynamic influences a crystallization and structure of a micro-granite. All of these sandstones show alteration, but at the same time exhibit remarkable transitions from a normal sandstone to a rock closely resembling a cryptocrystalline granite. The quartz grains are granitoid in structure, and do not show the action of water usually seen in a compact sandstone made up from the disintegrated material derived from an older rock. Accompanying these quartz grains are flakes of muscovite with some ferrite and calcite. It is evident that the beds have undergone a marked change since they were originally laid down. That these rocks are of sedimentary origin no one would question, yet they are associated with others which have undergone so great an alteration that they present many structural features of igneous rocks. The transition from undoubted sandstone to the highly metamorphosed beds shows every stage of gradation and it is impossible not to see the close relationship existing between them. In the more highly altered rocks may be observed well developed feldspars, both orthoclase and plagioclase. Most of the feldspars, however, have undergone decomposition, and are accompanied by calcite and other secondary products. Singularly enough, some of the more crystalline bodies exposed along the west sides of Signal and Modoc peaks attain a much greater width. In one instance the rock measures about 200 feet across its broadest development, but diminishes rapidly to only a few feet. Here it loses its distinctive features as a sedimentary bed, and, on the contrary, appears to cut across the limestones, suggesting an intrusive dike. That these nearly identical rocks should, in some cases, have the characteristics of sedimentary deposits, and in others those of an intrusive dike, is, to say the least, most remarkable; but, after a study in the field of their mode of occurrence, no other conclusion seems reasonable than that they are similar rocks which have undergone various degrees of metamorphism. These occurrences have no special bearing upon the history of the sedimentary strata, as they occupy very limited areas in the limestones, and perhaps still less upon the history of the Tertiary volcanic outbursts of the Eureka region. They are well worthy an investigation, and Mr. Iddings, in his chapter on the microscopical petrography of the crystalline rocks, has devoted considerable space to a discussion of the phenomena which these rocks exhibit.

Signal Peak.—On this peak the limestones belong exclusively to the Upper Nevada horizon, being massive grayish black rocks, distinctly bedded. They dip northeast about 35°. The fauna is characterized by Upper Devonian corals, associated with species found all the way through the Nevada epoch. North of Reilley Canyon the beds dip eastward at a still lower angle, throwing the overlying quartzite to the east, out toward the valley. On the summit of the ridge north of the last named canyon occur *Syringopora hisingeri*, *Bellerophon mæra*, and other more common forms, the beds carrying occasional corals, without being confined to any special horizon.

The Gate.—At The Gate occurs a marked change in the structure of the region. The ridge, which from Brush Peak northward maintains a fairly uniform course, here undergoes an abrupt break, trending off more to the west, and at the same time the entire mountain mass north of The Gate has been thrust eastward, bringing the beds on opposite sides of the break unconformably against each other. The Gate is a deep, narrow gorge, cutting completely through the ridge along the line of the dislocation. It cuts down to the very base of the range, draining the broad desert region of Hayes Valley out into Diamond Valley. On the south side of The Gate the beds strike N. 20° W., dipping 20° easterly, but on the north side they strike N. 55° W., with a dip increased to 30° easterly. Owing to the thrust which forced the beds toward the east the walls on the south side belong mainly to the Diamond Peak quartzite, while those on the north side are formed of a bold cliff of Nevada limestone. The sections across the strata on opposite sides of the gorge are readily correlated by structural features confirmed by paleontological evidence. Fortunately, just beneath the Diamond Peak beds south of The Gate a fauna characteristic of the Upper Nevada limestone occurs in the low ridge near the west entrance to the pass. There is exposed here a thickness of 1,000 feet of the upper limestones. The underlying beds are dark gray in color, with poorly preserved fossils, followed by a black band bearing many large *Stromatopora* and other corals. Interstratified in these limestones are several quite shaly beds, seldom more than 1 foot in thickness. These gray beds are followed by a belt of distinctly stratified black limestones, weathering a light color, and yielding numerous corals. Above this, again, are thinly bedded, dense limestones, extending up to the overlying quartzites. In these latter beds occur the Upper Devonian fauna already mentioned. Conformably overlying the limestones occurs a broad belt of Diamond Peak beds, forming the wall along the south side of The Gate and extending in low, round, monotonous hills out to Diamond Valley. The cliffs on the north side of The Gate expose about 500 feet of massive, dark limestones, passing into shaly and fissile beds 2 or 3 feet in thickness. A rich and varied fauna from this locality will be found published in full on page 83. The locality would well repay a more diligent and careful search.

Absence of White Pine Shale.—On both sides of the gorge the overlying siliceous beds are much the same, the base of the series being made up of quartzites, interbedded, impure sandstones, compact, dense argillites, fine conglomerates, and black cherty layers, rapidly passing into purer quartzites. On the south side the black cherty belts present a greater thickness and are not confined to the base of the horizon.

It will be noticed that no mention has been made of the White Pine shale, which on the east side of the Eureka District exposes such an enormous thickness. There is but little doubt that these lower beds represent the White Pine horizon, but, as they are so poorly developed as compared with the shales at Newark Mountain and so difficult to trace along any definite horizon, they have been omitted on the geological map. No exposure of these beds was seen more than 100 feet in thickness and in places they are entirely wanting. It would seem that after the deposition of the limestones the conditions here were more favorable for purely siliceous beds than at Newark Mountain, and that the transition was more or less rapid. It must be remembered that the White Pine shale, although of great thickness at White Pine and on the east side of the district, is of local occurrence, never as yet having been recognized in other parts of the Great Basin. The occurrence in the argillites just south of The Gate of a few obscure plant remains and the species *Discina minuta* is strong evidence, taken in connection with their stratigraphical position, that these beds represent the White Pine shale.

The Diamond Peak beds which overlie the limestones on the north side of The Gate form the great mass of Anchor Peak, showing a greater thickness of strata than the same horizon exposes in the Diamond Range; the explanation being found in the argillites of the White Pine shale giving out and being replaced by a greater development of siliceous material. After the coming in of the siliceous beds north of The Gate the quartzites stretch for nearly a mile beyond the limits of the map. At the west base of Anchor Peak there is a small exposure of Devonian limestones dipping under the quartzites, probably extending northward along the west base of the Piñon Range.

SILVERADO AND COUNTY PEAK.

This mountain block is mainly outlined by profound faults, along which igneous rocks of varied composition have burst forth in vast quantities, almost completely isolating it from adjoining sedimentary regions. On the south and east the Quaternary accumulations of Newark and Fish Creek valleys rest against the base of the hills and probably in a large degree conceal eruptive rocks which broke out along the edge of the uplifted mountain mass, but nowhere attained any considerable elevation. This mountain block is, for the most part, made up of sedimentary beds belonging to the Silurian and Devonian. In the chapter devoted to a sketch of the general geology of the district the principal features of this region are given, and in the chapter on the Devonian rocks a description will be found of the Nevada limestones, together with some discussion upon the development of the Devonian fauna, as shown upon Sentinel Mountain, Woodpeckers Peak, and Rescue Hill. Only such additional facts are here presented as may be of value in a detailed study of the region in the field and for comparative purposes in distant areas of the Great Basin.

County Peak Region.—The Pinto fault, which trends approximately parallel with the Hoosac fault, sharply defines this block on the west, and, like the latter fault, is probably deflected to the east at its northern end. The lowest rocks exposed by the fault are two bodies of Eureka quartzite, one immediately at the base of Richmond Mountain, the other near by, but separated from it by the tuffs of Hornitus Cone. The first exposure is so completely surrounded by igneous rocks that there is nothing to indicate its geological position but lithological habit and proximity to the second and larger body, the age of which is clearly determined by overlying Lone Mountain beds. At its northern end the quartzite of this larger body forms a broad-topped hill nearly 500 feet in height, with the beds inclined a few degrees to the east. As regards their lithological habit, they could not be distinguished from the corresponding beds along the Hoosac fault or those in the region of Grays Peak.

Along the Pinto fault the quartzite is exposed for nearly a mile, thinning out in a wedge-shaped body, and replaced by the Lone Mountain limestone, which, in turn, gives way to the Nevada limestone, the latter forming the fault wall opposite Dome Mountain. Erosion has worn out a deep, narrow ravine along the displacement, with the Carboniferous limestone, admirably shown on one side, dipping westerly, at angles never less than 60°, and the Lone Mountain limestone of the Silurian equally well shown on the other side, dipping easterly, but inclined at low angles, seldom, if ever, exceeding 20°.

The canyon wall is cut out of the Lone Mountain beds, but on the steep hill slopes they give way to the Nevada limestones, which continue eastward across the entire width of the mountains till they are lost beneath the lava beds of Basalt Peak. County Peak (8,350 feet) forms the culminating point of this broad, elevated mass of limestones, all the beds of which strike north and south and dip easterly, affording an excellent cross-section over 5,200 feet in thickness, with the Lone Mountain beds at the base. The sequence of rocks shown here may be taken as a typical one of the Nevada epoch and will be found on page 68, in a chapter devoted to the Devonian rocks. The cross-section E-F, atlas sheet XIII, is drawn across the summit of County Peak, and gives at a glance the structure of the mountains, which is shown better here than to the south, where it is difficult to obtain a continuous section for anything like the same distance across the strata at right angles to their strike. Midway on the ridge connecting County and Woodpeckers peaks, about 200 feet below the summit and 3,000 feet above the base of the limestone, occurs an important grouping of fossils exhibiting the most complete mingling of both upper and lower Devonian species yet found in the district. Radiating from County Peak in all directions occur numerous narrow gorges scored deeply into the mountains, frequently exposing 1,000 or 2,000 feet of strata and offering excellent opportunities for detailed studies across the middle Devonian strata. These gorges are the source of the two drainage channels that encircle Richmond Mountain, finally running out into Diamond Valley. North of County Peak toward Richmond Mountain, the limestones are characterized by a development of siliceous beds, aggregating a thickness of over 100 feet and rising in bold, rugged outcrops above the otherwise even hill slopes. Nowhere else were similar rocks recognized in the Devonian, the siliceous material apparently increasing in amount toward Richmond Mountain, although the higher horizons maintained their normal character. It is only directly west of County Peak that the upper members of the Nevada limestone are exposed, the basalts concealing more and more of the beds as they approach Richmond Mountain. In this area north of County Peak, scarcely any fossils were collected, and nowhere any grouping of species; consequently no locality indicating the presence of organic remains is marked upon the map. It is proper to say, however, that very little time was allotted to their search, but it seems hardly possible that they are absent, as occasional evidence of poorly preserved corals was noted in the purer limestones.

Silverado Hills.—South of Dome Mountain the Lone Mountain strata again come in along the Pinto fault, and with the exception of occasional breaks caused by overflows of both rhyolite and basalt continue to form the base of the sedimentary beds until the ridges pass beneath the deposits of Fish Creek Valley. These rhyolites and pumices, with the glassy basalts breaking through them, present identical features with those found in the basin south of Richmond Mountain, while the basalts in the limestone do not differ essentially from those occurring as dikes in pyroxene-andesite.

The drainage from the slope of Hoosac Mountain follows a southeast course until it meets the upturned Silurian ridge on the east side of the Pinto fault, then runs south across the Pinto Basin, where, instead of continuing southward following the natural grade along the line of the fault and across the soft, easily eroded pumices, it turns abruptly and follows a deep channel cut clear through the hard rocks of English Mountain, finally running southward to Fish Creek Valley. The divide between this water course and the broad drainage channel running southward along the Pinto fault and also emptying into Fish Creek Valley, lies only a few feet above the level of the two stream beds. So far as can be made out the barrier between the streams is wholly formed of recent lavas. It is similar to the case mentioned in describing the drainage of Secret Canyon, where the stream, after following the course of the canyon for a long distance, suddenly crosses the upturned ridge of Cambrian and Silurian rocks, avoiding the low and insignificant ridge of volcanic material which blocks the entrance to the canyon. The cause of this sudden turn in the course of these stream beds is difficult to understand, but it is worthy of note that the drainage channel breaking through English Mountain lies nearly due east of the one cutting Hamburg Ridge.

The Lone Mountain beds are not so uniformly made up of limestones as the corresponding horizon elsewhere. Many of the intercalated strata resemble the underlying Eureka quartzites, but, as the latter nowhere carry any considerable layers of calcareous material, such a reference is out of the question. That they correspond to the Lone Mountain horizon there can be no doubt, the only difference being that the siliceous beds occur here more prominently developed than on the west side of the Hoosac fault with the friable sandstones altered to compact quartzites. Moreover, they are seen to pass into Nevada limestones, except where their continuity is broken by outbursts of basalt. In the region of English Mountain this connection is in no way disturbed by intrusive material and the transition into the Nevada beds may be readily made out. Nevertheless, there occurs along the Pinto fault one or two exposures of siliceous beds whose geological position it is difficult to determine. One of these is found east of the Pinto Mill, where a long, narrow ridge, largely made up of quartzites, dips from 25° to 35° to the east. A ravine, which cuts through this ridge, gives a fair idea of the beds, and it is not improbable that they belong to the Eureka horizon. Another instance may be found southeast of Pinto Basin, near the place called The Wells, where a small isolated hill occurs, apparently a faulted mass composed of white vitreous quartzite with intercalated bluish gray limestones. Except for these limestones the evidence would point quite as much to the Eureka quartzite as to the overlying Lone Mountain beds. English Mountain offers the best locality for a study of these Lone Mountain beds to be found on the east side of the district, as they show a great thickness of strata dipping uniformly eastward, overlain by the lower beds of the Nevada limestones. The base of English Mountain is formed of quartzites and sandstones, followed by gray limestone, in turn capped by brownish red, vitreous quartzite. The latter is a rough and jagged rock, full of nodules and water-worn cavities.

On the south side of the Silverado Hills the Silurian rocks rise above the pumices and tuffs that follow the base of the hills and in a large degree conceal the sedimentary beds. Here the limestones have gradually changed their strike and dip and lie inclined to the northward with the great body of Devonian limestone that forms the bold escarpment of Red Ridge resting upon them. Continuing eastward, the limestones gradually swing around until they assume a westerly dip, forming a synclinal fold, with those of English Mountain. This Red Ridge escarpment offers excellent vertical sections of the middle portions of the Nevada limestones, and the variegated red, gray, and brown belts, with the interbedded sandstones, may be traced for long distances from one mountain to another. In this way it becomes an easy matter to correlate strata in such blocks as Island and Leader mountains and Sugar Loaf. The deep gorges penetrating the limestones afford grand exposures. Sugar Loaf offers one of the best points of view for gaining a clear understanding of the synclinal structure of the Silverado Hills, the characteristic belts of sandstones and mottled limestones being readily traceable from an easterly to a westerly dip. The summit of Sugar Loaf is formed of Upper Devonian strata, with abrupt escarpments on all sides. At the east base of this isolated mountain, the Rescue Canyon fault may be traced crossing the ridge between the head of Rescue Canyon and the faulted block of White Pine shales at Charcoal Canyon. From Sugar Loaf northward to Packer Basin all the limestones on the west side of the fault dip westerly, the fault following the line of contact between the Nevada limestone and the White Pine shale. Opportunities for observing these westerly dipping beds may be found in Charcoal and Ox Bow canyons, the streams which cut the ravines crossing the strata nearly at right angles to their strike.

Packer Basin.—Packer Basin is a small depressed block of Nevada limestone lying between the northern end of the main ridge and the broad basalt table, the abrupt wall of the latter shutting in the basin on the north. As the basin lies on the very edge of a broad volcanic field, it has naturally undergone a good deal of dislocation, and is much broken up by pumices and tuffs, which partly fill the basin, having poured out along a fissure on the west side of the faulted block. It is interesting to see here the same association of pumices and tuffs, followed by a later outburst of basalt, in all respects similar to those occurrences seen in so many other places bordering the uplifted block. The limestone still maintains the north and south strike and westerly dip of the main ridge to which it really belongs. Its chief interest lies in the finding in a massive blue limestone a fauna characteristic of a somewhat higher horizon than those observed at Woodpeckers and Basalt peaks. Additional interest is derived from the disappearance of the Rescue fault and the accompanying White Pine shales beneath the basalts.

Rescue Hill.—Scarcely any mention need be made here of this locality as the essential structural features and the list of species obtained in the upper beds have been given in the chapter describing the Devonian rocks. The hill is a block of limestone faulted over 1,000 feet below its true stratigraphical position. It lies in the angle formed by the intersection of the Rescue and Silverado faults. The beds lie inclined at a very low angle presenting an excellent section for comparative purposes with beds found elsewhere. Owing to the faulting of this block the variegated beds of Red Ridge can not be followed on Rescue Hill, but to the north they are easily traceable on Island Mountain and Sugar Loaf.

Century Peak Ridge.—Rescue Canyon severs the Century Peak Ridge from the main body of Silverado Hills, a separation which is intensified by the rhyolitic outbursts along the line of the canyon. Structurally the country east of the canyon differs in a most striking manner from Red Ridge and Rescue Hill, the horizontal, plateau-like character of the former giving way to a narrow ridge with steep slopes. This ridge, of which Century Peak is the highest point, presents a sharp, anticlinal fold, the beds dipping away from the axis at angles varying from 70° to 80°. The axis of the fold follows closely the crest of the ridge, with a strike approximately north and south. On the summit of Century Peak occurs one of the many intercalated beds of quartzite found in the Nevada limestone, and here forms the greater part of the west slope, extending down the ridge nearly to the line of rhyolite. Just where this quartzite belt belongs in the limestone was not determined, but the entire uplift is of Upper Devonian age, as is shown by the lithological character of the beds. No fossils identifying any special horizon were obtained, but those found were forms having a wide vertical range, such as *Atrypa reticularis*. The corals belong to the upper portion of the limestone and, although too obscure for specific identification, closely resemble the forms found in the limestones at the northern end of the Mahogany Hills. Along the line of the Silverado fault the rocks give evidence of considerable disturbance and folding with abrupt flexures and breaks. For the greater part of the distance along the canyon the Nevada limestone may be seen south of the fault, with the White Pine shale on the north or opposite side of the gorge resting unconformably against it. On the north side of the Silverado fault, between the White Pine shale and the rhyolites occurring at the head of Rescue Canyon, is a triangular block of limestone inclined to the east. This block of limestone lies on the east side of the Rescue fault, conformably underlying the White Pine shale and offering ample structural evidence that it belongs to the highest beds of the Nevada horizon. The amount of faulting along Silverado Canyon has never been determined, but probably does not exceed a few hundred feet, which is additional evidence that the Century Peak beds belong to the upper portion of the Devonian. South of Century Peak there is a decided break in the strata and the entire limestone ridge dips off toward Fish Creek Valley, with a northeast and southwest strike.

Alhambra Hills.—The low ridge of limestone designated as the Alhambra Hills lies to the east of the Century Peak ridge and is connected with the latter by a continuous body of limestone. North of this connecting ridge Quaternary deposits lie between these hills and Century Peak ridge, but they are of no great thickness and undoubtedly overlie a depressed area of limestone. Alhambra Hills rise but a few hundred feet above the plain. They present a dull, monotonous, arid aspect, with but few scattered trees and without soil. The limestones belong to the upper members of the Nevada horizon and are massive, distinctly bedded, grayish blue rocks. But little time was devoted to the search for fossils, but such as were found denoted the upper beds of the Nevada and were mostly corals similar to those found in the neighborhood of Century Peak, associated with the ever present *Atrypa reticularis*. Beyond this identification of the age of the beds the Alhambra Hills present no special geological interest. A few mineral veins penetrate the limestone, but so far as known are unaccompanied by rhyolite intrusions. The latter rock, while it probably encircles the Alhambra Hills, does not appear to enter the limestone body.

White Pine Shale Area.—There is little that need be said about this area in addition to the observations presented elsewhere in discussing the geological position and the paleontological evidence of the age of the White Pine shale. On page 81 will be found a description of the strata across the entire thickness of shales and sandstones, at least until they are overlain by Quaternary deposits. They measure over 2,000 feet. This section was made east of Sugar Loaf, where the underlying limestones are exposed, passing conformably beneath the broadest expansion of overlying shales. The occurrence of this limestone is exceedingly fortunate, as upon it rests the evidence of the position of the overlying shales, whereas, north of Charcoal Canyon no limestones occur beneath the shale, and as the beds trend to the northwest with a greater angle than the course of the Rescue fault, the lower strata are cut off along the line of the displacement. Direct evidence is wanting of the precise position of the beds lying next the fault. From Silverado Canyon northward to Packer Basin the strata dip uniformly eastward. Charcoal Canyon, Ox Bow Canyon, and the other drainage channels traversing the formation, fail to give any good sections across the beds, as the valleys, though broad, are extremely shallow, with the underlying rocks more or less covered with soil and gravel, derived from the disintegration of the friable interbedded sandstones. The stream bed coming from Packer Basin has eroded somewhat more deeply into the shale formation, the beds lying more highly inclined, but shortly after leaving the mountains it enters the tuffs which overlie the shales.

Cliff Hills.—South of Silverado Hills, and separated from them by the broad expanse of Fish Creek Valley, lies a low ridge designated Cliff Hills on account of the mural-like escarpment which they present to the Quaternary plain. These hills have no direct topographical connection with the Eureka Mountains and are referred to here only because they happen to come in on the southeast corner of the map. By reference to atlas sheet XII, their relations to the Eureka Mountains may be seen at a glance. Geologically they are of great interest, as the White Pine shale, which has been recognized over such limited areas, occurs here under conditions similar to those found east of Sugar Loaf. Low undulating ridges of shale and sandstone formed of westerly dipping beds pass beneath a broad, flat-topped body of pyroxene-andesite. It is this andesite which gives the cliff-like appearance to the hills, the dark bare rocks presenting a forbidding aspect as they rise above the desert valley. In their mode of occurrence and petrographical habit these andesites closely resemble those of Richmond Mountain, and show the same modification in color, density, and chemical composition; in mineral composition they are identical. These resemblances are borne out by microscopical investigation, the differences in structure in Richmond Mountain finding their counterpart in Cliff Hills.

Cropping out beneath the andesites at the north end of the hills are three small exposures of gray limestones, only one of which is represented on the map. It dips westerly at an angle of 15° and strikes nearly north and south. No evidence of the age of these limestones could be obtained, but from their proximity to the White Pine shale and their general resemblance to the Devonian rocks of the Silverado region, they have been referred to the Nevada limestone. In the White Pine shale a few fragmentary plant remains were procured, none of which were sufficiently well preserved to admit of identification, although they bear the closest resemblance to the plants found elsewhere at this horizon.

DIAMOND RANGE.

Few of the narrow longitudinal ridges in central Nevada form so prominent a physical feature as the Diamond Range. Only the southern end, however, comes within the limits of the Eureka District, but here it is so intimately connected with the County Peak and Silverado uplift as to form a part of the same geological region.

Diamond Peak, the highest elevation in the range, is situated just within the limits of the survey, although the north and east slopes lie beyond the boundaries of the map. In a study of the sedimentary rocks of the Eureka district, this peak is of the highest interest, showing the relationship between the Devonian and Carboniferous beds in a manner unsurpassed elsewhere in the Great Basin, and at the same time carrying the Paleozoic section nearly, if not quite, to the top of the Upper Coal-measure limestone.

Newark Mountain.—As seen from the east, Newark Mountain presents a bold front of blue limestone rising nearly 2,000 feet above Newark Valley, the upper 1,000 feet an abrupt cliff, followed by a highly inclined slope to the plain. Along the summit it is a narrow ridge 3 miles in length, falling off gradually toward the west in strong contrast with the opposite side. In structure, Newark Mountain is an anticlinal fold whose axis may be traced all along the base of the cliff, the eastern side of the arch having dropped about 1,000 feet, causing a picturesque escarpment. It is a fine example of a limestone wall formed by a displacement. The easterly inclined beds, begining at the base of the cliff with a dip from 15° to 25°, gradually fall away with a less and less angle, stretching in low broken hills and knolls far out toward the plain. Along the face of the cliff on the west side of the anticline the strata incline into the mountain, arching overfrom an angle of 25° on the crest of the ridge to 55° along the western base in Hayes Canyon. At the southern end of the ridge the beds rise steeply out of the Quaternary plain along the line of an east and west fault. They strike a few degrees east of north, gradually curving more and more to the east, coinciding approximately with the trend of the ridge until at the northern end they fall away toward Newark Valley and pass beneath the east base of Diamond Peak. The limestones of Newark Mountain belong to the upper portion of the Nevada Devonian. They are usually dark blue and gray in color and distinctly bedded. It is estimated that there are exposed on the mountain about 3,500 feet of these upper Nevada limestones, which would carry the beds down nearly to the middle of the formation They may be correlated readily with the limestones of Silverado Hills by the sequence of strata and by their physical habit. Their stratigraphical position is determined without doubt by the overlying White Pine shale in Hayes Canyon, the contact between the two formations being easily traceable for miles, all the way from the entrance to the canyon around to the northern base of Diamond Peak. Paleontological evidence confirms other evidences by the finding of upper Devonian species in several localities in two distinct horizons, one, near the summit of the limestones along the west base of the mountain, the other, several hundred feet lower down in light gray, somewhat shaly beds on the south side of Milk Canyon. Fossils may also be obtained near the summit of the mountain. A list of the species obtained from both horizons will be found in the chapter devoted to the discussion of the Devonian rocks, and, while they both contain specific forms having a wide vertical range, they are characterized by types found only in the upper Devonian. The species *Beyrichia occidentalis,* obtained just below the White Pine shale in Hayes Canyon, occurs on the east side of the mountain 1,000 feet or more below the summit; it has also been identified from the top of Telegraph Peak at White Pine, where it also occurs not far below the base of the shale.

At the summit of the Nevada beds a reddish gray, impure limestone passes gradually into the black, argillaceous shales of the White Pine series, the contact between the two formations being admirably shown all along Hayes Canyon at the base of Newark Mountain. The drainage channel marks closely the line of contact. Hayes Canyon lies wholly in the shales, erosion having carved out of them a broad valley, similar in topographical structure to Secret Canyon, between the Prospect Mountain and Hamburg limestones. Upon one side of Hayes Canyon rises a wall of dark blue, Devonian limestone, and on the other light blue and gray Carboniferous limestone. At the summit of Hayes Canyon the shales following the course of the limestones of Newark Mountain trend off to the northeast and rapidly pass under Diamond Peak. The relationship between the shales and the Diamond Peak quartzite may be best studied along the base of Bold Bluff, the former being seen to dip conformably beneath the quartzites at an angle of 30°.

Diamond Peak.—The summit of Diamond Peak attains the highest elevation of any point within the limits of this survey, reaching an altitude above sea level of 10,637 feet. From Newark Valley it rises for over 4,000 feet with an almost unbroken slope to the summit. No peak commands a more favorable view for a study of the relationship between the topographical configuration and geological structure of the country. The structure of the peak is that of a sharp, synclinal fold, the axis of which, striking northeast and southwest, lies along the crest of the ridge. The westerly dipping beds form the entire eastern slope of the peak, exhibiting a great thickness of Devonian and Carboniferous rocks. At the base of the peak, just outside the limits of the map, the Nevada limestone comes in, overlain by a broad belt of black shales, which form the lower slopes, but, as denudation has worn them smooth, they present rather a monotonous aspect. Following the shales are the Diamond Peak quartzites, in rough and rugged ridges and bold walls, extending within 1,200 feet of the summit, over which come the massive Coal-measure limestones forming the top of the peak.

The following section gives the broader divisions of the beds from base to summit, including those exposed on Newark Mountain, as the Nevada limestones on Diamond Peak are shown only to a very limited extent:

		Feet.
Carboniferous.	1. Bluish gray distinctly bedded limestones	1,000
	2. Green and brown and chocolate colored clay shales, with interbedded siliceous bands and cherty beds	500
	3. Dark gray quartzites, compact conglomerates, with interbedded layers of jasper and siliceous grits. Near the base narrow belts of blue limestone, carrying *Productus semireticulatus*	2,500
Devonian.	4. Black argillaceous shale, more or less arenaceous and similar to the lower black shale	1,000
	5. Compact, fine grained sandstone, with minute dark siliceous pebbles scattered through the beds	100
	6. Black argillaceous shale, with fine intercalated beds of arenaceous shale. These shales crumble on exposure to atmospheric influence	500
	7. Reddish gray shaly calcareous beds	100
	8. Dark gray heavily bedded siliceous limestone, passing into bluish gray limestone, in places finely banded	3,500
	Total	9,200

The importance of this section lies in the fact that it gives over 9,000 feet of conformable limestones, shales, and sandstones of Upper Devonian and Lower Coal-measure strata, the best section as yet recorded from this portion of the Paleozoic series in Nevada. It will be noticed that at the base of this series of beds less than one-half of the thickness of the Nevada limestone is represented, and at the top only about one-quarter of the entire thickness assigned to the Lower Coal-measures is exposed on the summit of Diamond Peak.

Along the summit of the range occupying the axis of the fold the Coal-measure limestone extends for a long distance, and on Diamond Table, at their southern limit, they present a bold body of nearly horizontal beds, 300 feet in thickness, resting directly upon the quartzites. In Water Canyon, which drains the southern end of Diamond Peak, the position of these two formations is well brought out, erosion having carved a magnificent amphitheater, with abrupt walls, 2,000 feet into the quartzite. In the bottom of the canyon the White Pine shale comes out beneath the quartzites, all three formations being shown in the canyon walls.

Scattered throughout these limestones may be found Coal-measure fossils, the best locality noticed being on the summit of the ridge about one-third of a mile south of the peak and 150 feet below the highest point. Ten species were obtained here, the list being given on page 91. The two most interesting species are *Spirifera trigonalis* and *Camarophoria cooperensis*, the latter identical with the Missouri form. Both of them, as pointed out by Mr. Walcott, are characteristic of the lower Carboniferous in the Mississippi Valley. It is these two species that serve to correlate the low limestone ridges south of Newark Mountain with the base of the Lower Coal-measures.

Immediately northwest of the crest of the ridge the strata dip easterly, and at about the same distance below the summit, as observed on the opposite side of the peak, the quartzites come in conformably beneath the limestones, dipping easterly into the ridge. No considerable thicknesses of quartzites are exposed, as they are abruptly cut off by the profound Alpha Peak fault, which brings the Upper Coal-measure limestones unconformably against them. Following the quartzites southward, they are seen to be much broken up and dislocated, and southwest of the peak again dip westerly, with an angle of about 15°, a dip which they maintain as far south as Bold Bluff, where they terminate abruptly against the Newark fault. By reference to atlas sheet VI the position of the quartzites may be readily made out, completely encircling Diamond Peak on all sides.

Newark Fault.—This line of faulting, starting in at Bold Bluff, trends southward along the abrupt west wall of Hayes Canyon, following the contact between the two dissimilar formations—the gray Lower Coal-measures and the black White Pine shale. It is easily traceable for nearly 3 miles. At the southern end it gradually trends off to the southeast, completely cutting off the shales, as well as the Diamond Peak quartzite, and at the mouth of Hayes Canyon brings the Lower Coal-measures directly against the Nevada limestone of Newark Mountain.

Region of Alpha and Fusilina Peaks.—The Lower Coal-measure limestone overlying the Diamond Peak quartzite forms an unbroken narrow ridge, extending southward for over 9 miles, and falling away gradually until it passes beneath the Quaternary of the valley. This ridge presents great simplicity of structure and monotony of appearance, the beds exhibiting much the same lithological habit throughout and everywhere lying inclined toward the west at high angles.

At Bold Bluff, where the quartzite gives out, the Newark fault brings the lower members of the limestone next the White Pine shale. Along the west side of Hayes Canyon both formations dip into the ridge, but it is somewhat difficult to recognize the unconformity along the contact, owing to the amount of débris, in spite of the fact that the angle of dip between the two horizons varies from 20° to 30°. Several observations, taken at different points along the canyon wall, gave about 25° as the angle of unconformity. The evidence of the unconformity is strengthened by the absence of the entire thickness of quartzite, the true position of which, between the limestone and shale, is so well exhibited both on the east side of Diamond Peak and in the neighborhood of Bold Bluff and Water Canyon. Again, the wedging out of the White Pine shale, which is completely lost at the mouth of Hayes Canyon, gives additional evidence of the unconformity.

The upper members of the Lower Coal-measures are quite as sharply defined on the west side by the Alpha fault, which for a short distance follows along the steep northwest slope of Diamond Peak, bringing the Upper Coal-measures unconformably against the quartzite. Nearly due west of the summit the fault trends off to the southwest and the Lower Coal-measures come in next the quartzite, the line of fault marking the contact between the two bodies of Carboniferous limestone. The Alpha fault continues southward along the base of Alpha Peak, but terminates abruptly on reaching the north slope of Weber Peak. It is rarely that an unconformity in Carboniferous limestone strata is more strikingly shown than by the two Coal-measure formations along the Alpha fault. There may be seen here on one side of the fault, the underlying limestones dipping westward at angles varying from 65° to 85°, and on the opposite side, the overlying limestones inclined at angles rarely exceeding 10°.

At Weber Peak, where the Alpha fault terminates, an east and west fault brings up the Weber conglomerate, and from here southward the beds of the latter epoch are found in their true geological position conformably overlying the Lower Coal-measures. This east and west fault does not cross the Alpha fault, at least the limestones appear to have undergone no displacement. West of the Alpha displacement the course of the east and west fault after passing Weber Peak is lost, being buried beneath the accumulations of igneous rocks.

The thickness of the Lower Coal-measures may be best estimated south of Fusilina Peak, where the upper members of the epoch are determined by the position of the Weber conglomerate, and, although there exists no positive evidence that the beds resting on the White Pine shale are the equivalent of the lowest members found elsewhere, they probably do not belong far above the base. It is estimated that the limestones measure about 3,800 feet in thickness.

Organic remains may be found scattered throughout the limestone, but nowhere were any grouping of species obtained which were of special interest or which could be regarded as the equivalent of the Spring Hill fauna. At the head of Newark Canyon, which starts in near the base of the limestone immediately resting on the White Pine shale, were found *Productus longispinus, P. semireticulatus,* and *Spirifera camerata,* while south of Fusilina Peak, at the top of the horizon, the same species occur associated with *Fusilina cylindrica* and other Coal-measure forms. On the map will be found a number of localities designated where fossils were procured but they indicate only a few of the horizons where they are known to exist.

Weber Peak and Pinto Springs Region.—Under this heading may be designated the area of the Weber conglomerates lying between the two great bodies of Carboniferous limestone. From Weber Peak southward they overlie conformably the Lower Coal-measures, although not extending southward out into the open valley quite as far as the limestone, being buried beneath either basaltic flows or the alluvial deposits of Pinto Creek. Along the line of contact the Weber conglomerates form a well defined series of ridges parallel with the Alpha and Fusilina ridges, the two formations standing out sharply contrasted by their surface forms, atmospheric agencies acting quite differently on the fine crystalline limestones and the coarse conglomerates. In like manner erosion acting upon the more easily disintegrated conglomerates has worn out a number of narrow drainage channels along the contact which serve still more sharply to define the boundaries. The conglomerates stretch out toward the west until cut off by the broad basaltic tableland of the Strahlenberg, which, concealing everything over a wide area, leaves to conjecture the probable structural relations of the Carboniferous rocks of the Diamond Range to the immense block of Devonian limestone of the County Peak uplift. East of Strahlenberg, the highest point on the eastern rim of the basaltic field, the conglomerates present a broad, high ridge, with a strike of N. 30° W. and an easterly dip of 75°. It is against this ridge that the basalts have been piled up, the ridge acting as a barrier to their further progress in that direction. Between the basalt and the Lower Coal-measures of Alpha Ridge the conglomerates are plicated into a broad syncline followed by a sharp anticline, the axes of both folds being traceable the entire length of the conglomerate area. The conglomerate ridge lying next to the Lower Coal-measures forms the east side of the syncline, the beds coming up again on the opposite side of the fold in a ridge nearly parallel with the first one. The anticlinal fold presents a much sharper axis, the beds on both sides of the arch dipping at angles varying from 55° to 65°.

One of the most fortunate occurrences in working out the structural geology of the region is the belt of light gray Upper Coal-measure limestone lying between the westerly dipping beds of the anticlinal fold and the basalts. It furnishes within the district evidence of the position of the Weber conglomerate between the two great belts of Coal-measure limestone and although ample proof could be found elsewhere, it makes the chain of evidence complete for all the divisions of the Paleozoic series of rocks in the Great Basin. It is a narrow strip of limestone, in places only a few hundred feet in width and about one mile in length, being cut off both at the north and south by igneous rocks. It strikes nearly north and south and dips between 55° and 60° to the west, coinciding with the inclination of the underlying conglomerates on the west side of the anticlinal fold. In a yellowish gray bed occurs a characteristic fauna of the Upper Coal-measures; a list of the species procured here will be found elsewhere. The continuity of this body of Upper Coal-measure limestone with the larger body north of Newark Canyon is broken not only by igneous flows, but the connection is completely severed by a line of faulting along the canyon. The distance between them measures only about one-half mile and is mainly occupied on the surface by rhyolitic pumices and tuffs.

No special mention need be made of the physical characters of the Weber conglomerate, as it has been described in sufficient detail in the chapter devoted to the Carboniferous rocks, nearly all the observations there given being taken from this region.

West Slope of Diamond Range.—From Newark Canyon northward and westward of the Alpha fault, the country, both in topographical features and geological structure, presents much the same general aspect over the entire area. It is the most monotonous and least disturbed region within the limits of the survey. The opposite sides of Newark Canyon offer marked geological contrasts; on the one side folded and distorted beds of coarse conglomerates, on the other a uniformly inclined slope of limestones. Along the lower end of the canyon the contact of the two rocks is broken by overflows of pumices, tuffs, and basalts, but higher up and north of the drainage channel the relations between the two horizons are strikingly shown on the north slope of Weber Peak about 150 feet below the summit. Here the conglomerates lie inclined about 18° to the west, with the limestones resting against them at an angle of only 6°, but without any essential difference in their strike, both rocks following the trend of the Alpha and Fusilina ridge. This change is all the more strongly marked by the contrast in topographical features and unconformity of strata between the two bodies of limestone on the opposite sides of the Alpha fault. This region is sharply defined by the Alpha fault on the east. From the fault to the Quaternary deposits of Diamond Valley there is a nearly uniform slope three miles in width, with a fall of over 1,200 feet. It is crossed by frequent drainage channels at fairly regular intervals, all of them having a course a little north of west. Nowhere have they cut down into the underlying limestones more than a few hundred feet, the bottoms of the valleys, as a rule, being shallow ravines with narrow strips of meadow land along the stream bottoms. All the intervening slopes present much the same superficial features, for the most part smoothly worn down, with here and there an occasional elevation, seldom rising more than 100 feet above the average height of the surrounding country.

Over this entire area the only rocks which have been recognized are the Upper Coal-measures, inclined toward the west at low angles agreeing closely with the slope of the country. This prevents any considerable thickness of strata being exposed, and it is doubtful if there can be seen here a greater development of beds than those found south of Newark Canyon, where it is estimated that 500 feet are shown in the ridge which rises above the basaltic flows. At the latter locality the base of the horizon is unquestionably exposed, but along the line of the Alpha fault there is no structural evidence that the basal rocks come to the surface. Almost anywhere scattered through these limestones organic remains characteristic of the Coal-measures may be found, but the most promising field for collection is on the summit of the ridge just north of Garden Canyon. Nearly all the forms obtained here are common enough elsewhere, with the exception of *Ptilodictya (Stenopera) carbonaria* and *P. serrata.* Far to the south of this latter locality, north of Weber Peak, and just above the Alpha fault, occurs a nearly similar grouping without the latter two forms, but with the addition of *Macrodon tenuistriata.*

Perhaps the most important geological feature of this inclined table of Upper Coal-measure limestone is the occurrence of an interstratified bed of conglomerate varying in thickness from 15 to 20 feet. It is exposed in one or two of the long ridges stretching out toward Diamond Valley, and in one instance occupies a low depression on the top of the ridge. This conglomerate is made up of pebbles of chert, jasper and quartz such as are found throughout the Weber epoch, firmly cemented together into a hard sandstone. Mingled with these siliceous pebbles occur rounded fragments of limestone carrying organic remains such as *Syringopora* and *Fusilina cylindrica* and other forms common to the Carboniferous limestones below the Weber conglomerate, but in no instance are specific forms obtained other than those previously recognized in the underlying limestones. This implies that after the deposition of the lower portion of the Upper Coal-measures the country underwent some slight changes in elevation, subjecting the Weber conglomerate and Lower Coal-measures to the influences of erosion, the material being redeposited. All indications point to the fact that this material of the interbedded conglomerates, was derived from some land mass in close proximity to the present beds, as it seems hardly possible from the size and nature of the easily disintegrated limestone that it could have been exposed for any great length of time to subaqueous influences.

CARBON RIDGE AND SPRING HILL GROUP.

The area embraced within this block is situated in the center of the Eureka Mountains and stretches in a narrow belt from Diamond Valley to Fish Creek basin. It lies hemmed in between Prospect Ridge and the County Peak and Silverado uplift, presenting somewhat the appearance of a depressed and broken region bounded by two elevated and well defined mountain masses. This appearance is, in part, due to its relatively slight elevation, and in part to the struggle for supremacy between sedimentary strata and the volcanic lavas spread out over them concealing large areas and breaking the continuity of strata. At Pinto Peak the rhyolites have been piled up until they have attained an elevation higher than any point reached by the upturned limestones. These igneous rocks divide the sedimentary beds into two areas, one a northern, of which Spring Hill is the center, the other to the south, designated as Carbon Ridge. Both regions, however, present much the same geological conditions and consist wholly of Carboniferous rocks, the only two epochs represented being the Lower Coal-measures and Weber conglomerate.

New York Hill.—The direct contact between the Silurian and Carboniferous rocks on opposite sides of the Hoosac fault may be best seen where the Lower Coal-measures of New York Hill rest against the Lone Mountain limestones of McCoy's Ridge, as along the fault between these two ridges no lavas have reached the surface to obscure the sedimentary beds. New York Hill is in some measure isolated from the rest of the Carboniferous rocks, being completely surrounded by lines of faulting. On two sides the Hoosac fault outlines it from the Prospect Ridge uplift while a secondary fault of but slight displacement breaks the continuity of strata between the hill and the beds underlying Richmond Mountain on the east and Spring Hill on the south. The limestones of New York Hill strike approximately parallel with the trend of the canyon, which in turn coincides with that of the Hoosac fault. The beds dip uniformly to the southeast with an average inclination of 30°. There is no direct means of determining the base of the Lower Coal-measures anywhere in the Spring Hill block, although the lower beds of New York Hill are probably not far from the base of the epoch and occur as low down in the series as any strata to be found along the east side of the Hoosac fault. Between the base of the Lower Coal-measures at Diamond Peak and those of New York Hill some resemblance may be traced, but lithological evidence is not of much value, as the beds change rapidly in the character of their sedimentation. On the west slope of New York Hill, Coal-measure fossils may be found scattered through the beds and in one locality in a shaly limestone near the summit the following species were collected:

Fusilina cylindrica.
Fusilina robusta.
Productus semireticulatus.
Productus nebrascensis.
Productus prattenianus.

At the extreme northeast end of New York Hill the drainage channel, instead of following closely the line of the fault between the Silurian and Carboniferous rocks, deviates to the northward, cutting through, for some unexplained reason, the Lone Mountain strata, leaving a portion of the latter limestone resting upon the slope of New York Hill on the south side of the canyon. At the northeast end of New York Hill, but east of the Silurian limestone, occurs 100 feet or more of thinly bedded clays, grits, and argillaceous limestones, passing into purer beds, which are apparently unconformable with the main body of limestones as they dip to the northward, toward the fault, at an angle of 30°. They occupy only a small area, but it seems difficult to tell just how they are related to the main body of limestone, or to connect them in the section with the southeasterly dipping beds. That they are low down in the limestones is evident from the fact that they can be correlated with the beds on the east side of Eureka Canyon which lie near the base of the uplifted strata, dipping under Richmond Mountain. Their geological position would be of no importance except that it is in these beds that the fresh and brackish water shells occur which have already been described in the chapter devoted to the Carboniferous rocks. Their mode of occurrence everywhere shows evidence of shallow water, but they rapidly pass into beds indicating much deeper water. Associated with these fresh-water shells are numerous fragments of plant remains, proving, without doubt, the existence at no great distance of a land surface. The specific characters of these shells will be found described elsewhere by Mr. Walcott.[1]

Limestone of Richmond Mountain.—Between Eureka Canyon and Richmond Mountain lies a body of limestone uniformly inclined to the east until it passes beneath the andesites of the latter mountain. It rises nearly 700 feet above the valley, with a fairly regular slope, except where trenched by short drainage channels which have cut deeply into the rock, giving the ridge a somewhat ribbed appearance. The beds strike N. 16° E. and dip from 40° to 50° under the lavas. The Richmond Smelting Works are situated near the northern end of this limestone body. Just back of the smelters the base of the limestones are well exposed, and near the railway cut there may be seen a good exposure of strata. At the base of the cliff occurs a series of dark argillaceous shales of unknown thickness weathering on exposure to blue and gray clays. In these clays may be found indications of plant remains associated with the *Physa prisca* and *Ampularia* obtained on the opposite side of the ravine in New York Hill, the shells serving to correlate the beds. It is to be regretted that their strike and dip could not be determined with precision, but they give every appearance of passing conformably beneath the overlying strata.

The following section was made across the strata extending from the top of the series down to the clay beds at the base:

	Feet.
1. Coarse conglomerate cemented in fine arenaceous grains	50
2. Compact gray and yellow sandstones carrying a little calcareous material, and occasional thin belts of limestone	200
3. Fine smooth pebbles in a yellow matrix	100
4. Brownish white sandstone	200
5. Fine conglomerate, with an admixture of calcareous material throughout.	100
6. Gray limestone, passing into a light gray and yellowish sandstone	75
7. Cherty limestone, passing into fine siliceous limestone	75
8. Light colored and banded vitreous quartzite	25

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[1] Paleontology of the Eureka District, Mon. VIII, U. S. Geological Survey, p. 261.

	Feet.
9. Cherty bluish gray limestone, carrying *Griffithides portlocki*, *Productus semireticulatus*, *P. longispinus*, *P. pratteuianus*, *Fusilina cylindrica*...	300
10. Blue limestones in massive layers, with thin interbedded calcareous shales carrying *Pleurotomaria conoidea*, *Metoptomia peroccidens*, *Macrocheilus*, *Nucula*, *Orthoceras*, *Leperditia*..........................	400
11. Dark argillaceous shales, weathering to blue and gray clays, carrying fresh water shells and plant remains....................	Unknown thickness.
	1,525

Throughout the entire series of beds above the quartzite band (No. 8) occurs a grouping of characteristic Coal-measure fossils from which twenty-eight species have been determined. The list will be found in the chapter devoted to the Carboniferous rocks. Overlying the limestones the andesitic rocks rise in precipitous walls for over 800 feet.

Spring Hill.—The uppermost members of the Richmond Mountain beds are traceable across Eureka Canyon, the conglomerates standing out conspicuously along the west slope of Spring Hill dipping into the ridge. A line of displacement runs along the Secret Canyon Road valley, and, as it approaches the Hoosac fault, the continuity of strata becomes more and more difficult to follow, showing signs of displacement under the influence of the outpouring of lavas near the centers of volcanic activity About a mile up the valley a complete change in structure takes place and a low hill, somewhat isolated from the ridge, stands out between the main body of Spring Hill and the Hoosac fault. It rises about 400 feet above the level of Secret Canyon Road and from its peculiar outlines, the result of erosion, it has been designated as Conical Hill. It presents a small block of Lower Coal-measure strata which, instead of dipping easterly in conformity with the rest of Spring Hill, forms an anticline with the main ridge, the beds dipping westerly directly toward the Hoosac fault. On Conical Hill the strata strike from N. 20°–25° E., parallel with the Canyon Road valley, and dip 30° W.[1] On both sides of the axis of the fold the series of beds are easily traced, consisting of limestones, calcareous shales, arenaceous layers, with a well defined bed of coarse conglomerate about 75 feet in thickness. This conglomerate appears on the

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[1] Owing to an error in the proof-reading of the map, the beds on Conical Hill are represented as inclined steeply to the east, whereas the dip of 30° to the west, as given in the text, is correct.

west side of Conical Hill and again near the summit of Spring Hill, standing out prominently on both sides of the fault as a well defined body, serving as an excellent datum ledge in determining the position of the beds. The transition from the calcareous to the siliceous beds is rapid, both above and below the conglomerate. This description of Conical Hill is given somewhat in detail, as it is here that the Lamellibranchiate fauna of the Carboniferous occurs. On the east slope of this hill, near the saddle which connects it with Spring Hill, there is found in a shaly limestone a small but most typical Coal-measure fauna. Above these shaly beds, about 200 or 300 feet, occur the limestones carrying the Lamellibranchiate fauna, associated with Coal-measure species, as described in the chapter on Carboniferous rocks. Overlying the Lamellibranchiate beds, on the east side of the fold, on the east side of Spring Hill, characteristic Coal-measure fossils come in, but without the mingling of the fauna found below.

These limestones are in turn overlain by a belt of fine conglomerate 100 feet in thickness, in places altered to an indurated sandstone, which forms the lower slope of the ridge on the west side of Eureka Canyon south of Spring Hill. It crosses the canyon near the toll-house, with a strike of N. 16° E. and is traceable on the opposite hills without difficulty. At the east base of Spring Hill, along the bottom of the Eureka Canyon and underlying these conglomerates, occurs a thin band of black, fissile, argillaceous shale, from which were collected *Spirifera lineata* and a small *Discina* not unlike *D. minuta.* This shale varies somewhat in thickness, but was estimated at 50 feet. The origin of the canyon is in part due to a fracture in the quartzite and in part to the nature of the easily eroded shales, but it does not appear to be accompanied by any considerable amount of displacement of strata, as is the case with nearly all the other principal longitudinal drainage channels; in this respect, however, it resembles Secret Canyon. Overlying the conglomerates blue and gray limestones continue on up to the summit of the section, with occasional thin bands of chert and arenaceous layers, but with less and less siliceous material. On the top of the ridge east of the toll-house the gray limestones carry a typical Coal-measure fauna, and in a thin bed on the west side, about 100 feet below the summit, there were collected:

Fusilina cylindrica.
Chonetes verneuiliana.
Productus costatus.
Productus longispinus.
Productus punctatus.
Productus semireticulatus.

Spring Hill and the limestone ridge lying on the west side of the Pinto fault form a synclinal fold whose axis is situated on the western side of the high hill east of the toll road. The strata dip away from the Pinto fault into the ridge at high angles, but on the opposite side of the fold they lie more regularly inclined at a much lower angle. The synclinal structure here does not differ essentially from that shown southward along the geological section E-F, atlas sheet XIII.

On the south side of Conical Hill a fault coincides with a narrow ravine separating it from the next hill to the south. Both the ravine and fault trend to the south and the latter is finally lost beneath the andesites. On this second hill the beds are still in accord with those of Conical Hill and dip westerly, but to the southward of it runs a cross fault connecting the Hoosac fault with the Conical Hill fault. To the south of this cross fault the limestones again dip easterly in conformity with those of Spring Hill.

A short distance south of this latter fault the geological section E-F, atlas sheet XIII, crosses the Carboniferous rocks lying between the Hoosac and Pinto faults. The entire block of limestones west of the Conical Hill fault dips easterly at about 30°. With apparently only a slight break in the strata along this displacement the beds on the east side of the fault-plane still dip easterly at about the same angle followed by a synclinal fold, the westerly beds of which attain angles as high as 70° and both north and south of the cross-section reaching even 80°. Taken as a whole, the Carboniferous rocks included within this block consist of limestone strata more or less arenaceous with interstratified belts of both fine and coarse conglomerate and carrying from base to summit characteristic Coal-measure species. It is estimated that the Lower Coal-measure beds along the line of this section have a thickness of about 3,400 feet, but it is evident that the base of the series is not reached, and that there are at least 300 or 400 feet of beds, and probably more, on New York Hill and Richmond Mountain unrepresented here. Measurements of the Lower Coal-measures in the Diamond Range calculated from observed strikes and dips give 3,700 feet of beds. From this data the development of the Lower Coal-measure epoch at Eureka is placed at 3,800 feet; this thickness is probably rather under than over estimated.

Region South of Spring Hill.—Along the divide which separates Spring Hill from Carbon Ridge vast accumulations of andesites, rhyolites, pumices, and basalts have poured out, submerging over a large area all sedimentary beds. An exception is found in the broad, deeply eroded basin just north of Pinto Peak, Carboniferous rocks again coming to the surface.

Within this basin occurs several exposures of limestones, and on the north side there is a short narrow ridge nearly 200 feet in height in which the beds are seen to strike N. 24° W. and dip steeply to the east. At the western end of these exposures there occurs a well defined belt of sandstones, beneath which crops out an area of clay shales. The latter are so obscured by Quaternary accumulations that but little could be made out of them. They resemble, however, similar shales to the west of Carbon Ridge. The sequence of beds indicates their close relationship to those of Spring Hill, but their geological age is still more strongly shown by the grouping of fossils obtained from the limestones. The complete list is given here, as it is rather a characteristic grouping of the Lower Coal-measures of Eureka and carries with it a number of species found elsewhere in the district at both lower and higher horizons. The list is as follows:

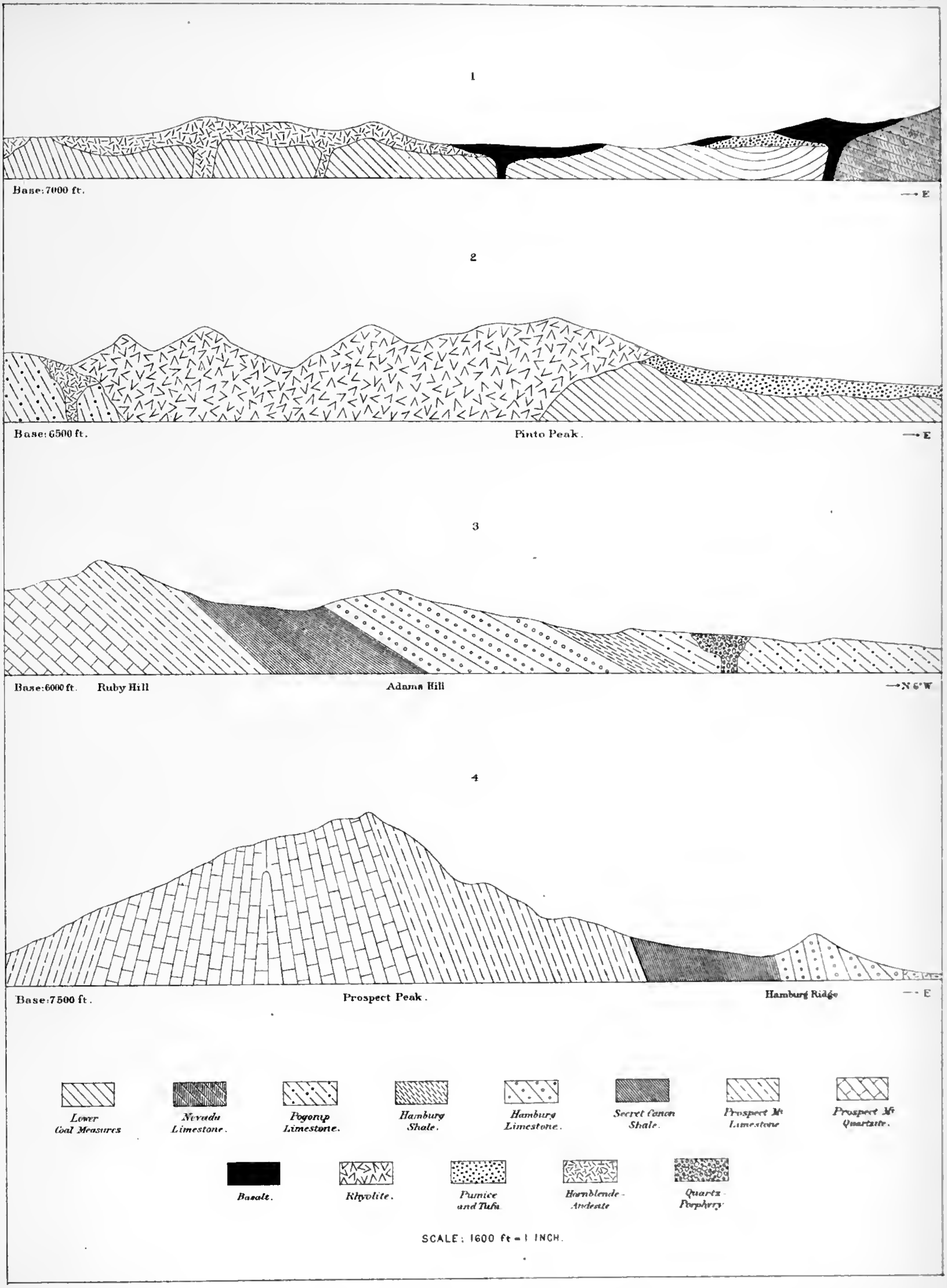
Stromatopora, sp. ?
Zaphrentis, sp. ?
Syringopora.
Ptilodictya.
Lingula mytaloides.
Orthis resupinata.
Chonetes granulifera.
Productus semireticulatus.
Productus prattenianus.
Spirifera camerata.
Spirifera striata.
Rhynchonella eurekensis.
Aviculopecten pintoensis.
Aviculopecten peroccidens.
Streblopteria similis.
Crenipecten hallanus.
Pterinea pintoensis.
Pinna consimilis.
Myalina subovata.
Myalina congeneris.
Modiomorpha? pintoensis.
Sanguinolites retusus.
Microdon connatus.
Schizodus cuneatus.
Schizodus pintoensis.
Bellerophon majusculus.
Orthoceras randolphensis.
Orthoceras, sp. ?
Leperditia, sp. ?
Griffithides portlocki.

Carbon Ridge.—The area included under this designation is almost completely encircled by volcanic rocks, and nowhere does it come in direct contact with sedimentary beds of adjacent regions. The nearest approach to such contact occurs just northeast of Gray Fox Peak, where a body of rhyolite about 700 feet in width separates the Carboniferous rocks from the Eureka quartzite situated on the west side of the Hoosac fault. If the superficial detrital material along the southeastern slopes of Carbon Ridge were scraped away it seems highly probable that the isolation of this block would be still more noticeable, as there is good reason to believe that igneous rocks lie just beneath the surface. This is indicated by the configuration of the drift-covered hills, the superficial drainage channels, and the nature of the detrital material itself. The exposures of the andesites, rhyolites, and pumices which are shown in the narrow ravine draining the southern slopes of Carbon Ridge are portions of much more extensive bodies bordering the southern end of the mountains. Not only is the continuity of sedimentary beds destroyed by volcanic overflows, but nowhere are the Carboniferous rocks of Carbon Ridge recognized immediately along the lines of the two great displacements—the Hoosac and Pinto faults. On both sides of Carbon Ridge the precise trend of these faults is obscured by igneous rocks, although at several localities it is possible that they may form only superficial layers over the sedimentary beds. Carbon Ridge measures about 2¼ miles in length, but varies in width, owing to irregularities in the volcanic flows. Across its widest expansion, as seen on the surface, it measures 1½ miles. Along the summit of the ridge the beds strike nearly north and south and maintain an average dip of 70° to the east, presenting a fairly regular uplifted block of limestones and conglomerates. Along the west base of the ridge runs a band of gray granular sandstone, beyond which to the westward lies an area of fissile clay shales, exhibiting no good exposures and without reliable dips and strikes, as they are much broken up and disturbed, owing to their proximity to the Hoosac fault. Apparently they lie unconformable with the limestones of Carbon Ridge, but their relationship with the latter is by no means satisfactorily made out. A line of faulting of which little is known cuts them off from the main body of limestones, the shales lying at a much lower angle than the highly inclined beds of the ridge. It seems probable that they are identical with the shales observed underlying the limestones in the exposures north of Pinto Peak. On Carbon Ridge the beds exhibit much the same sequence of sediments as are found in the Spring Hill region, the limestones being more or less siliceous and carrying interbedded conglomerates. On the summit of the ridge there is a considerable development of thinly bedded calcareous shales, in places fossiliferous. Unlike this horizon at Spring Hill, abundant structural evidence exists here to show that the uppermost members of the Lower Coal-measure series are represented, as the Weber conglomerates overlie them conformably. Between the beds of the two epochs a peculiar structural feature may be noticed in the narrow ravines which have been worn out by erosion along the contact of the limestones and conglomerates. These ravines, which start in with approximately north and south trends, invariably curve to the east and cross the conglomerates at right angles to their strike, breaking up the formation into individual blocks, which are united to the main body of Carbon Ridge by low, connecting saddles of conglomerate.

Everywhere the conglomerate is seen to overlie the limestone conformably. Estimating from the observed dips and strikes, the Lower Coal-measures of Carbon Ridge show a thickness of 3,500 feet, which does not vary essentially from the development found on Spring Hill and is within the measurement obtained for the horizon in the Diamond Range, where the structural relationships with both the upper and lower beds are much better determined. The Weber conglomerate has been regarded as dipping uniformly, throughout the entire development, at 70°, and upon this assumption is assigned a thickness of 1,900 feet. This allows the conglomerate 100 feet less than the estimated thickness in the Diamond Range, but here the uppermost beds are known to be buried beneath a greater or less accumulation of tuffs and pumices. That there is about the same thickness of beds and great similarity in the nature of the sedimentation, is evident from a comparative study of the two regions. No specially favorable locality for the collection of fossils was recognized in the limestones, mainly because none were sought, but throughout the entire series of beds Coal-measure forms may be found. Such species as *Productus semireticulatus*, *P. longispinus*, *Athyris subtilita*, and *Spirifera camerata* are sufficient to establish the Carboniferous age of the limestones, and their position beneath the Weber conglomerate assigns them, beyond question, to the Lower Coal-measures.

On Pl. II will be found two cross sections drawn across the volcanic rocks that stretch between the Hoosac and Pinto faults, separating the Carboniferous strata into distinct areas. Both sections lie between the two general sections E–F and I–K. They are drawn on due east and west lines and measure a little over 2 miles in length. Section I, atlas sheet VIII, passes just south of the Spring Hill limestone body and crosses the hornblende andesite nearest its broadest expansion. At the extreme western end occurs a small exposure of Carboniferous limestone, only a few hundred yards in length, completely surrounded by andesite. As shown in the section these andesites extend with a very irregular outline for a long distance, beyond which a body of basalt comes in, followed by limestone, in turn followed by pumices overlain and buried beneath other basalts. These latter basalts give out on the steep slopes of Dome Mountain, which is made up of Nevada limestone, lying on the west side of the Pinto fault.

Section II, atlas sheet X, is drawn so as to show the great body of Pinto Peak rhyolite, and passes just south of the summit of the peak. Along this section, between the two great meridional lines of displacement, none other than volcanic rocks reach the surface, the pumices all along the east slope resting against the upturned Silurian rocks of English Mountain. In this section the Pogonip limestone is seen beyond the line of the Hoosac fault, but its direct connection with the fault is wholly lost by outbursts of lava. By reference to the atlas sheets the position of this Pogonip limestone on the west side of the fault and the Carboniferous limestone on the east side, will be readily understood.



GEOLOGICAL SECTIONS.

EUREKA DISTRICT, NEV.

CHAPTER VI.

GENERAL DISCUSSION OF THE PALEOZOIC ROCKS.

Paleozoic Shore-line.—Between the Wasatch Range, which incloses the Great Basin on the east, and the western border of the Paleozoic area in central Nevada, the sedimentary beds which make up the greater part of the meridional mountain ranges may, as regards their broader divisions, be fairly well correlated with each other. In most instances paleontological evidences are sufficient to determine at least the age of one or more of the great bodies of limestone usually found in these mountain uplifts, and the sequence of strata correlates the geological position of overlying and underlying beds. Differences in the character of these sediments exist, but they are mainly those dependent upon distance from land areas and depth of water in which the material was originally deposited. Along the Wasatch the sequence of strata exhibits much the same physical conditions of deposition, and the horizons may be recognized and their positions determined in great measure by similarity of sedimentation. Over a large part of central Utah and eastern Nevada the beds at many geological horizons indicate deep water or off-shore deposits quite unlike those of corresponding age found both to the east and west. Here and there over this region some evidences of ancient land areas may be found. In central Nevada, however, there occurs throughout the beds abundant evidence of deposition in shallow seas. The western limit of this Paleozoic ocean across the broadest expansion of the Great Basin was not far from longitude 117° 30′. In width it measured along the line of the fortieth parallel nearly 300 miles. It is by no means definitely established that the waters rolled unbroken, from shore to shore, across this broad surface free from all land barriers. In the neighborhood of the East Humboldt Range a pre-Cambrian barrier may have existed, but the evidence seems rather in favor of islands rising out of an ocean, which stretched across the entire area between broad continental regions.

The evidence of this ancient shore-line rests, as has been pointed out elsewhere, upon the complete and unmistakable differences in the character of the beds which now lie uncomformably upon the older rocks of the continental area and the deposits upon the ocean bottom to the east. Upon this pre-Cambrian continent no Paleozoic rocks have as yet been recognized in western Nevada, while the enormous thickness of uncomformable strata laid down since the uplifting of the Paleozoic area bears ample evidence of a Jura-Trias fauna, as shown in the Piute and West Humboldt ranges. Again, the Mesozoic rocks of the Wasatch and those of western Nevada bear but slight resemblance to each other, either in the nature of the material deposited or in the character of the life represented. Across this broad intervening area all evidences of Mesozoic sediments are wanting and the opposite sides are sharply contrasted by their physical and faunal distinctions. In all probability the Paleozoic ocean in Nevada presented an indented shore-line with a general northeast and southwest trend, accompanied by outlying islands stretching far eastward and rising high above the water level. This ancient coast line has never been traced, consequently its outlines are most indefinitely determined. It is obscured by enormous quantities of erupted material, in places literally mountain high, burying for long distances all traces of preexisting rocks.

The course of this eruptive action was in great part determined by the profound displacements which accompanied the elevation and transformed an ocean bottom into an area of dry land. Measured at right angles to the supposed trend of the shore are broad areas 40 miles in width across which no other rocks are exposed than Tertiary lavas or the recent Pleistocene deposits of the valleys. That these lavas followed the trend of the old shore is indicated by their parallelism with the mountain uplifts, and that they conformed to the course of the preexisting continental ranges is shown by the frequent outcrops of Jura-Trias rocks projecting above the vast accumulations of volcanic material. Ranges situated eastward of the supposed shore-line expose above flows of rhyolite long ridges of quartzite which have been referred to the Paleozoic age. They are at all events quite unlike the rocks of the region to the west. In a study of the geological history of continental development it is important to know that it was along this ancient shore-line that volcanic activity has displayed its greatest energy in Nevada. Upon one side of these accumulated lavas is found an enormous thickness of Paleozoic strata with no rocks younger than the Upper Coal-measures, and on the opposite side a great development of alpine Trias and Jura is seen with an absence of the Paleozoic beneath it. These facts furnish strong evidence for belief in the existence of a continental area in western Nevada during Paleozoic time. To the south the shore-line probably ran out toward the California boundary; to the northward it may be traced well up into central Nevada. This old coast line is a region of great interest and one which would well repay careful investigation and yield valuable geological results.

If this interpretation of observed facts is correct, the degradation of the land surface during Paleozoic time should have supplied an enormous mass of detrital matter to the ocean to the east. Now, by a study of the Eureka Paleozoic strata, this is precisely what is found to be the condition of things. Along this coast line coarse conglomerates and mechanical sediments derived from the neighboring land areas attest the fact that this detrital material must have come not only from the west, but from a land area at no great distance. Along the shore the conglomerates form heavy masses of material, indicating littoral deposits, but to the east these same formations gradually pass into fine grained sandstones, the beds in general becoming more uniform in character. Exceptional occurrences of coarse and rapidly changing material can be found in eastern Nevada, but for the most part they occupy restricted areas, and may be accounted for by their nearness to pre-Cambrian islands. All evidence goes to show that Eureka was situated not far from this western boundary, and its geological record affords ample proof of elevation and depression throughout Paleozoic time, with intervals of shallow water and nearness of land areas between periods of relatively deeper seas.

Nature of Material.—The 30,000 feet of sediments at Eureka between the base of the Prospect Mountain quartzite and the summit of the overlying Upper Coal-measure limestone are made up of well defined bodies of siliceous, calcareous, and argillaceous strata, each representing a distinctive epoch in the geological history and development of the region. These rock masses grouped according to the character of their sediments show clearly the relative amount of the three classes of deposits into which subaqueous sediments may be divided.

SILICEOUS.

	Feet.
Prospect Mountain (Cambrian)	1,500
Eureka quartzite (Silurian)	500
Diamond Peak quartzite (Carboniferous)	3,000
Weber conglomerate (Carboniferous)	2,000
Total	7,000

CALCAREOUS.

Prospect Mountain limestone (Cambrian)	3,050
Hamburg limestone (Cambrian)	1,200
Pogonip limestone (Silurian)	2,700
Lone Mountain limestone (Silurian)	1,800
Nevada limestone (Devonian)	6,000
Lower Coal-measure limestone (Carboniferous)	3,800
Upper Coal-measure limestone (Carboniferous)	500
Total	19,050

ARGILLACEOUS.

Secret Canyon shale (Cambrian)	1,600
Hamburg shale (Cambrian)	350
White Pine shale (Devonian)	2,000
Total	3,950

For the most part the siliceous formations are composed of pure quartzites, sandstones, or conglomerates, interstratified beds of foreign material occupying very inferior positions. On the other hand the calcareous and argillaceous deposits are more or less interrupted by occasional belts of other material or impure layers of mixed sediments occurring as transition beds.

In the Prospect Mountain limestones occur narrow belts and lenticular bodies of clay shales, in contradistinction to the Pogonip, which is characterized by a series of grits and sandstones. Throughout the 6,000 feet of Nevada limestone the pure sandstone beds, taken together, would scarcely measure more than 300 feet, varying from 25 to 100 feet in thickness, while argillaceous strata are exceptional occurrences. In the White Pine shale, which is mainly argillaceous, occur several beds of reddish sandstone near the summit, amounting in the aggregate to several hundred feet. Deducting from the limestone epochs the beds that are decidedly siliceous and argillaceous, but leaving the impure strata, which are mainly calcareous, we find the aggregate thickness of the three classes of sediments as follows: Argillaceous, 3,000; siliceous, 9,000; calcareous, 18,000; or as 1 : 3 : 6.

The Prospect Mountain quartzite throughout, at least so far as it is exposed at Eureka, can hardly be otherwise than an off-shore deposit. The base of the formation is largely composed of coarse conglomerates, made up of a great variety of unassorted siliceous pebbles, while the finer beds nowhere present any considerable thickness, and show evidence of strong currents. It is certain that such material could not have been transported for any great distance in deep water. At the top transition beds of siliceous sands pass rapidly into the limestones of the Prospect Mountain series, which, across a thickness of 3,000 feet, carries but one heavy, persistent belt of clay shale.

The Secret Canyon shale, a remarkably uniform horizon throughout its great thickness, presents a wholly different character of deposits from the two underlying formations. Nowhere are there any evidences of rapid deposition. Following the latter formation comes a second belt of limestone, with occasional beds of siliceous material in place of the clayey beds found in the Prospect Mountain limestone. Above this second belt of limestone occurs the Hamburg shale, indicating a complete change in the sedimentation and reproducing conditions like those of the Secret Canyon period, although only 350 feet in thickness. In the character of its deposits it changes more rapidly and shows unstable conditions in its mode of sedimentation. Next in order is found the widespread Pogonip limestone, the base of the Silurian system. The transition beds show a constant change in the deposit, all of them presenting more or less mixed material, developing into argillites, grits, and arenaceous schists, finally passing into distinctly bedded uniform limestone. Overlying the Pogonip rests the Eureka quartzite, about 500 feet in thickness, but singularly uniform in its material and wholly unlike all the other siliceous formations, being formed of pure white siliceous grains completely metamorphosed to quartzite. Through this formation, except at its base, there is a marked absence of mixed sediments and off-shore material. All the conditions of deposition suggest deeper water and a quieter sea bottom. Immediately above the Eureka quartzite comes an immense development of limestone, with occasional interbedded sandstones at varying intervals, but comparatively free of earthy matter. Taken together, the Lone Mountain and Nevada formations which make up these limestones measure nearly 8,000 feet in thickness, apparently laid down without any decided break in the conditions of deposition, although the accumulation of such a vast amount of calcareous sediment must have occupied a long period of time. That it was sufficient, notwithstanding its uniformity, to bring about marked changes in the life of the sea is shown by its faunal development. There exists no greater break in the character of the sediments than that found between the Nevada limestone and the overlying White Pine shale. The change from the calcareous deposit of a quiet ocean with a marine fauna to an argillaceous deposit full of carbonaceous material with evidence of cross-bedding, rapid currents, and shallow water recalls a retreating sea and the proximity of a land surface.

Remains of vegetable life are of rare occurrence in the Paleozoic rocks of the Great Basin and eastward of the East Humboldt Range are quite unknown. The White Pine shale, both at Eureka and White Pine, carries innumerable fragmentary bits of twigs and stems throughout the entire formation, although for the most part too poorly preserved for specific determination, yet indicating land areas throughout a long period of time. Over the White Pine shale was laid down the Diamond Peak quartzite, a uniform deposit of fine grained siliceous material without any special evidence of the proximity of land, either in the life or mode of deposition. An interstratified bed of limestone carrying *Productus semire-*

ticulatus establishes the Carboniferous age of the quartzite. After the Diamond Peak quartzite attains a thickness of 3,000 feet, a change sets in with alternating beds of coarse shales and conglomerates more or less mixed with calcareous sediments, the entire series being admirably exposed at the base of the Lower Coal-measures on the southwest slope of Richmond Mountain. Here we find positive evidence of the existence of fresh-water shells associated in the same beds with plant life fairly well preserved, although specific determinations are impossible. This is the only instance yet discovered of the existence of fresh-water species in the Paleozoic rocks of the Great Basin, and points conclusively to the existence of a land surface at no great distance and long after the White Pine shales had been buried beneath 3,000 feet of sands. Even if they had been deposited in an estuary and washed into their present position by rapid currents the land area could not be far away. This group of rocks carrying a fresh-water fauna soon becomes submerged beneath the limestones of the Lower Coal-measures, which occupy such widespread areas of the Great Basin and which, so far as the physical conditions of deposition are concerned, closely resemble the Nevada limestone.

Additional evidence of land areas during the Carboniferous is found at Pancake and Bald Mountain, a somewhat similar series of strata occurring in both localities, with well developed coal seams, bituminous shales, and evidences of plant life both above and below the coal.

Next in turn overlying the Lower Coal-measures occurs the Weber conglomerate, a formation 2,000 feet in thickness, of coarse siliceous material made up of pebbles varying in size, composed of quartz, jasper, chert, and hornstone, unquestionably an off-shore deposit in shallow water. Such coarse material could not have been transported any great distance. The conglomerates of Agate Pass, in the Cortez Range, and at Moleen Peak present identical physical conditions with evidences of the same off-shore deposits. To the eastward, removed from the continental area, the sediments of this epoch become finer grained and arenaceous in texture. How long a time was occupied in the accumulation of this great thickness of siliceous pebbles it is of course impossible to say. Finally it was followed by a submergence accompanied by a deposition of limestone characterized by a fauna which did not differ in any marked degree from the underlying limestone of the Lower Coal-measures.

The Upper Coal-measures indicate once more that a deeper sea swept over the siliceous beds as the limestones of this upper horizon were laid down over a wide area, presenting great uniformity in composition and marine life. Of these overlying rocks we have only 500 feet at Eureka, and with them the geological record of Paleozoic time comes to an end.

From this recapitulation of the record of the Eureka rocks, it is evident that they were laid down under very varying physical conditions. In its broader outlines this sequence of strata may be correlated with the rocks of the Great Basin stretching as far eastward as the Wasatch, with this difference, that at Eureka there may be seen immense thicknesses of shallow water sediments derived from a continental area to the west, whereas in going eastward evidences of deeper waters are met with, the material being more uniform in character and deposited in a quieter sea. In the latter rocks there is, so far as yet recognized, a marked absence of argillaceous and calcareous deposits enriched with plant remains and fresh-water shells.

Naturally, it is the siliceous formations that exhibit the greatest lithological contrasts, and in going eastward from off-shore to deep-water deposits it seems highly probable that Cambrian quartzite in places approximates the Eureka quartzite in appearance, and may possibly have been mistaken for it. In the same manner the widely deposited Weber formation passes from the coarse conglomerate as represented at Eureka into fairly uniform beds of quartzite or sandstone. Owing to its geological position between the Upper and Lower Coal-measures, it becomes a comparatively easy matter to correlate the Weber quartzite of Eureka and Agate Pass with sandstones farther eastward or the Weber shales of still other localities. Again, the Weber epoch, when composed of fine siliceous grains and carrying a considerable amount of calcareous material, may be difficult to separate from the overlying and underlying limestones.

Paleontological Divisions.—As already mentioned, the 30,000 feet of strata have been divided into the four great periods of Paleozoic time, and at Eureka they have again been subdivided into epochs mainly based upon the lithological character of their sediments. For the advancement of geological science it is necessary for the geologist and paleontologist to agree upon some broad principle governing the division of Paleozoic time and for the purpose of correlating the strata of one locality with those of another. From long experience it is found that a division based upon paleontological data is the only one which will meet the requirements over widely separated areas of the globe. Structural breaks, based upon unconformities of deposition or lithological distinctions, determined by manner of occurrence, may meet the needs of local geological provinces far better than a paleontological classification, but for broader continental areas they are far too restricted for the purposes of correlation. The broad divisions at Eureka are based upon paleontological evidence. In the 6,000 feet of Cambrian sediments above the base of the *Olenellus* shale, the Lower, Middle, and Upper Cambrian horizons are all well represented by characteristic faunas. The line between the Cambrian and Silurian is drawn just above the Hamburg shale, and is determined wholly by faunal development. In the interstratified grits and limestones, which bring in the Pogonip, animal life undergoes a gradual change with the extinction of an old fauna and the coming in of a new one. Without any marked physical disturbance and a continuance of limestone strata, a commingling of forms is to be expected. A few of the more persistent Potsdam types are found at the base of the Pogonip, but a characteristic Chazy fauna rapidly takes the place of the life found below the Hamburg shale. At the top of the Pogonip the Trenton epoch is foreshadowed by the presence of a number of species characteristic of that horizon on the Atlantic border. The Eureka quartzite affords no evidence of animal life, but immediately upon the renewal of conditions favorable to limestone deposition several of the same Trenton species reappear, strongly reinforced by a group of forms decidedly Trenton in its aspect, while by far the greater part of the life observed below the quartzite has passed away forever. The Trenton is followed by a monotonous limestone 2,000 feet in thickness, carrying a few scattered corals, *Halysites catenulatus* being sufficiently characteristic to identify the beds as belonging to the Niagara. The Silurian of Eureka consists, then, of two heavy bodies of limestone with distinct faunas, separated by a dense white quartzite.

Without any discordance in deposition or chemical change in composition of the limestone, the next great period of Paleozoic time as determined by its life comes in, marked by the appearance of *Atrypa reticularis* and associated species, followed by an abundant and strikingly characteristic Devonian fauna, which is maintained to the top of the Nevada limestone. A decided change in the nature of the sediments brings in the White Pine shale with its peculiar fauna and flora, but still characterized by its Devonian aspect.

The Diamond Peak quartzite carries the first evidence of an unquestioned Carboniferous life, as shown by one or two Coal-measure species in an interbedded limestone. From the summit of this horizon upward the easily recognized Carboniferous fauna, as seen in so many ranges over the Great Basin, continues to the summit of the Paleozoic sediments, through two heavy masses of limestone and an intermediate quartzite or sandstone.

Physical Divisions.—There can be no question that a geologist making a division of the Paleozoic rocks of Eureka, if he were guided solely by the physical conditions found there, would carry the first period up to the Eureka quartzite. In doing this he would be drawing a line in accordance with the most important break to be found in the faunal development of the lower Paleozoic rocks, the greatest change occurring between the life found just below the Eureka quartzite and that coming in a short distance above it. It would be a line in agreement with a sharp lithological change which brought about conditions detrimental to life, and at the same time would make a separation which would coincide with the one unconformity by deposition as yet recognized in the record of the Lower Paleozoic rocks in the Great Basin. The conformable series of limestones and shales between the Prospect Mountain quartzite and the Eureka fall naturally into one grand period. As already pointed out, the Hamburg shale separates the Cambrian from the Silurian at Eureka, but in other localities this shale is entirely wanting, the Hamburg limestone passing up into the Pogonip without any lithological break. Even at White Pine, only 40 miles away, the shale is wanting. In working out the structural relations of the entire series of Paleozoic sediments over much of the Great Basin, one of the chief difficulties has been to connect the Cambrian and Lower Silurian rocks below the Eureka quartzite with the Upper Silurian and Devonian above it.

Again, from a physical point of view there are obvious reasons for linking together in one group the enormous development of limestones lying between the Eureka quartzite and the Diamond Peak quartzite. So imperceptible is the transition in physical characters between the Lone Mountain beds of the Silurian and the Nevada limestone of the Devonian that no line can be sharply drawn, and while the fauna slowly undergoes change there are hundreds of feet of sediments that might as well be placed in one as the other of the two formations. *Atrypa reticularis* and other species found near the base of the Devonian have at other localities been obtained, associated with species regarded as belonging to the Silurian.

With the coming in of the Diamond Peak epoch another great change takes place in the physical conditions, and with it a marked faunal break, which brings in the Carboniferous period. From the Diamond Peak quartzite to the summit of the Paleozoic rocks the beds form one natural group, no matter from what point of view they may be considered. The lithological distinctions hold good over wide areas.

From the standpoint of physical geology the record shows three grand divisions: first, one with the Prospect Mountain quartzite at the base, folowed by a series of limestones and shales; second, beginning with the Eureka quartzite, followed by another series of limestones to the top of the Devonian; third, a great quartzite belt, followed in turn by a limestone, a conglomerate, and a second limestone.

LOWER PALEOZOIC IN ADJOINING REGIONS.

After the completion of the field work, upon revisiting several of those ranges in the Great Basin where the descriptions given of the lower Paleozoic sections differed essentially from the sections exposed at Eureka, it was found that, as regards sequence of beds, they stood singularly in accord and could easily be correlated with those of the latter locality. A knowledge of the sedimentary beds at Eureka serves to unravel in neighboring ranges several knotty problems previously not clearly understood, and to show that similar physical conditions existed over a wide area of ocean bottom. For comparative purposes, therefore, it may be well to introduce here, with more or less detail, some descriptions of the geological structure and occurrences elsewhere in the Great Basin of those portions of the lower Paleozoic horizons that happen to be well represented at Eureka. The section at Eureka may be taken as a standard.

The Oquirrh Mountains.—In the Oquirrh Mountains, the first range west of the Wasatch, the *Olenellus* horizon has been identified in a thin bed of yellow shale conformably overlying a reddish white quartzite of unknown thickness, above which occur from 3,000 to 4,000 feet of limestone carrying Lower Carboniferous and Coal-measure fossils. The geological position of the shale bed is determined by the following species: *Lingulella ella, Olenellus gilberti*, and *Bathyuriscus producta.* Mr. S. F. Emmons,[1] while engaged upon the Geological Exploration of the Fortieth Parallel, examined this range and shrewdly suggested, from orographic evidences, that a fault existed between the shales and overlying limestones—a structure which would be in accord with the observed facts brought out at Eureka.

The Highland Range.—The Highland Range, about 125 miles south of Eureka, presents a geological structure in many respects similar to Prospect Mountain, although by no means as simple or furnishing an unbroken section of equal extent. At Pioche, at one time a flourishing mining town, situated on an eastern spur of the main range, Mr. E. E. Howell obtained two species of the genus *Olenellus*, which Mr. F. B. Meek[2] described as *O. gilberti* and *O. howelli.* According to Mr. Howell[3] they occur in a reddish yellow arenaceous shale about 400 feet in thickness, overlying 1,200 feet of quartzite. In the published section the shale is represented as conformably overlain by gray limestone, which he regarded as of Carboniferous age, although no paleontological evidence was presented. If these strata are conformable it would seem highly probable, from the known sequence of beds at Eureka as well as elsewhere in the Highland Range, that the overlying limestone belongs to the Prospect Mountain epoch.

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[1] U. S. Geol. Explor'n 40th Par., vol. 2, Descriptive Geology, p. 444.

[2] Geographical Surveys West of One hundredth Meridian, vol. 3, p. 182.

[3] Op. cit. vol. 3, p. 258.

Subsequently, during the summer of 1885, Mr. C. D. Walcott studied the structure at Pioche, and also made an extended examination of the Cambrian and Silurian rocks of the main uplift of the Highland Range. He estimated about 7,000 feet of strata between the summit of the Prospect Mountain quartzite and the base of the Eureka quartzite, as against 9,000 feet at Eureka. Between Bennett Spring and Stampede Gap the lower members of the group were carefully measured, the section presenting the beds more in detail and showing greater variation of sedimentation, with more interbedded siliceous material than observed in the corresponding horizons at Eureka. Detailed lithological sections, however, across the Cambrian rocks are perhaps of little value, owing to the rapid changes in the character of the beds. Sections made across Prospect Mountain show considerable difference in detail, but agree substantially in general features. The section at Bennett Spring is as follows:[1]

	Feet.
1. Dark reddish brown quartzite, evenly bedded and ripple-marked in places.	350
2. Bluish gray limestone Fossils: *Olenellus gilberti.*	35
3. Buff argillaceous and arenaceous shales, more or less solid near the base and laminated in the upper portions Fossils: Annelid trails and fragments of *Olenellus* in the lower part; higher up the heads of *Olenellus gilberti* and *O. iddingsi* occur in abundance.	80
4. Light colored gray limestone and bluish black limestone	16
5. Sandy, buff colored shale Fossils: Annelid trails, *Cruziana*, sp.?	40
6. Dark bluish black limestone	46
7. Finely laminated buff argillaceous shale Fossils: *Hyolithes billingsi* and *Ptychoparia piochensis.*	80
8. Gray to bluish black compact limestone	18
9. Buff arenaceous shales	64
10. Compact cherty limestone	50
11. Compact shaly sandstone in massive layers	40
12. Hard siliceous gray limestone, almost quartzite at base	12
13. Yellow to buff sandy shales	70
14. Bluish black limestone	16

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[1] Second Contribution to the Studies on the Cambrian Faunas of North America. U. S. Geol. Surv. Bull. No. 30, 1886, p. 34.

		Feet.
15. Yellow to buff sandy shales		40
16. Bluish black, hard, compact limestone Fragments of fossils.		12
17. Shaly sandstone in massive layers		52
18. Gray arenaceous limestone		2
19. (*a*) Buff sandy shale	40	
(*b*) Gray arenaceous limestone	30	
(*c*) Sandy calcareous shale	3	
		73
20. (*a*) Massive bedded bluish gray limestone Fragments of fossils.	200	
(*b*) Compact gray siliceous limestone, almost quartzite in places	400	
(*c*) Bluish black evenly bedded limestone	6	
		606
Strike N. 30° W., dip 10° E.		
21. Buff to pinkish argillaceous shale, with fossils, and a few interbedded layers of limestone from 3 to 15 inches thick Fossils: *Eocystites?? longidactylus*, *Lingulella ella*, *Kutorgina pannula*, *Hyolithes billingsi*, *Ptychoparia piochensis*, *Olenoides typicalis*, *Bathyuriscus howelli*, and *B. producta*.		125
22. Massive bedded siliceous limestone, weathering rough and broken into great belts 200 to 300 feet thick by bands of color in light gray, dark lead, to bluish black; on some of the cliff faces the weathered surface is reddish		1,570
23. Bluish black limestone in massive strata that break up into shaly layers on exposure to the weather. The latter feature is less distinct 850 feet up, and the limestone becomes more siliceous, with occasional shaly beds Fossils: Near the summit specimens were found that are referred to *Ptychoparia minor*.		1,430

The upper limestone on the line of the section is not favorable for the preservation of organic remains, but the same horizon a short distance to the southward yielded a fauna similar to that from the Upper Cambrian at Eureka, two species being identically the same, while two others, *Bellerophon antiquatus* and *Dicellocephalus pepinensis*, occur in the Potsdam sandstone of Wisconsin.

Timpahute Range.—Mr. G. K. Gilbert reports from the southern end of Timpahute Range a section over 2,300 feet in thickness, which, taken together with paleontological evidence, may be readily correlated with the lower part of the Cambrian of Eureka and the Highland Range. The thicknesses are estimated. The section is as follows:[1]

South end of Timpahute Range. Eastern Nevada.

		Feet.
1. Heavy bedded gray limestone, light and dark		400
2. Yellow argillaceous shale:		
(*a*) Yellow shale	350	
(*b*) Yellow sandstone	75	
(*c*) Yellow and green shale, with fillets of fossiliferous limestone (*Conocoryphe*)	500	
		925
3. Purple ripple-marked vitreous sandstone, with bands of siliceous shale		1,000
Total		2,325

The lower bed corresponds to the Prospect Mountain quartzite. In the overlying yellow shale he collected a few fossils, determined by Mr. Walcott as *Olenellus gilberti* and *O. iddingsi.*

Silver Peak.—Still farther west, in a bed of yellowish brown limestone with intercalated gray argillaceous shales at Silver Peak, a small collection of fossils was made, which Prof. J. D. Whitney[2] placed before the California Academy of Sciences as early as 1866. At that time he regarded them as Upper Silurian or Devonian. Quite recently Mr. Walcott[3] has examined the collection and determined the following species:

Archæocyathus atlanticus.
Archæocyathus, undt. sp.
Ethmophyllum whitneyi.
Strephochetus? sp.?
Kutorgina (like K. cingulata).
Hyolithes princeps.
Olenellus gilberti.

A number of species proved to be identical with those found on the coast of Labrador and the horizon is evidently the equivalent of the Georgia or Lower Cambrian formation of Prospect Mountain. He also determined *Olenellus gilberti* as closely resembling *Olenellus thompsoni* from L'Anse au Loup.

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[1] Geographical Surveys West of One hundredth Meridian, Washington, 1875, vol. 3, p. 169.

[2] Proc. Cal. Acad. Sci., vol. 3, p. 270.

[3] Second Contribution to the studies on the Cambrian Faunas of North America. U. S. Geol. Surv. Bull. No. 30, 1886, p. 38.

Silurian and Devonian.—Exposures of Silurian and Devonian rocks presenting a development of strata at all comparable with the Eureka section are known in but few localities in the Great Basin, and nowhere are the structural relations of the Cambrian, Silurian, and Devonian so clearly brought out as here. Nevertheless, numerous mountain uplifts present so many partial exposures of the Eureka section that the evidence is sufficient to determine the same succession of strata over a wide area of the Great Basin.

Geological Section, White Pine.—In the year 1872 the writer[1] visited White Pine and Eureka and established the identity of a great thickness of the Pogonip beds at both places. The fossils collected at that time from Pogonip Mountain, White Pine, and the hills east of the Jackson Mine at Eureka, were submitted to Messrs. Hall and Whitfield and shown by them to be specifically identical. At that time, however, neither the base nor the summit of the epoch was clearly defined and not until after the thorough survey of the Eureka district were their exact limitations known, nor could they be determined until after the collection of a large amount of paleontological material. Topographically, Pogonip Ridge holds much the same relation to the White Pine Mountains that Prospect Ridge does to the Eureka Mountains. It forms the most prominent uplift in that district, occurring as a sharp longitudinal ridge, the highest point attaining an elevation of nearly 10,800 feet above sea level. Across this ridge the oldest sedimentary beds of the district lie inclined at high angles to the east, the northern end being made up almost wholly of Silurian rocks. The structure is simple, the beds which trend obliquely across the ridge being easily followed from the summit of the peak to the northern base.

After the completion of the work at Eureka Mr. C. D. Walcott made a careful examination of the Silurian rocks at White Pine where, according to him, the Pogonip strata measure over 5,000 feet in thickness. The oldest strata identified by their organic remains are the beds at the base of the Hamburg limestone, several species being identical with those from the corresponding horizon at Eureka. These Hamburg limestone beds, several hundred feet in thickness, are cut off by a fault bringing them in contact

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[1] U. S. Geological Exploration of the Fortieth Parallel, vol. 2, Descriptive Geology, pp. 542 and 547.

with a heavy bed of quartzite that forms the western central spur of Pogonip Ridge. As the Hamburg shales are wanting, the Hamburg limestone and the included fauna continue to the base of the Pogonip. Here, as well as at Eureka, the base of the Pogonip is determined by a commingling of Cambrian and Silurian species, the line of demarcation resting wholly upon paleontological evidence. Mr. Walcott examined the beds from the lower quartzite across the Pogonip, Eureka quartzite, and Lone Mountain, until the upper beds of the latter epoch were lost beneath the detritus of the plain.

The section is as follows:

	Feet.
NIAGARA.	
1. Yellowish shaly limestone	50
2. Light colored, massive bedded siliceous limestone, with plates of crinoids, etc	650
3. Light blue siliceous limestones with impressions of corals, *Halysites catenulatus*, *Stromatopora?*	150
4. Light gray siliceous limestones	50
TRENTON.	
5. Evenly bedded pure bluish gray limestones	50
Fossils: *Cystidian plates*, *Bryozoa* 3 sp., *Rhynchonella capax*, *Trinucleus concentricus*, *Streptorhynchus filitexta*, *Orthis subquadrata*, *Pterinea*.	
6. Dark colored siliceous limestone in massive beds	500
EUREKA.	
7. Light vitreous quartzite, ferruginous near the base	350
POGONIP.	
8. Dark blue and black limestones, with numerous shaly belts, characterized by the fossils of the Upper Pogonip as seen at Eureka, nearly all the genera being recognized, with the exception of *Receptaculites*	900
9. Dark evenly bedded limestones, with more or less siliceous bands	4,300
Fossils: *Acrotreta gemma*, *Illænus eurekensis* *Triplesia calcifera* in the lower portion, followed higher up by the same forms as found at Eureka east of the Jackson mine and east of Hamburg Ridge.	

HAMBURG.

	Feet.
10. Dark bluish black limestone, carrying Hamburg limestone fossils.......	800
	7,800

Divided according to the epochs adopted at Eureka we have:

Lone Mountain limestone..	1,450
Eureka quartzite..	350
Pogonip limestone...	5,200
Hamburg limestone...	800

The Hamburg limestone yielded the following species:

Protospongia sp.?
Lingulepis minuta.
Orthis sp.?
Agnostus bidens.
Agnostus communis.
Conocephalites sp.?
Crepicephalus nitidus.
Crepicephalus unisulcatus.
Chariocephalus tumifrons.
Illænurus sp.?

While at White Pine the relationship between the Cambrian and Silurian is well shown, the Devonian has not been recognized directly overlying the Lone Mountain Silurian. Between Pogonip Mountain and the next ridge to the eastward a displacement brings up the Nevada limestone, forming the massive beds of Mount Argyle and Treasure Peak.[1] This limestone is here overlain by the black argillaceous shale, which passes into sandstone, followed by Carboniferous limestone. The black shale is the counterpart of the corresponding terrane at Eureka, a comparison of the two sections showing the greatest resemblance. The coarse yellow sandstone above seems to be the equivalent of the Diamond Peak quartzite, although here at White Pine it is represented by only a few hundred feet, while the black shale attains a development of 1,000 feet. From the Nevada limestone there has been collected an abundant fauna characteristic of the middle and upper beds. It was for the most part obtained by the

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[1] U. S. Geological Exploration of the Fortieth Parallel, vol. 3, Mining Industry, p. 409, and accompanying atlas sheet 14.

writer from Mount Argyle and Treasure Peak, and represents thirty-three genera and forty-nine species, as follows:

Cyathophyllum sp.?
Fenestella (2 sp.?)
Thamniscus sp.?
Lingula alba-pinensis.
Discina lodensis.
Chonetes sp.?
Strophodonta canace.
Strophodonta inequiradiata.
Strophodonta sp.?
Orthis macfarlani.
Orthis impressa.
Productus hirsutiforme.
Productus subaculeatus.
Productus sp.?
Spirifera alba-pinensis.
Spirifera disjuncta.
Spirifera engelmanni.
Spirifera piñonensis.
Spirifera strigosus.
Spirifera subumbona.
Spirifera sp.?
Cyrtina davidsoni.
Ambocœlia umbonata.
Retzia radialis.
Atrypa reticularis.
Rhynchonella duplicata.
Rhynchonella emmonsi.
Rhynchonella occidens.
Rhynchonella (L) quadricostata.
Cryptonella circula.
Pentamerus lotis.
Terebratula sp.?
Aviculopecten catactus.
Pterinopecten sp.?
Lunulicardium fragosum.
Cardiomorpha missouriensis.
Nuculites triangulus.
Paracyclas peroccidens.
Conocardium sp.?
Platyostoma sp.?
Euomphalus laxus.
Euomphalus sp.?
Loxonema sp.?
Platyschisma sp.?
Bellerophon neleus.

A more characteristic White Pine fauna is preserved in the black shale than has yet been obtained in the corresponding beds at Eureka, and a belt of intercalated limestone in the shale similar to that found east of Sugar Loaf at Eureka bears equal evidence of its Devonian age. Here the limestone appears as a lenticular body in the shale, with beds identical in composition both above and below. While there is much in the grouping of forms foreshadowing the Carboniferous, the shales maintain their Devonian aspect by carrying certain characteristic species up nearly to the top of the series, and in this respect resemble the black shales found at Hays Canyon west of Newark Mountain.

From Applegarth Canyon the White Pine shales yielded the following species:

Cyathophyllum sp.?
Fenestella (2 sp.?)
Thamniscus? sp.?
Lingula alba-pinensis.
Discina lodensis.
Chonetes (of type of C. illinoisensis).
Productus hirsutiforme.
Productus subaculeatus.
Productus (of type of P. semireticulatus).
Spiriferina cristata.
Ambocœlia umbonata.
Retzia radialis.
Athyris (of type of A. plano-sulcata).
Rhynchonella (L) quadricostata.
Aviculopecten catactus.
Nuculites triangulus.
Cardiomorpha missouriensis.
Lunulicardium fragosum.
Hyolithes sp.?
Pleurotomaria sp.?
Goniatites kingii.
Goniatites sp.?
Prœtus sp.?
Cytoceras cessator.

With the exception of some indeterminable fragments of crinoid columns and a few impressions of stems and twigs, the sandstones have yielded no life. The few vegetable remains, however, are important, as they are of rare occurrence in Paleozoic sandstones of Nevada. The Carboniferous limestones overlying this belt of sandstones have been but little studied since the explorations of the fortieth parallel, and no additional material throwing light upon the life of the period has been obtained.

Silurian and Highland Range.—In the Highland Range the Silurian rocks have not been as carefully studied as the Cambrian. Indeed, it is by no means certain that in the area covered or in the exposure of beds that the Silurian is as well represented as in a number of other ranges, although, as has been already shown, the Cambrian compares favorably with the same epoch in the Eureka Mountains. Both the Pogonip and Eureka quartzite, however, are well exposed on the west side of the range in a hill just north of the road leading from Bennett Spring to Hyko, where the fauna in the limestone immediately below the quartzite is so characteristic that both formations are readily determined. At this locality, in beds below the Eureka quartzite, Mr. Walcott made the following collection:

Orthis perveta.
Orthis tricenaria.
Orthis pogonipensis.
Strophomena fontinalis.
Modiolopsis occidens.
Modiolopsis pogonipensis.
Raphistoma acuta.
Murchisonia, 2 sp.?
Subulites sp.?
Orthoceras sp?
Orthoceras (Annulated species).
Leperditia bivia.
Ceraurus sp.?
Illænus crassicauda.
Bathyurus pogonipensis.
Pleurotomaria lonensis.

Fossil Butte.—At Fossil Butte, 10 miles north of Hyko, on the east side of Pahranagat Valley, the Pogonip is again seen overlain by the Eureka quartzite. The butte stands out as an elevated ridge, but presenting an exactly similar succession of strata as seen along the east side of Prospect Mountain, Pogonip Ridge, and the western base of Lone Mountain. In the limestone occur the following species:

Receptaculites mammillaris.
Orthis tricenaria.
Strophomena fontinalis.
Triplesia? sp.?
Leperditia bivia.
Maclurea subannulata.
Maclurea, 2 sp., undet.
Metoptoma phillipsi.
Ecculiomphalus, like E. distans.
Orthoceras multicameratum.
Endoceras multitubulatum.
Modiolopsis occidens.
Modiolopsis pogonipensis.
Illænus crassicauda.

Taken together these two groups from Bennett Spring and Fossil Butte carry the more marked fauna of the Upper Pogonip. Overlying the quartzite occur some light gray limestones, without organic remains, but resembling the Lone Mountain beds. Along the east side of Pahranagat Valley limestone ridges extend for several miles. The beds have been much disturbed and have undergone considerable faulting, preventing accurate sections, but it is estimated that there are from 2,000 to 3,000 feet of limestones exposed. They are more or less siliceous, weathering reddish brown and brownish gray. The lower members may possibly belong to the Lone Mountain series. Near Hyko there is an exposure of shaly limestone, overlain by massive beds of dark arenaceous limestone, carrying a Devonian fauna. The specimens, although poorly preserved, allowed of the following determinations:

Stromatopora sp.?
Spirifera sp.?
Atrypa reticularis.
Pentamerus lotus.
Modiomorpha sp.
Holopea sp.?
Euomphalus (P) laxus.

Pahranagat Range.—On the west side of the valley the Pahranagat Range forms a long, continuous ridge, for the most part made up of sedimentary strata faulted and broken into massive blocks by outbursts of acidic lavas. Quartz Peak, the culminating point, affords a fine exposure of Silurian strata, with much the same series of beds as seen in the central part of the State, with this exception that neither the Upper Pogonip at the base nor the Niagara at the summit are represented in their full development. Upon the south side of the peak, extending from the base to the summit, there is an unbroken exposure of strata 2,000 feet in thickness, striking N. 30° E., with an average dip of 20° N. The summit of the peak is formed of the Niagara limestone. The section, with the accompanying fossils, is, according to Mr. Walcott, as follows:

	Feet.
LONE MOUNTAIN—NIAGARA.	
1. Massive bedded gray siliceous limestone, with occasional layers of sandstone and chert	535
LONE MOUNTAIN—TRENTON.	
2. Massive bedded dark siliceous limestone, with a stratum 30 feet thick, almost made up of a species of *Pentamerus* like *P. galeatus*. These occur not far above No. 3	335
3. Bluish black and bluish gray thin bedded limestone, with numerous fossils. *Zaphrentis*, sp.?, *Bryozoa*, 3 sp., *Streptorhynchus filitexta*, *Orthis testudinaria*.	30
4. Massive bedded dark iron-gray siliceous limestone	150
EUREKA.	
5. Hard, vitreous white quartzite, becoming tinged with a reddish color toward the base	400

POGONIP.

	Feet.
6. Evenly bedded layers of a dark bluish black and bluish gray limestone, thin layers making more massive beds that break up on exposure to the influence of the atmosphere *Receptaculites mammillaris*, *Orthis pogonipensis*, *Orthis tricenaria*, *Porambonites obscurus*, *Bellerophon*, sp.?, *Hyolites*, sp. undet., *Endoceras multitubulatum*, *Leperditia bivia*, *Illænus crassicauda*.	150
7. Thinner bedded bluish gray limestone that is shaly in places Fossils numerous.	400
8. Massive bedded gray limestone, in layers from 1 to 4 feet in thickness *Orthis*, *Murchisonia*, and *Orthoceras* are seen in the lower layers, and *Receptaculites mammillaris* and *R. elongata* 150 feet higher up.	200
	2,200

This section gives for the different horizons as follows:

Niagara	535
Trenton	515
Eureka	400
Pogonip	750

On the northeast slope of Quartz Peak there is a heavy mass of light gray siliceous limestone, roughly estimated at 1,000 feet, without fossils, which, by its stratigraphical position and lithological habit is easily referred to the upper beds of the Lone Mountain, a continuation of the beds upon the summit of the peak as given in the section. To the south of Quartz Peak occurs a great development of limestone. A section across the beds is of special interest, owing to the thickness of the limestones from the Lone Mountain to the Carboniferous, which is unbroken by the presence either of Diamond Peak quartzite or White Pine shale, as in both the Eureka and White Pine sections. The section is as follows:

CARBONIFEROUS.

	Feet.
1. Siliceous limestone, sandstone, and quartzite	500
2. Cherty siliceous limestone	250
3. Shaly limestone in massive layers	55
4. Massive bedded gray limestone, hard and compact; it passes into granular dark gray limestone and then into more thinly bedded bluish black limestone	1,260

	Feet.
5. Bluish black limestone in thin layers, overlain by shaly limestone, with intercalated beds of bluish black limestone. The limestone in layers gradually replaces the shaly limestone until the latter disappears from the section. Upper beds characterized by Lower Carboniferous fauna. (List follows the section.)	390
At 95 feet from the top, *Spirifera lineata* and *Spirifera cristata* were observed.	
DEVONIAN.	
At 140 feet from the top, numerous fragments of crinoids, crinoidal columns were seen for the last time, and *Atrypa reticularis* began to appear.	
At 350 feet from the top, buff shaly limestone predominates and a more evenly grained, smoother, harder limestone begins to appear as thin layers in the shaly limestones. Fossils few in number and badly preserved.	
6. Hard, compact, yellowish sandstone in thin layers	25
7. Calcareous sandstone overlain by arenaceous limestone, and above that bluish gray thin bedded limestone	175
8. Gray siliceous limestone with shaly limestone partings and bands of bluish black limestone	340
At 125 feet from the top, a band of bluish black thinly bedded limestone carries numerous fossils of the Upper Devonian age. (List follows the section.)	
At 240 feet from the top, *Stromatopora* and coralline markings appear.	
9. Hard buff colored sandstone	25
10. This is almost a repetition of No. 8, the three grading into each other in places	225
Seventy-five feet down from the top, *Stromatopora* and a small slender coralline stem crowd the darker siliceous layers.	
11. Light gray siliceous limestone, almost a sandstone in places, passing up into a dark siliceous limestone, and then into thinner bedded bluish black and bluish limestone	1,920
The upper layers contain *Strophomena perplana, Atrypa reticularis, Cyrtina*, sp.? *Pleurotomaria.*	
12. Gray quartzitic sandstone in massive layers	100
13. Gray siliceous limestone	110
14. Quartzitic ferruginous sandstone	85
15. Light gray and dirty brown siliceous limestone in alternating bands of color, of varying degrees of hardness. The siliceous and calcareous matter varies considerably in the different layers. Toward the lower portion many layers are almost made up of a species of *Stromatopora* and slender stems of a branching coral one-eighth to one-fourth of an inch in diameter	2,100

SILURIAN.

	Feet.
16. Light gray siliceous limestone	1,000
	8,560

In the bluish black limestone at the top of No. 5 the following Lower Carboniferous fauna comes in:

Amplexus, sp.?
Syringopora, sp.?
Acervularia pentagona.
Fenestella, sp.?
Chonetes, sp.?
Chonetes granulifera.
Chonetes, sp.?
Productus nebrascensis.
Productus punctatus.
Productus tenuicostatus.
Productus semireticulatus.
Productus, sp?
Productus, sp?
Orthis resupinata.
Streptorhynchus crenistria.
Syringothyris cuspidatus.
Spirifera pinguis.
Spirifera pulchra.
Spirifera striata.
Spirifera (M) lineata.
Cyrtina, sp?.
Athyris subquadrata.
Rhynchonella.
Terebratula, sp.?
Platyceras, sp.?
Bellerophon, sp.?
Euomphalus, sp.?
Euomphalus laxus.
Euomphalus (Straparollus) ophinea.
Straparollus, sp.?
Holopea, sp.?
Loxonema.
Loxonema.
Pleurotomaria, sp.?
Pleurotomaria, sp.?
Edmondia, 2 sp.?
Leperditia, sp.?
Prœtus peroccidens.

The following Devonian fauna was collected from No. 8:

Lingula (like L. ligea).
Orthis impressa.
Productus shumardianus.
Productus (like P. lachrymosa).
Strophodonta, sp.?
Spirifera, sp.?
Nucleospira concinna.
Cyrtina hamiltonensis.
Ambocœlia (like young of A. umbonata).
Rhynchonella duplicata.
Rhynchonella sinuata.
Athyris? sp.?
Pentamerus lotus.
Modiomorpha, sp?
Euomphalus, sp.?
Platyostoma lineata?
Orthoceras, sp.?
Orthoceras, sp.?
Leperditia, sp.?

In this section we have about 8,000 feet of nearly continuous limestone strata, broken occasionally by thin beds of yellow sandstone, the heaviest not over 100 feet in thickness. It is not singular that in a massive bed of limestone it becomes a difficult matter to divide the Silurian, Devonian, and Carboniferous with any degree of precision. Between the Silurian and Devonian at the base of the section it is impossible to draw any line of demarcation. It is safe, provisionally, to place 1,000 feet of the light gray limestone in the Lone Mountain period, leaving strata carrying *Stromatopora* and branching corals included in the Devonian. In the 390 feet of bluish black limestones (No. 5 of the section) a marked Devonian fauna occurs at the base and Lower Carboniferous fauna at the summit, without any change in the lithological character of the beds. Provisionally the line is drawn so as to include in the Carboniferous all beds carrying *Spirifera lineata* and *Spirifera cristata*, and leaving *Atrypa reticularis* in the Devonian. By this division we have the following thicknesses for the different periods:

	Feet.
Carboniferous	2,160
Devonian	5,400
Silurian	1,000

Piñon Range.—To these sections south and southeast of Eureka may be added still another, constructed across Piñon Range about 60 miles northward. This range is a long, narrow ridge, stretching from the Humboldt River southward until it joins the Eureka Mountains at The Gate, the southern end of the range coming within the area of this survey.

The Piñon Range attains its greatest elevation just south of the Humboldt, where the best continuous sections of the Lower Paleozoic rocks occur. The range was crossed at several points by the geologists of the Fortieth Parallel Exploration, the Devonian rocks being traced by the writer for nearly their entire length from The Gate to the Humboldt River. At the request of the writer, Mr. Walcott visited the northern end for the purpose of a comparative study of the section exposed at Ravens Nest with the corresponding rocks at Eureka. Here the beds strike obliquely across the trend of the range from the northwest base of Ravens Nest to the base of Pinto Peak, the course of the range being approximately north and south.

The following ideal section was made by Mr. Walcott:

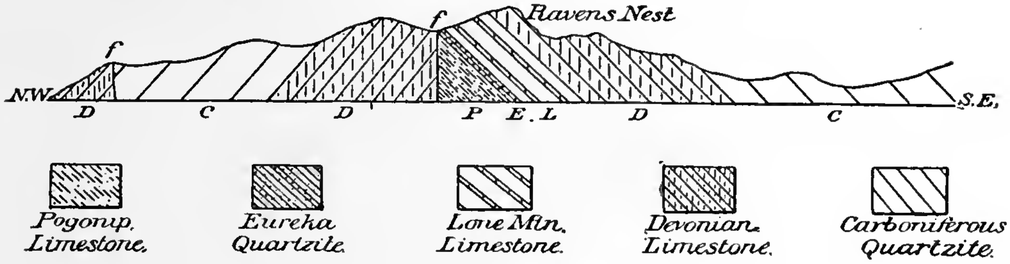

FIG. 4.—Section across Piñon Range.

Across the range from west to east along the line of the section a dark blue limestone, carrying a few fossils of the Lower Devonian, rises above the plain. Beyond the limestone a sharp oblique fault brings up a broad mass of quartzite, conglomerates, and black siliceous pebbles. These, in turn, are conformably underlain by blue limestone, from which a sufficient fauna was secured to identify Upper Devonian beds. The limestones are again cut off by a profound fault, apparently along a line of an anticlinal axis. To the west of this fault the beds all dip westward, but beyond this point present an easterly dip, at least as far as the base of Pinto Peak. Directly eastward of the fault a dark ferruginous quartzite stands out prominently, followed by light gray siliceous limestones, the age of which is determined by the presence of *Halysites*. The beds gradually assume the habit of the Devonian and carry a fauna sufficiently characteristic to establish the horizon of the Lower Devonian, and still higher up in the series yielded Upper Devonian species. Overlying the limestones occurs a great thickness of quartzites and sandstones, with occasional argillaceous bed. Near the junction of the Devonian limestones with the overlying quartzites the beds upon both sides of the anticline are identical, showing the corresponding horizons without the evidence of the fauna. If the White Pine shale of Eureka is at all represented in the Piñon Range it is found in the argillaceous and finely siliceous beds immediately overlying the Devonian limestones on both sides of the fault. These beds resemble those observed at the same horizon at The Gate, already described, and the continuance northward of similar sediments is not without interest, especially when taken in connection with the great thickness of White Pine shale to the southeast as developed in the Diamond Range, Cliff Hills and White Pine.

Roughly estimated, the thicknesses of the beds in the above section are as follows:

	Feet.
Eureka quartzite	400
Silurian and Devonian limestones	5,500
Carboniferous quartzites and sandstones	7,000

Tucubit Mountains.—In the Tucubit or Wild Cat Mountains, north of the Humboldt River, occurs a long stretch of massive limestones that have evidently undergone much faulting and disturbance. In a black calcareous shale belt overlying yellow calcareous shales there were found *Atrypa reticularis*, *Spirifera vanuxemi* and *Orthis multistriata*, and other species, showing the extension of Devonian beds into the northern part of the State. These limestones in the Tucubit Mountains have been estimated by Mr. S. F. Emmons as from 4,000 to 5,000 feet in thickness.[1]

Unconformity in the Silurian.—In the descriptive chapters references have frequently been made to an unconformity existing in the Silurian, between the Eureka quartzite and Lone Mountain limestone. This unconformity is also indicated in the accompanying atlas sheets, where different horizons of the Lone Mountain and Nevada limestones are seen to rest directly upon the underlying quartzite. The Lone Mountain beds may frequently be seen to wedge out in places; in others, Devonian beds, determined as such by their associated fossils, come down nearly if not quite to the top of the Eureka quartzite. In only one locality along the southern base of Comb's Mountain do the beds show the lithological characters or the fauna of the Trenton limestone, but here they are overlain by a broad development of the Niagara, the upper member of the Lone Mountain epoch, before the coming in of the Devonian. Evidences of uncomformity by erosion have been recognized in a few localities, but the nature of the quartzite is such that they could hardly be expected to be conclusive, the amount of erosion being slight. In most instances in the more elevated regions where the Eureka quartzite lies horizontally the overlying limestones have been eroded, but this, however, is not the case on the ·plateau in the region of Grays Peak, where isolated patches of limestone occupy depressed areas and shallow basins in the undulating surface of quartzite.

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[1] U. S. Geological Exploration of the Fortieth Parallel, vol. 2. Descriptive Geology, p. 524.

Movement in Carboniferous.—In the chapter devoted to the Upper Coal-measures descriptions have been given of the coarse conglomerates interbedded in the limestone, containing siliceous pebbles and worn fragments of limestone carrying Coal-measure fossils, evidently derived from neighboring land areas undergoing denudation. Many of the siliceous pebbles have the appearance of coming from the Weber conglomerate, but this can not be positively stated. The *Productus semireticulatus* and other species found in these rolled fragments may have been derived from either the Upper or Lower Coal-measures. The change in sediment from limestone to conglomerate is abrupt, and no indications of erosion in the underlying rocks were observed. The evidence of movement rests wholly upon the lithological character of the material forming the conglomerate, which was in turn covered by deposits in every way similar to the limestone below it. It seems evident that fragments of fossil-bearing limestone could not have withstood the disintegrating action of water for any great length of time or have been transported for any great distance.

Distribution of Upper Silurian and Devonian.—Over large areas of the Great Basin, Upper Silurian and Devonian sediments are either wanting or have not as yet been recognized. Several longitudinal ranges have been described in their geological structure as tilted blocks formed either exclusively of Carboniferous rocks, or else made up of the Pogonip of the Lower Silurian overlain conformably by Coal-measure limestones, the intervening horizons, which at Eureka are known to measure over 12,000 feet in thickness, being entirely unrepresented. Sediments of Upper Silurian and Devonian age, while they occupy limited areas, nevertheless play a most important part in the ranges which rib the central portion of Nevada. To the north of the Humboldt River, as already pointed out, the Nevada limestones have been recognized in the Tucubit Mountains; they form the greater part of the Roberts Peak Mountains west of the Piñon Range, where they probably overlie a considerable but unknown thickness of Lone Mountain Silurian, and the writer has traced the Devonian beds all along the Piñon Range, connecting them with the grand exposures of the Eureka district. At Ravens Nest, at the northern end of this latter range, that portion of the Eureka series of beds lying between the Silurian quartzite and the Coal-measures is strikingly reproduced, the structure being a faulted anticline with corresponding beds upon both sides of the axial plane. Between the ancient shore-line to the west and the Humboldt Range on the east, there appears to have been a deep meridional trough-like depression in which all the beds from the Eureka quartzite up to the top of the Devonian were deposited. How far northward they can be traced continuously is still a matter of conjecture, but we know that the Devonian beds occupy large areas along the valley of the Mackenzie River. To the south this narrow channel or trough apparently widens out into a broad bay or open sea.

To the southeast of Eureka, in the White Pine Mountains, the Eureka quartzite, and both the Trenton and Niagara members of the Lone Mountain epoch are well developed on the northeast end of Pogonip Ridge, and the Devonian on Treasure and Babylon hills. The sequence of strata, together with the associated fauna from the base of the Pogonip to the Diamond Peak quartzite, may be easily correlated in the two localities. Still farther southward, on the east side of Pahranagat Valley, both the Upper Silurian and Devonian are exposed in a great thickness of limestones bordering the valley. In the uplifted block at Quartz Peak, in the Pahranagat Range, we have Pogonip, Eureka, Trenton, and Niagara all well exposed, but neither the upper nor lower horizon is shown in its full development.

Special mention should be made of the grand exposure of limestone found south of Quartz Peak. Here we have over 8,000 feet of conformable beds starting in with the Niagara at the base, passing through a great thickness of Devonian, and continuing on up into beds characterized by a rich fauna of the Lower Carboniferous. In this section the White Pine shale and the Diamond Peak quartzite are wholly wanting. While this series of beds shows in some respects the closest resemblance to the Eureka section, it is also significant as indicating an equally strong resemblance to the massive body of Wasatch limestone carrying Silurian, Devonian, and Lower Coal-measure limestones without intervening siliceous belts of any considerable thickness.

Such exposures on a grand scale are sufficient to show a very great development of Silurian and Devonian rocks stretching for long distances from southeastern Nevada well up toward the northern part of the State, if not far beyond. Throughout this entire distance, wherever they have been studied, these limestones maintain a great thickness of strata. At the southern end of this belt near Quartz Peak, the Silurian and Devonian limestones are estimated at 6,400 feet, and at Ravens Nest, just south of the Humboldt River, the estimate gives 5,500 feet, while at Eureka they present even a greater thickness.

As yet we know but little about the occurrences and distribution of the Diamond Peak quartzite. According to the section at Quartz Peak it is wholly wanting. In the Diamond Range at Eureka, it attains a thickness of 3,000 feet; on the opposite side of the valley in the Piñon Range it can not measure less, and at Ravens Nest it attains a development of 7,000 feet. In the northern part of Nevada we see an enormous development of arenaceous beds separating a Devonian from a Carboniferous fauna. This material thins out to the south, and in place of it we find a continuous limestone body extending all the way from the Eureka quartzite well up into the Carboniferous, without any well defined intervening siliceous horizon. Too few observations have been made to determine the geological history or geographical distribution of the Upper Silurian and Devonian rocks. As to the character of their sedimentation eastward, the thickening or thinning out of strata, or their lithological transitions, we know but little. It is a most significant fact, and one by no means easy to explain, that the entire series of beds included within the second period in which the Paleozoic rocks of Eureka have been classed, based upon their physical history, should apparently be wanting over such large areas in Utah and eastern Nevada. In other localities, while they may not be wholly wanting, they appear to be represented by thin beds of Lone Mountain strata, identified by a stray *Halysites*, and the Devonian by an occasional *Atrypa*.

Another interesting fact as regards the position of these rocks is this: Notwithstanding the enormous thickness of the Upper Silurian and Devonian beds at Eureka, the same relative position which has been observed in so many places elsewhere, with the Coal-measures resting upon the underlying Pogonip, may be seen here, the Upper Silurian and Devonian being absent. The occurrence of the two limestone bodies lying in juxtaposition may be seen all along the east base of Prospect Ridge, where the Hoosac fault brings the Lower Coal-measures up against the Pogonip, organic remains characteristic of both epochs being found within a few hundred yards of each other, with the intervening space occupied mainly by igneous extrusions along the fault-line. Here, however, they have been brought into their present position by profound orographic displacement.

The Wasatch and Kanab Sections.—The Wasatch Range, which shuts in the Great Basin on the east, combines, in a marked manner, many of the geological characters of both the Rocky Mountains and the Basin ranges. In structure, however, it is closely related in its essential features to the ranges of Utah and Nevada. There is exposed in the range a very remarkable section of conformable beds, extending through 30,000 feet of sediments and exhibiting nearly every geological period from Lower Cambrian to Permian. For the purpose of comparison a section constructed by the Geological Exploration of the Fortieth Parallel is reproduced, as it shows not only certain resemblances, but also striking differences in the sequence beds from the section as exposed at Eureka:

Wasatch section, Utah: 30,000 feet; conformable.

PERMIAN, 650 feet	Permian		650	Clays, marls, and limestones; shallow.
CARBONIFEROUS, 14,000 feet	Upper Coal-measure limestone		2,000	Blue and drab limestones; passing into sandstones.
	Weber quartzite		6,000	Compact sandstone and quartzite; often reddish; intercalations of lime, argillites, and conglomerate.
	Lower Coal-measure limestone	Wasatch limestone.	7,400	Heavy bedded blue and gray limestone, darker near the base, with siliceous admixture, especially near the top.
	Waverly			
DEVONIAN, 2,400 feet.	Nevada limestone			
	Ogden quartzite		1,000	Pure quartzite, with conglomerate.
SILURIAN, 1,000 feet	Ute limestone		1,000	Compact, or shaly, siliceous limestone.
CAMBRIAN, 12,000 feet	Cambrian		12,000	Siliceous schists and slates, quartzites.

In the Wasatch section the 12,000 feet of metamorphosed schists, slates, and quartzites probably occur below the Cambrian beds as exposed at Eureka, except so far as they may be represented in the upper members by the Prospect Mountain quartzite, while the great thickness of Cambrian limestones and shales of the Eureka section is included within the 1,000 feet of Ute limestone in the former section. Again, at Eureka the Permian at the top of the section is wholly wanting and the Upper Coal-measures, which in other parts of Nevada attain a development of nearly 2,000 feet, the thickness which has generally been assigned to them in the Wasatch, are limited to 500 feet. It will be seen, therefore, that the upper and lower portions of the section as exposed in the Wasatch, on the edge of the Great Basin, are wanting in the Eureka section. Taking out the 12,000 feet of Cambrian at the base and 2,000 feet of Permian and Upper Coal-measures from the summit of the Wasatch sections, there remains 16,000 feet of strata, which, from the base of the Prospect Mountain limestone to the top of the series, are represented in the Eureka section by the enormous development of 28,500 feet of sediments.

Mr. C. D. Walcott[1] constructed a section across the entire series of Paleozoic rocks as exposed in the Kanab Valley of the Lower Colorado in the plateau province. This section presents 5,000 feet of beds from the Cambrian to the Permian inclusive, and is republished here as it offers so much that is of interest in a study of the Paleozoic rocks of the Cordillera.

Kanab section, Arizona: 5,000 feet.

PERMIAN, 855 feet	Upper Permain	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	Massive 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 base.

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

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[1] Am. Jour. Sci., Sept., 1880.

Paleozoic Rocks in British America.—In this connection attention should be called to the remarkable sections across the Paleozoic rocks of British America exposed along the line of the Canadian Pacific Railway where it crosses the grandest parts of the mountains. A description of the geological structure of the country, accompanied by maps and diagrams, will be found in a paper of Mr. R. G. McConnell, published in the reports of the Geological Survey of Canada.[1] The region described embraces a belt of country about 70 miles in width, and for the most part lies just north of the fiftieth parallel of north latitude. Within this belt several transverse sections have been run across the Bow River Valley so as to include the mountains on both the east and west sides. Sections constructed across Mt. Stephen, Cathedral Mountain, and the Castle Mountain range present an instructive sequence of strata for the Cambrian rocks, while those in the vicinity of Cascade Mountain and along the Devil's Lake Valley offer equally good exposures for the Silurian, Devonian, and Carboniferous. The upper members of the Cambrian are exposed in both series of strata, serving to connect the lower with the upper Paleozoic rocks. From the standpoint of this work the chief value of the Canadian section consists in its close agreement in many of its details with the sequence of strata found at Eureka. According to Mr. McConnell[2] the thickness of the Paleozoic rocks in the region explored by him measures 29,000 feet. This, it will be seen, is not far out from the thickness given for the corresponding rocks at Eureka, where the best estimates place the thickness at 30,000 feet. The fossiliferous Cambrian limestone, together with the underlying quartzite, may be correlated with the Prospect Mountain quartzite and limestone. Beds carrying the *Olenellus* fauna have been identified in the Canadian rocks, although there they occur far below the limestone, the underlying quartzite having a much greater thickness than is exposed at Eureka. It is difficult to determine how great a thickness should be assigned to the Pogonip, although it is evidently well represented. Limestones carrying *Halysites* are in many ways similar to the Lone Mountain beds, and have a

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[1] Report on the Geological Features of a portion of the Rocky Mountains. Accompanied by a section measured near the fifty-first parallel. Geological Survey of Canada. Annual Report. New series, vol. 2, 1886, pp. 24-30.

[2] Op. cit., p. 15.

thickness of 1,300 feet as against 1,800 feet assigned to them in Nevada. In the Canadian section the Devonian exposes only 1,500 feet of strata as against 5,000 feet of Nevada limestone, but on the other hand the Carboniferous limestone immediately overlying the Devonian exhibits a much greater development than the corresponding horizon at Eureka.

The sequence of strata in the Canadian localities shows a closer agreement with the conditions of sedimentation at Eureka than do many exposures of Paleozoic rocks situated but a comparatively short distance eastward of the latter area. In some respects the Canadian section more closely resembles the Wasatch than it does the Eureka, as is shown in the great thickness of Cambrian rocks below the *Olenellus* horizon. On the other hand, there is no such development of Silurian and Devonian rocks in the Wasatch as is shown both at Eureka and in Canada. Changes in sedimentation appear much more sudden and varied in passing eastward from Eureka than when followed northward. In structural and orographic features the two regions present much in common, great lateral compression, with anticlinal and synclinal folds, accompanied by north and south lines of profound displacement.

STRUCTURAL FEATURES.

For a clear understanding of the relation of the different orographic blocks to each other and to the numerous outbursts of igneous rocks, a number of cross sections have been constructed across the central part of the Eureka District. In one very marked way these transverse sections across the mountains are of more than ordinary interest, as they bring out the geological structure connecting a number of distinct and, at the same time, interdependent mountain masses, whereas in most instances in the Great Basin sections are drawn across single uplifted ridges, isolated by broad valleys whose recent deposits conceal everything beneath them. As these valleys are frequently from 5 to 10 miles in width without rock exposures, it is largely a matter of conjecture to say what the geological structure is which underlies them. The most impressive orographic feature at Eureka is the close relationship between the anticlinal and synclinal folds to the north and south faults. It is these great meridional faults, at points attaining a displacement of 13,000 feet, that have determined the orographic blocks. A study of the structural details as presented in this work shows that the folding and flexing of the beds are largely due to lateral compression. The grandest effects of this lateral compression are seen along the central portions of the mountains between the Spring Valley and Rescue faults. It is here that the greatest energy has been displayed. Within these lines lie the abrupt anticlinal fold of Prospect Ridge, the sharp synclinal fold of Spring Hill between the Hoosac and the Pinto, and the broad syncline in the Nevada limestone between the Pinto and the Rescue faults. Westward of Spring Valley the structure stands out in marked contrast with the mountain blocks included between these great faults. Receding from the fault, the plication of strata becomes more and more gentle to the west without any violent orographic disturbance, the limestones falling away in broad sweeping rolls with relatively low angles of dip. East of the Rescue fault a powerful compression of strata is shown by anticlinal and synclinal folds in the region of Diamond Peak.

Faulted anticlines.—The structure which, in the opinion of the writer, is most common in the Great Basin ranges, that of a faulted anticline with a downthrow along the axial plane, is not brought out in the sheet of geological sections, but is nevertheless well represented in the district, both in the Fish Creek Mountains and at Newark Mountain. In both these uplifts the displacement is accompanied by an escarpment along the fault which is coincident with the axial plane. In the Fish Creek Mountains we have a broad, gently inclined, westerly dipping limestone body, with the axis of the anticlinal near the eastern edge of the uplift, the downthrow measuring about 600 feet. On Newark Mountain, which is a sharp single ridge, the downthrow also occurs along the eastern crest of the uplift, the escarpment measuring, approximately, 1,000 feet. In both instances the easterly dipping beds extend down the mountain slope until lost beneath valley accumulations. On the west side of Newark Mountain the flexible White Pine shale affords an excellent example of plication without fracture. Details in regard to the structural features of both the Fish Creek Mountains and Newark Mountain will be found in the chapter devoted to the descriptive geology of those areas.

On Prospect Peak we have a sharp anticlinal fold, with beds on both sides of the fault standing at an angle of 70°, but without any great amount of faulting.

In certain of the Great Basin ranges the axial plane occurs along the center of the ridge, as seen at Ravens Nest in the Piñon Range. In others it follows along the edge of the uplift, an escarpment usually facing the valley. Of this latter structure, Newark Mountain is an excellent example. In some of these ranges there may be no faulting of strata along the axis of the anticline; in others it may be confined to a few hundred feet, or the faulted block may have suffered a downthrow measured by thousands of feet. In the latter instance it is easily seen that the strata along the downthrow side may be lost to sight, being carried down below the present level of the Pleistocene deposits. Where this is the case only one side of the fold is exposed, leaving a simple monoclinal ridge. This is what has actually occurred in several of the narrow uplifts in the Great Basin.

GEOLOGICAL CROSS—SECTIONS.

These sections, atlas sheet XIII, will be readily comprehended when examined in connection with the geological map, and the detailed descriptions of each block of Paleozoic sediments as given in the text may be followed easily without much additional explanation. As the sections have been constructed, as far as possible, across the strike of the beds, and for the most part at right angles to the principal meridional lines of faulting, they measure with a considerable degree of accuracy the amount of displacement and indicate approximately the compression of strata. All sections are carefully drawn on a scale of 1,600 feet to the inch, with a base line taken at 6,000 feet above sea level, the height of the adjacent valleys on all sides. So far as practicable they have been selected to show the average thickness of all sedimentary rocks, from the base of the Cambrian to the summit of the Carboniferous. Of course all underground structure is based upon observed dips and strikes taken at the surface, but these have been obtained, so far as possible, at frequent intervals and with every precaution which could be exercised. In a country so broken by faults, dislocated by igneous outbursts, and where bedding planes are so frequently wanting, the construction of sections must necessarily, to a great extent, be based upon theoretical reasoning.

On the geological maps, lines of cross-sections are laid down by narrow black lines designated at the borders of the sheet by block letters.

SECTION A-B.—This section is drawn only halfway across the Eureka Mountains, and is confined to the northeast corner of the District, atlas sheet VIII. At the extreme western end of the map the section exhibits 200 or 300 feet of the Hamburg limestone just west of the Jackson fault, followed on the east side of the fault by the Pogonip limestone, which in turn is capped by Eureka quartzite shown on the summit of Caribou Hill. On the east slope of Caribou Hill the rhyolitic ashes and tuffs conceal the quartzite and stretching eastward across the valley rest against the steep wall of Richmond Mountain. These ashes and tuffs underlie the town of Eureka, although nowhere of any great thickness, and probably over much of this area overlie solid rhyolite not far below the surface. In the section the Eureka quartzite is represented as underlying the valley as far eastward as the Hoosac fault or the prolongation of the fault as recognized south of the Richmond Smelting Works. The representation of a narrow strip of Lower Coal-measure limestone is a theoretical deduction based upon strong evidences observed at the latter locality. The basic andesites of Richmond Mountain stretch eastward for 15,000 feet, followed by 7,000 feet of basalts, completely cutting off all evidences of any continuation of either the Spring Mountain or County Peak blocks. The depression of Hunter's Creek and the gentle inclination of the basalt table toward it are well brought out in cross-section. Nowhere are two epochs of Carboniferous limestone with the intervening Weber conglomerate better shown than along the line of the section. Rising above the basalt the Upper Coal-measures exhibit 500 feet of beds dipping 45° to the west, resting upon Weber conglomerate. The conglomerate is inclined at the same angle, but soon develops into an anticline standing at 50° east, followed by a syncline varying from 50° east to 30° west. It is an admirable example of the effects of lateral compression. The thickness obtained for the complete series of conglomerates measures 2,000 feet. Underlying the conglomerates come the Lower Coal-measures, the section crossing Alpha Ridge just south of Fusilina Peak and showing a uniform dip to the west at an angle of 25° or 30° with the horizon. With the observed dips and strikes they measure 3,700 feet. As described in the chapter devoted to the descriptive geology of the Diamond Range the Lower Coal-measures rest unconformably upon the White Pine shales, the dip of the beds in the latter epoch reaching an angle of 50° along the Newark fault. These latter shales are shown to lie conformably on the Nevada limestone along the line of Hayes Canyon. The anticlinal structure of Newark Mountain is not brought out in section, as the axis of the fold only comes in near where the border of the map cuts off the easterly dipping strata. The latter stretch far out into Newark Valley.

Section CD-EF.—This section is constructed across the central portion of the Eureka Mountains (atlas sheets VII and VIII), and stretches in an east and west line from Antelope to Newark valleys. It presents more of the salient structural features of the region than is shown in either of the other sections, as it passes through the broadest part of the Mahogany Hills, the flat-topped summit of Spanish Mountain, the steep anticline of Prospect Peak, the syncline of Spring Hill, and the easterly dipping strata of County Peak, and crosses the Spring Valley, Hoosac, and Pinto faults. The section starts in at the western end of the Mahogany Hills and runs obliquely across the strike of the beds, which lie nearly horizontal or inclined at very low angles. In order to bring out the structural features of the country, the Lone Mountain beds are represented as underlying the Nevada Devonian above the base line of the section. At Dry Valley there is a considerable but unknown thickness of valley accumulations with the Nevada limestones on the west side and the Lone Mountain beds resting against the flanks of Spanish Mountain on the east. These Lone Mountain beds lie against the Eureka quartzites which come to the surface on the slopes of Spanish Mountain long before reaching the summit. The mountain presents in general a broad anticlinal fold, although broken by numerous cross-faults and dislocations. One of these dislocations is represented in the transverse section, giving a small exposure of Lone Mountain beds overlying the quartzite. On the east slope of Spanish Mountain, where the beds dip away steeply to the east, there is a small exposure of highly siliceous limestones without bedding partially concealed by Quaternary accumulations. These, from their position resting directly upon the quartzites, have been referred to the Lone Mountain beds. The Spring Valley fault brings these Silurian beds up against the Cambrian of Prospect Ridge. The section intersects Prospect Ridge just to the north of the summit of Prospect Peak and brings out the anticlinal structure in the quartzite on the west slope overlain on both sides of the fold by the Prospect Mountain limestone which on the west side comes down to the line of the Spring Valley fault. Prospect Mountain limestone here forms the summit of the main ridge. This is in turn overlain by Secret Canyon shale, Hamburg limestone, and Hamburg shale, the remaining subdivisions of the Cambrian, all of which stand inclined at about 70° to the east. As the section is drawn across quite a high saddle at the head of New York Canyon, connecting Prospect Peak with Hamburg Ridge, the erosion of the Secret Canyon shale, which is so marked a feature of the region, is not so well shown as it would be if the section were drawn either to the north or south of this point, but it is sufficient to bring out the prominence of the Hamburg Ridge, which is everywhere parallel to the main ridge. Overlying the Hamburg shale occurs the Pogonip limestone and the Eureka quartzite, the latter occupying the slope down to the Hoosac fault.

At the base of the long uniform slope of Pogonip limestone, which is well shown in the surface outline, the line of the section has been moved northward 700 feet, in order to illustrate to better advantage several structural features. By thus moving this line the Eureka quartzite is shown on both sides of the hornblende-andesite body, which in breaking out along the Hoosac fault has shattered the quartzite all along the fault. Immediately along the line of the section only a small outcrop of the quartzite occurs to the east of the andesite, but by reference to the geological map it will be readily seen that the exposure forms a part of a continuous body of considerable extent. East of the fault the Carboniferous limestones come up dipping easterly, but separated from the main body by a minor fault, which, so far as can be determined, is accompanied by only a slight displacement. This is followed by a synclinal fold, described elsewhere, lying between Spring Hill and the Pinto fault. Continuing along the line of the section east of the Pinto fault the Lone Mountain limestones rise as a precipitous wall, abutting against Carboniferous limestones, followed by a great development of Nevada Devonian. The former are estimated at 1,700 feet and the latter at 4,500 feet across the lower and middle members of the Nevada series. At Basalt Peak igneous intrusions spread out eastward for 9,400 feet, concealing the sedimentary beds and completely obscuring the structural features produced by the Rescue fault. Beneath these basalts the section is constructed wholly upon observed data, both to the south and east, and will be understood by reference to the map. From here to the end of the atlas sheet basalt flows or Quaternary accumulations cover everything with the exception of two outcrops—one, easterly-dipping beds of Weber conglomerate, almost wholly encircled by igneous rocks, and the other, a low, gentle swell of Carboniferous limestones, rising out of the valley deposits not much above the base level of the sections.

Section GH-IK.—This section (atlas sheets IX and X) is drawn across the southern end of the mountains in a continuous line from west to east, passing through Grays Peak, Gray Fox Peak, Carbon Ridge, and Century Peak, and crossing at right angles the Hoosac, Pinto, and Rescue faults. It crosses the mountains about 4½ miles south of section CD-EF, and for the most part runs along the extreme southern end of the different mountain blocks, touching, however, the Fish Creek Mountains at their northern end, but passing far to the south of the Diamond Range. The section passes along the base of the Mahogany Hills, following the Lone Mountain limestones approximately parallel with their strike, the beds dipping northward into the hills beneath the Nevada Devonian. Across Spring Valley, for a width of 6,000 feet, all Paleozoic strata are concealed beneath the Quaternary, but with the rising of the hills on the east side the Pogonip limestones come in capped on the summit of the ridge by the Eureka quartzites. Here the broad anticlinal structure of the Fish Creek Mountains is clearly brought out, but without the fault recognized on the east side of the higher portion of the mountains. East of Castle Mountain there occurs a shallow basin or depression in quartzite occupied by Lone Mountain and Devonian beds, beyond which there is a second anticline, with the Eureka beds arching over the summit. At Lamoureux Canyon occurs a slight displacement, the walls on both sides where the section crosses exposing the quartzite in abrupt escarpments. Between Lamoureux Canyon fault and Pinnacle Peak fault the mountain mass presents another broad anticlinal mass, of which Grays Peak forms the summit. The beds on the peak lie nearly horizontal, falling away on both sides at relatively high angles. Toward Pinnacle Peak the Nevada limestones come in, resting unconformably against the uplifted block between Pinnacle Peak and Lookout Mountain faults. Between these two latter faults, measuring on the surface but scarcely more than 2,000 feet, the only beds exposed are the Eureka quartzites, dipping eastward and capping Pinnacle Peak. East of the Lookout Mountain fault there is a block of Pogonip limestone, beyond which comes the Prospect Mountain Ridge uplift. The only Cambrian rocks found on the surface are the Prospect Mountain limestones, the overlying horizons, together with the Pogonip limestone and Eureka quartzite of the Silurian, being either buried beneath flows of rhyolite or Quaternary accumulations. About a quarter of a mile to the north of the line of this section the entire Cambrian series is exposed, and the beds are introduced here very much as they are found beyond the line of the rhyolites and pumices. Between the Hoosac and Pinto faults the section again crosses the Carboniferous block, which here includes nearly all of the Weber conglomerate, as well as the Lower Coal-measure limestones, both members lying at angles inclined from 60° to 70° to the east. Along the Pinto fault the line of contact is obscured by tuffs and pumices. Along the southern extremity of the Silverado Mountains no structural evidences were obtained, as the underlying rocks are for the most part concealed by tuffs and pumaceous material, but in the section the lavas are represented as overlying Lone Mountain beds, as the latter are found higher up in the foothills above the line of igneous rocks. At the entrance of Rescue Canyon the rhyolites, which break through the Nevada limestone along the line of the Rescue fault, are represented with a width of nearly 3,000 feet. The section crosses the summit of Century Peak and brings out clearly the anticlinal structure of the limestone ridge on the east side of Rescue Canyon. On the east side of the peak the beds gradually fall away toward Newark Valley and are lost beneath the Quaternary deposits.

On Pl. II of this volume will be found a geological section drawn across the summit of Prospect Peak, exhibiting the relations of the great body of Cambrian limestone to the crest of the ridge, the limestone here rising to the top of the peak. The position of Prospect Ridge to the Hamburg Ridge is also more clearly shown than in the general section. The same series of rocks at the northern end of the ridge across Ruby Hill and Adams Hill are also shown on this plate. On the same plate a section is given across Pinto Peak, and about 1½ miles to the northward of the latter section is another east and west section, drawn from the Pinto to the Hoosac fault.

CHAPTER VII.

PRE-TERTIARY IGNEOUS ROCKS.

Igneous rocks have played a most important part in the development of the geological history of the Eureka District. They may be separated into two distinct groups: first, those which reached their present position in pre-Tertiary times; second, a younger and much more extended series of eruptions, those of Tertiary and post-Tertiary age. Not only do they belong to distinct geological periods, but their mode of occurrence is quite unlike and their petrographical characters in every way different.

Granite, granite-porphyry, and quartz-porphyry are the types of the pre-Tertiary rocks. Their surface exposures are very restricted, being quite insignificant as compared with the more recent volcanic lavas, and only to a very limited degree have their extrusions influenced the present physical features of the country.

Granite.—Between the Sierra and the Wasatch there are probably few of the many longitudinal ranges which rib the Great Basin, other than those made up entirely of volcanic lavas, that do not show one or more bodies of granite or crystalline schists of greater or less extent. Along the lines of upheaval of one or two of these ranges, the accumulations of recent lavas have been on so vast a scale that all direct evidences of an older preexisting range are to-day wholly wanting. In some instances granite and gneisses cover large tracts of country and occasionally culminate in peaks rising high above the surrounding regions, but so abrupt are the changes in the Archean topography that they occur for the most part only as subordinate exposures over limited areas. The granite is found cropping out along the base of the foot-hills beneath the Paleozoic sediments, occasionally occupying low passes through breaks in the ranges, or, as is frequently the case, they are associated with extrusions of volcanic lavas and accidentally left bare or else uncovered by recent erosion. Westward of the Salt Lake Basin, granite is found in isolated patches in such uplifts as the Ombe, Gosiute, and Peoquop ranges. The East Humboldt Mountains present the grandest mass of the older crystalline rocks, stretching with the trend of the range over sixty miles in a nearly north and south direction, and is the most extensive area of pre-Cambrian rocks to be found in central Utah and Nevada along the country examined by the Fortieth Parallel Exploration. Immediately westward of this latter range in the country occupied by the Diamond and Piñon ranges, no exposures of granites occur, and it is one of the largest areas known in the Great Basin, in which all evidences of granite and of an Archean body are wanting. There are good reasons for believing that in early Paleozoic time this area east of the Humboldt Mountains was a deep trough of the sea, in which Cambrian, Silurian and Devonian sediments were deposited. At all events, the mountain ranges within this region offer excellent sections of the lower Paleozoic strata, which over large areas of the Great Basin are unknown.

At Eureka, where the Diamond and Piñon ranges unite in a broad elevated mass of sedimentary beds of great thickness, singularly broken up by great faults into bold mountain ridges, only one obscure outcrop of granite is known. It is, however, not without considerable interest, and when the geological position of these granites and allied rocks of the Great Basin come to be studied in detail in their relation to the Archean masses and the uplifts of the parallel ranges, it may be found to throw much light upon some complex structural problems. Here at Eureka the outcrop does not occur rising above the Quaternary plain along the base of a ridge, nor in the bottom of some deeply eroded canyon. On the contrary it is found 1,000 feet above the level of Diamond Valley, at the extreme northern end of Prospect Ridge, on the steep south slope of the ravine which separates Ruby Hill from the main ridge. It is so insignificant and so covered with débris derived from the limestone hills above that it might easily escape attention, especially as it presents no inequalities of surface. This granite is best seen on coming up the ravine from the west, and is exposed just above the path, some miners having cut into it, attracted by the red color of the decomposed rock. It extends from the footpath up the steep slope for 300 feet to within 50 feet of the top of the hill.

Although upon the surface this granite body is limited in extent, there is reason to suppose that it represents a much larger mass and has exerted a considerable influence on the geological structure of the ridge. Prospect Mountain quartzite, the oldest sedimentary beds in the District, surrounds the granite upon the northwest and northeast slopes and dips away from it in irregular broken masses. To the south the Prospect Mountain limestones, which form the main ridge, occur resting directly upon the granite. That this exposure of granite along the steep slopes of the ravine is due to the erosion of the crushed quartzite can not well be questioned, and the ravine itself probably owes its existence to the fracturing of the quartzite from some upward orographic movement of the granite. The farther away the quartzite lies from the granitic center, the less disturbance is seen in the beds.

The age of the granite is unknown. Quite possibly it formed a portion of an Archean body around which the sands were deposited, subsequent orographic movements disturbing and breaking up the sedimentary beds. If the granite is later than the sedimentary beds it only broke through the quartzite at the northern end of the range and failed to cut the limestone. No intrusive dikes of granite are known penetrating the overlying beds. At the time of the sinking of the Richmond shaft the workmen found, at a depth of 1,200 feet from the surface, near the bottom of the shaft, fragments of a decomposed crystalline rock. They were so highly altered that the microscope failed to detect with certainty the nature of the rock, though it carried quartz and mica and kaolinized feldspar. This evidence, though slight, would indicate an off-shore deposit for the quartzites.

A peculiarity of this granite is the varied texture it offers over so small an area, presenting, however, a true granitic habit. The essential minerals are quartz, orthoclase, plagioclase, hornblende, and mica, the latter being very abundant. The quartz is grayish white in color, in irregular, pellucid grains. Hornblende is apparently more abundant in the fine than in the coarse grained varieties.

Quartz-porphyry.—Only two small exposures of quartz-porphyry have been observed, both occurring on Mineral Point, north of Adams Hill, and, although separated by limestone, it seems probable that below the surface the two bodies have a common origin, inasmuch as on top they present nearly identical features. Neither body rises above the general level of the country, erosion wearing away equally both limestone and dike.

The larger outburst is an irregular body with an east and west trend; the other, a few hundred yards northward, and a short distance beyond the Bullwhacker mine, occurs as a dike from 300 to 400 feet long, with a direction N. 20° W. Both quartz-porphyry exposures are much decomposed and discolored by oxide of iron. Under the microscope they show, however, orthoclase, quartz and mica, with characteristic isotropic glass. The feldspars are altered into kaolin, with a secondary formation of potash mica; the quartz grains carry both liquid and glass inclusions. In the Bullwhacker mine the porphyry is seen as a dike, striking north 18° W., with a dip 35° to the east. In one place, at least, on the main level it occurs as a white rock, differing from the surface exposure not only in color, but by a relatively large amount of quartz grains and by a development of numerous modified cubes of pyrites. The pyrites in the dike, in distinction from that carried by the surface body, is perfectly fresh and may account to some extent for difference in color. It is probable that the pyrites is a secondary product, formed after the cooling of the original magma. Careful assays show that the pyrites carries both gold and silver. The quartz-porphyry differs structurally from all other igneous rocks in the region, being distinct from granite on the one hand and from rhyolite on the other. None of the rhyolites at all resemble it. It is possible that it occurs as an offshoot from a large body of granite, the structural features being due to conditions of cooling. No direct evidence of the age of the quartz-porphyry is afforded other than that it penetrates the Pogonip limestone of the Silurian.

Granite-porphyry.—The important granite-porphyry bodies are confined to the country lying between the Fish Creek Mountains and the Mahogany Hills. They occur in two large masses separated by a narrow belt of limestone with a few smaller outlying exposures, probably offshoots from the parent mass. The principal exposure of this porphyry lies immediately to the west of Wood Cone along the southern base of the Mahogany Hills, and with an undulating surface gradually falls away to the broad valley beyond the limits of the map. Its extension westward is lost beneath the Quaternary. It presents an oval-shaped mass one mile and a quarter long by three-quarters of a mile wide, partially hemmed in on both the north and south sides by ridges of Silurian limestones which rest against it. For the most part it is a coarse grained rock disintegrating readily under atmospheric agencies. Much of it might easily pass for granite, but other portions possess a decidedly porphyritic structure, especially along the line of contact with the Pogonip limestone on the south. Geologically, a more important body is the bold prominent dike trending approximately north and south for over 2 miles, with a varying width, measuring across its broadest expansion nearly 1,000 feet. At the surface no direct connection can be traced between the main granitic area and the dike, the continuity being broken by an arch or saddle of Pogonip limestone which passes beneath the Eureka quartzite of Wood Cone. This limestone saddle is scarcely more than 300 hundred feet in width. There can be no reasonable doubt that the granite-porphyry dike is an offshoot from the main body in much the same way as the branch dikes described farther on are related to the larger one. A strong proof of this connection is seen in an isolated exposure of the crystalline rock worn bare by erosion on the summit of the limestone saddle.

The southern end of the main dike contracts to one hundred feet or less in width and splits up into numerous small dikes ramifying in various directions, becoming finally lost in the limestone. Between the surface outlines of the two walls of the dike there exists a marked contrast. On the one side the western wall curves slightly and regularly in sharply defined lines. On the other the eastern side presents a most irregular outline, caused by numerous branch dikes, offshoots from the main dike, trending in nearly parallel courses in a northeastern direction. They break the regularity of outline, besides fracturing and displacing the limestone beds. Fig. 5 shows the position of the secondary dikes to the primary one and is a reproduction on a reduced scale of a portion of the map. The conventional signs indicate approximately the strike and dip of the adjoining limestone.

Of these branch dikes from the parent stock the longest has been traced on the surface for nearly 2 miles, gradually narrowing to a few feet and breaking up into stringers and veins of granite-porphyry at the northeast end in the same manner as the main dike. Other members of this system of parallel dikes may be equally as persistent in their trend, without appearing on the surface, erosion having failed to lay them bare. They vary from 25 to 250 feet in width, but all present much the same physical conditions as regards their occurrence and relation to the limestone. On the same general course two narrow dikes penetrate the limestone just west of Castle Mountain, and it is quite possible that they belong to the same system as the others if not actually connected with them beneath the surface. The absence of offshoots on the west side of the main dike and their frequency and persistency on the east are not without geological interest. By reference to atlas sheet XI the position of the dikes to the main granite-porphyry body and the Fish Creek Mountains and Mahogany Hills may be readily seen.

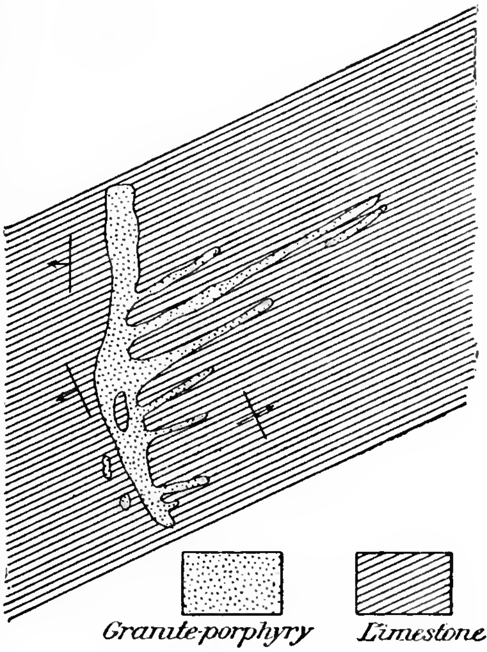

FIG. 5.—Granite-porphyry dike.

Limestone adjoining Porphyry.—The main granite-porphyry dike, like the quartz-porphyry, breaks through the Pogonip, and the smaller dikes on Castle Mountain break through the Lone Mountain, but all other evidence as to their age is wanting. Their mode of occurrence and their relations to the orographic blocks are quite unlike the extrusions of the Tertiary lavas. Although both sides of the main dike lie in limestone of the Pogonip epoch, the beds have undergone considerable displacement; those on the east side belonging to a higher horizon than those found in contact with the dike at the north end on the west side. Immediately adjoining the dike at the north end the limestone stands at angles between 70° and 90°, and farther south only 35° to 45°, but for the greater part of the distance along the contact crumpling and metamorphism have so altered it as to have obliterated all signs of stratification. Owing to the frequency of the secondary dikes this metamorphism of strata is much more noticeable on the east than on the west side. Instances may be seen where the limestone is completely altered into a fine crystalline white marble. Nowhere, however, does the alteration of strata produced by heat penetrate the limestone for any great distance from the dikes, not even between those which run parallel to each other only a few hundred yards apart. The effects of heat are shown far more on the cooling and crystallization of the intrusive molten mass than on the cold contact rocks. As the beds recede from the main dike the dip becomes less and less steep, the stratification less obscure, and toward the southern end of the dike the limestones lie nearly horizontal.

The main porphyry dike in cutting the limestone follows closely the strike of the beds, whereas the branch dikes trending approximately at right angles to the main one run across the strata. The position of the main dike is determined in part by a line of faulting and in part by an anticlinal fold. South of Wood Cone, where the dike first makes its appearance, it trends off to the southwest along the fault line, maintaining this course until near the summit of the limestone hill which lies midway between the two wagon roads that cross the dike. Here meeting the anticline, it curves slightly and follows the axis of the fold to the southeast. This anticline may be traced southward beyond the surface outcrop of the granite-porphyry, as is indicated by the dips and strikes on the map. Along the northern end of the dike the amount of displacement can not be determined beyond the fact already stated, that both sides of the fault lie in the Pogonip. Why the secondary dikes should break out approximately at right angles to the main one and not parallel with it, it is difficult to say. It would seem as if lines of least resistance would have been formed parallel with the line of the axial fold and the line of displacement along which the main dike reached the surface. On the east side the beds are a pure crystalline limestone, uniform in texture and bluish gray in color. The lower beds on the west side are darker in color, more siliceous in composition, and rich in black cherty nodules, characteristics which everywhere define the upper from the lower beds of the Pogonip limestone.

That the strata near the southwest end of the dike belong to the upper portion of the Pogonip epoch is evidenced by the patches of Eureka quartzite still in place and by a number of loose bowlders and quartzite débris scattered over the hill slopes.

In the middle of the main dike, just north of the road which follows the Spring Valley drainage channel, there occurs a curious bit of cherty limestone. It is several hundred yards in length, but only a few feet in width, and lies completely surrounded by granite-porphyry, which may be seen penetrating and filling up the irregular outline in the limestone. In places the molten mass appears to have eaten into the sedimentary body, although only to a very limited extent. Along the contact both the porphyry and limestone present the same phenomena of cooling as seen near the outer walls of the main dike. Even this narrow body of limestone does not appear to have undergone much metamorphism, except along the contact.

Structural Variatinos in Granite-porphyry.—The chief interest attached to the granite-porphyry lies in the very variable structural differences produced in the erupted material of the dike, differences which are mainly dependent upon the chilling effect of cold contact walls upon a rapidly cooling molten mass. The width of the dikes has much to do in determining these physical conditions governing crystallization. In other words, development of crystallization is dependent upon rate of cooling, and in narrow dikes a molten magma is more rapidly chilled than in broader bodies. There are probably few localities in the Great Basin where the results of rapid chilling and crystallization of a granite magma in narrow dikes along several miles of contact walls can be studied to better advantage or are more worthy of a detailed petrographical investigation. For petrographical details the reader is referred to the paper by Mr. Joseph P. Iddings.

The large oval-shaped area to the north and the broader central portions of the main dike are quite similar rocks, presenting the characteristics of a coarse grained granite composed of pellucid quartz, dark brown biotite, and orthoclase in Carlsbad twins, with varying proportions of plagioclase and strongly pleochroic hornblende. It everywhere weathers in rounded masses with rough surfaces, disintegrating like many varieties of granite. It is, however, only a limited portion of the dike which possesses anything like a granitic structure, the greater part of the main dike and all the secondary branches having a decidedly porphyritic structure. All through the central part of the dike the rock is formed of large ill-defined crystals, porphyritically imbedded in a groundmass of the same composition, which under the microscope is seen to possess a micro-granitic structure. This porphyritic structure can be traced for miles along all the dikes parallel with their course. From the normal type in the central portion of the dike toward the outer limestone wall there is a gradual and at first an almost imperceptible transition to the finer grained rock, with more and more of the porphyritic and less of the granitic structure. Across these transitional rocks the mineral components remain the same, the differences consisting in the size of the grains and their relative proportions and structural relations.

All thin sections show the rock to be entirely crystalline without isotropic glass. At a distance of from 20 to 30 feet from the limestone, varying with the width and position of the dike, the rock shows a marked porphyritic habit, though the larger crystals are still in excess. In the narrower dikes the transitions are not so well shown as the coarser portions and are less characteristically developed and the changes far less gradual. In the latter the quartz is very abundant and frequently occurs in well developed dihexahedrons, in strong contrast to the quartz, with irregular outlines, as seen in the granitic structure. From here to the limestone contact the change is more rapid, the larger crystals becoming less and less abundant, being replaced by more and more micro-crystalline goundmass.

Nearly everywhere along the immediate line of contact the rock presents the habit of a quartz-porphyry made up of a crystalline groundmass, with well developed crystals of quartz and orthoclase, and still accompanied by some plagioclase. Both mica and hornblende usually fall off in amount toward the edge of the dike, in the more porphyritic rocks, the hornblende being present only in the granitic types, and the first to disappear with structural changes. With this change in structure the rock becomes more compact and weathers in angular blocks with smooth surfaces, the contact products offering the greatest possible contrast with the central portion of the dike, which weathers in rounded masses with rough surfaces, disintegrating easily under atmospheric influences. Yet in the wider dikes these changes can be traced so readily, step by step, from the one rock into the other, that the evidence is clear that they are but different structural developments of the same erupted material, but not necessarily identical in chemical composition at the time crystallization took place. In crossing the dikes one passes within 100 yards, over excellent quartz-porphyry, on to normal granite-porphyry, and then on to a rock which can not be told from many varieties of granite; so that one is forced to believe that the only differences between granite and granite-porphyry is in many cases purely one of structure, dependent upon conditions in cooling rather than upon any differences in age or chemical constitution of the original magma.

A study of the dikes makes it evident that there could not have been any forcing of lava into the middle of a dike already partially occupied by an earlier crystalline rock. As the branch dikes are mostly narrow, the granitic and normal granite-porphyry structures are less fully developed and are frequently wanting, the effects of chilling and rapid cooling from both walls toward the interior producing only the types of quartz-porphyry developed along the walls of the broader dike. Another striking feature of the rapid cooling of the magma is seen in the marked tendency of the crystalline rock to develop a jointed structure near the lines of contact, in planes parallel to the walls.

In places the porphyry contacts present a fissile, sherdy structure, lines of parting becoming wider and wider apart toward the center of the dikes and gradually disappearing. In the jointed portion the rock is always fine grained, and frequently possesses an aphanitic structure, the mineral components, however, remaining the same. The rock frequently undergoes marked changes in color in passing from the coarse grained granitic structure to the contact rock. In these changes it will frequently pass from light gray into dark gray, blue, and along the contact becoming almost black.

Chemical Composition of Granite-porphyry.—The original magma injected into the limestone through the various openings was, so far as can be told, much the same in its ultimate composition. It is probable that the variation in chemical composition between rocks of different dikes is no greater than that between different parts of the same dike. While structural peculiarities across the dike are strongly marked, the mineral constituents remain much the same, although the walls are more acid than the center and carry less ferro-magnesian minerals. As regards tenure of silica the variation between one rock and another would not exceed 5 per cent, with corresponding variations in their essential ingredients. It is probable that the silica variations in the bulk of the granite-porphyry would fall within 4 per cent.

The following two analyses of granite-porphyry were made by Mr. Andrew A. Blair:

	No. 1.	No. 2.
	Per cent.	*Per cent.*
Silica	68·68	72·01
Alumina	16·28	15·51
Ferric oxide	·66	....
Ferrous oxide	2·55	1·36
Lime	2·24	1·35
Magnesia	·81	·51
Soda	2·88	2·36
Potash	4·07	4·71
Titanic acid	·05	Not det.
Carbonic acid	·17	·33
Water	·68	1·24
Total	99·07	99·38

Analysis No. 1 may be taken as representing the composition of a large area of the rock west of Wood Cone possessing a granitic structure, the essential minerals having no crystallographic outline. The quartz and feldspar are of medium size and are accompanied by nearly all the accessory minerals recognized in these rocks, including biotite, zircon, titanite, and allanite.

Analysis No. 2 is made from granite-porphyry obtained from the middle of a dike about 30 feet in width. It is probably slightly more acidic than the mass of the rock. The groundmass of the rock is made up of an aggregation of quartz and feldspar, the former crystallized in regular dihexahedrons. Biotite is present, but no hornblende, and in the hand specimens there is only a slight development of ferro-magnesian silicates. Both rocks analyzed carried a trace of chlorine. It will be seen that the rock from the central mass carries a higher percentage of all bases, except potash, than the narrow dike. The latter probably represents fairly well the contact rocks of the larger dikes.

It is possible that in a careful study of these rocks with reference to the development of crystallization it might be shown that the ferro-magnesian minerals exhibited a tendency to segregate in the central or less rapidly crystallizing portion of the dike, due to differentiation in the chemical composition of the molten lava. It may be well to mention here that in connection with these miles of porphyry dikes there are no evidences of any recent volcanic action. The granite-porphyries and the rhyolites seem to be wholly independent of each other as regards their mode of occurrence and their loci of eruption.

CHAPTER VIII.

TERTIARY AND POST-TERTIARY VOLCANIC ROCKS.

Eureka a Volcanic Center.—In the Eureka District the recent volcanic eruptions play a far more important part than the granites and porphyries just described. They occur in much larger masses, cover more extensive areas, and are more widely distributed over the district. While the older crystalline rocks have exerted little influence upon the surface features of the country, the volcanic rocks have greatly modified its topographical outlines, have built up isolated mountains, broad table-lands, and numerous small hills, and in coming to the surface have disturbed and broken up sedimentary formations, greatly complicating geological structure. Moreover, the volcanic rocks are of special interest from an economic point of view, owing to their intimate geological connection with the argentiferous lead deposits occurring in the adjoining Paleozoic rocks. As the Eureka Mountains are surrounded on nearly all sides by the characteristic broad valleys of the Nevada plateau, this volcanic region occupies a somewhat isolated position with reference to the neighboring ranges, constituting a region quite apart from all other centers of similar eruptions, yet at the same time bearing the closest resemblance in the nature of its extravasated material to many other localities in the Great Basin. Nowhere in the district have the accumulated lavas attained any great elevation above the surrounding mountains, but as regards mode of occurrence, peculiarities of distribution, and varieties of modification they offer a wide field for investigation. There is no such piling up of enormous masses of erupted material as in the Washoe District, and no such opportunity for an investigation of the more coarsely crystalline rocks, but, on the other hand, the relationship between the extrusive lavas and the uplifted blocks of Paleozoic strata is better shown than in any other carefully studied area in the Great Basin.

Distribution of Extrusive Lavas.—In regard to the distribution of volcanic rocks in the Eureka District it will be noticed by reference to the map that there are none in that part of the Diamond Range which comes within the area of the map. Although the southern end is completely cut off by recent lavas from the mountain block of County Peak, nowhere do they seem to penetrate into the range itself. In the southern end of the Piñon Range on the opposite side of Diamond Valley, there is the same absence of lavas, if we except a small outburst northwest of The Gate, which has but little to do with the main body of the Eureka Mountains. The Mahogany Hills west and north of Dry Lake furnish one or two small exposures of rhyolite along lines of faulting in limestone, notably at the head of Brown's Canyon, but they are of no special geological significance. In the Fish Creek Mountains no outbreaks of extrusive rocks are known and the same holds true of the mountains bordering the Spring Valley fault. In the extreme southeast corner of the map the Cliff Hills come in, formed of basic andesites similar to those of Richmond Mountain, but they lie wholly beyond the borders of the Eureka Mountains. This confines the area of the principal volcanic extravasations either to the region east of the summit of Prospect Ridge or to the country encircling the southern end of that ridge, where it sinks below Fish Creek Valley. Nearly every type and many of the varieties of volcanic rocks found upon the Nevada plateau have been erupted within these restricted limits of the Eureka District. Indeed, the region furnishes many rocks which may be taken as typical of a broad area of country lying between the Wasatch and the Sierra Nevada ranges.

Age of Eruptions.—It should be clearly understood that the Eureka District, like many other regions of central Nevada, offers no direct evidence as to the age of volcanic eruptions, as there occur no sedimentary formations between Upper Coal-measure limestones and recent Pleistocene deposits. While positive evidence may be wanting as to their precise age, there can be no doubt that the eruptions took place subsequent to the dynamic movements which brought about the flexing, folding, and mountain-building, and these, while it may not have been demonstrated, have been assigned upon excellent grounds to a post-Jurassic upheaval, already discussed in Chapter II. of this work. Moreover, that these orographic movements were followed by a long period of time before the outbursts of lavas is evident by the amount of erosion which took place before the extrusion of the latter rocks. This is shown by the position of the lavas in the bottoms of deeply eroded canyons, by the blocking up of old drainage channels and the cutting of new ones, all of which must have required considerable time to be accomplished by slow geological processes. On the other hand, based upon much the same kind of evidence, the amount of erosion since the volcanic period seems relatively slight. Although evidence of geological age of these lavas may be difficult to obtain over the greater part of the Great Basin, wherever such proof is observed it always points to the conclusion that the eruptions took place since the coming in of Tertiary time and for the most part during the Pliocene period. Nearly all geologists who have examined the volcanic areas of Nevada and Utah are in accord with the opinion that they belong to Tertiary time. In the region of the Montezuma and Kawsoh ranges, in western Nevada, the geologists of the Fortieth Parallel Exploration[1] have described the cutting by intrusive acid lavas of upturned Miocene strata carrying fresh-water molluscan shells and the overlying of the latter beds by basaltic flows. Evidence has also accumulated to show that several of the great rhyolite flows that preceded the basalt belong to the Pliocene epoch. From unquestioned evidence in other parts of the Great Basin as to the geological position of identical lavas, it is assumed that those of the Eureka District were also poured out during the Tertiary age. As regards the duration of volcanic activity there is scarcely any evidence. From the earliest outbursts, consisting of hornblende-andesites, to the latest eruptions of highly glassy basalts, volcanic activity may have extended over the greater part of late Tertiary time. That this activity continued at varying intervals throughout a long period seems clear from the amount of erosion, which, though relatively not excessive, must have required considerable time. There is no evidence to show that volcanic energy with varying intensity may not have extended through Pliocene well on into Quaternary time, although there is no reason to suppose that outbursts of basalt have taken place within what may be called historic periods.

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[1] U. S. Geol. Explor., 40th Par. Descriptive Geology, p. 771.

Classification of Lavas.—On the geological map all volcanic rocks have been classed under the following heads: Hornblende-andesite, dacite, rhyolite, pumice and tuff, augite-andesite,[1] and basalt. All the more important bodies of lava belong to some one of these sharply defined mineralogical groups. It must be borne in mind, however, that several of these types of igneous lavas pass by insensible gradations from one into another and it is not always easy to decide to which group an isolated exposure in the field or a hand specimen in the laboratory properly belongs. All division lines are more or less arbitrary. They are necessary for purposes of classification, although they may not exist in nature.

To inform those readers who have not kept up with recent advances in the classification of igneous rocks and at the same time to prevent all misunderstandings as to the use of terms, a brief description will be given of the physical characteristics of each group of lavas which have been recognized as occurring in the district. Those who desire a more detailed description of the special petrographical features of the rocks are referred to the report of Mr. J. P. Iddings, which accompanies this work. As he has presented the results of a most thorough microscopical investigation of the material collected in the field, in order to prevent a duplication of facts much that might properly find place in these pages is omitted, and only such data are employed here as are deemed necessary to make this chapter complete in itself and to bring out more clearly the important facts bearing upon the geology of the region.

Hornblende-andesite.—Under hornblende-andesites are classed those volcanic rocks which are composed mainly of triclinic feldspars and hornblendes as essential constituents. Here at Eureka the fresh unaltered

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[1] Since the printing of the atlas (1883) accompanying this Monograph, the pyroxenic minerals of the andesite of Richmond Mountain, which at that time were considered to be augites, have been shown to consist of both hypersthene and augite, the former mineral being in most instances largely in excess. The rock, therefore, should more properly be designated as pyroxene-andesite, a designation more in accord with the nomenclature now generally adopted by lithologists for similar rocks elsewhere.

Throughout this volume the term "pyroxene-andesite" will be used to designate the rocks of Richmond Mountain and Cliff Hills, the two localities colored as augite-andesite on the atlas sheets.

See Notes on the volcanic rocks of the Great Basin, Hague and Iddings: Am. Jour. Sci., June, 1884, p. 457.

rock is of a light reddish-purple color, for the most part holocrystalline in structure, with well developed secretions of the two principal minerals, accompanied by varying amounts of biotite. The black bordered hornblende is almost exclusively confined to macroscopic individuals which are for the most part decomposed into chloritic material, frequently giving the altered rocks a green color. Magnetite, though not sufficiently abundant to be regarded as an essential ingredient, appears to be evenly disseminated throughout the groundmass, and quartz, wanting in most varieties, serves as an accessory mineral in certain localities, especially in the more acid types. The mica gradually comes in as the rock becomes more and more acidic and as the acidic variety of this group predominates over the basic the mica occurs as a frequent if not constant constituent. Hornblende-mica-andesite covers much larger areas than normal hornblende-andesite. A characteristic and important feature of the hornblende-andesite of this district is the absence of all pyroxene. Very little of the hornblende-andesite is perfectly fresh and most of it has undergone a considerable decomposition, changing the color of the rock to light shades of red and yellow, while those portions which are most altered appear nearly white. Opal and chalcedony as secondary products are by no means uncommon in the more altered varieties.

Andesitic Pearlites.—Nearly every occurrence of hornblende-andesite is accompanied by more or less extensive outflows of andesitic pearlites, which so far as their mineral composition is concerned are quite similar to and in many instances identical with the crystalline types. They are in general more acidic in composition than the hornblende-mica-andesites, carry fewer well developed crystals, and in place of the holocrystalline structure are rich in glass base with microcrystalline secretions disseminated through it. It is the almost infinite varieties of this glass base which give to these pearlitic rocks their varying physical habit, color, luster, and density. Owing to their more acidic character, quartz becomes more frequent, but is shown rather in macroscopic secretions than in minute grains scattered through the groundmass. Sanidine, wanting in the normal varieties, may occur, although as a nonessential mineral, while biotite comes prominently to the front and to the eye appears as the most abundant macroscopic mineral, and relates the pearlites more closely to the hornblende-mica-andesites than to the more basic group. A variety of these pearlites exceptionally rich in glass is characterized by the appearance of hypersthene. As it is one of the most basic of this group of andesites it will be discussed farther on in this chapter. Many of the varieties possess a dense vitreous texture, breaking readily under a hammer-blow, while others are more or less pumiceous, crumbling easily under atmospheric agencies.

The largest body of hornblende-andesite occurs as a fissure eruption along the Hoosac fault, the lavas coming to the surface just to the south of the junction of the Ruby Hill branch with the main fault and extending southward till lost beneath rhyolitic flows. Like most acidic rocks these extravasated lavas have not spread out over large areas, but have piled up in irregular rounded hills, the highest reaching an elevation of 500 feet above the base of the limestones along the fault line in the valley. For the greater part of the distance along this fissure these lavas have undergone more or less alteration, due to solfataric action, kaolinization taking place with the formation of secondary minerals. Comparatively fresh rocks not far from the fault are still found northeast of Hoosac Mountain in the larger and least altered bodies. Associated with the more crystalline types occur excellent exposures of andesitic glasses and pearlites, products of more rapid cooling of the same magma under slightly different physical conditions. Other localities of hornblende-mica-andesite with the accompanying pearlites closely resembling each other in manner of occurrence and mineral composition are found at the southern end of Carbon Ridge, in the neighborhood of South Hill, at Spring Valley, and near Dry Lake. In all of the four latter localities hornblende-andesite and the hornblende-mica-andesite occupy positions quite inferior to the glassy varieties, so far as the amount of extravasated lava is concerned, but it is by no means easy, owing to insensible gradations, to draw a sharp line between the crystalline and glassy types. At the first two localities they occur, breaking out at the southern base of the upturned longitudinal ridges of sedimentary strata. In Spring Valley and along the Lookout fault, where the lavas penetrate the mountains on the west side of Prospect Ridge, the glassy varieties have poured out in relatively large masses, pearlites being the prevailing rock. They form gentle spurs 200 feet in height, resting against the sedimentary ridges. An interesting transition rock occurs here which unites the characteristic microcrystalline hornblende-mica-andesite with fine examples of pearlite. At Dry Lake, while the petrographical features are much the same, with similar transitions and variations, the geological occurrence is somewhat different, the locality being quite remote from the others and lying far to the west of Prospect Ridge and the principal lines of north and south faulting. A suite of specimens from any one of these localities could hardly be distinguished from those of others either in physical features or composition. Identical transition products, both as regards degree of crystallization and mineral variation, are recognized from all of them. They show the same order of succession and the same sequence of geological events. The petrographical features of these nearly identical series of lavas will be found described by Mr. Iddings in the chapter already referred to.

Dacite.—This rock is a variety of andesite, in which secretions of quartz play the part of an essential mineral, and is intimately related in mineral composition and structural habit to hornblende-mica-andesite. All the occurrences at Eureka are very similar in physical characteristics, possessing a light ash-gray color, a hackly fracture, and a rough, pumice-like texture which relate them closely to certain varieties of rhyolite with which in the field they are frequently associated and from which they are not easily separated, either in their mode of occurrence or lithological appearance. The feldspars are nearly all plagioclase and probably largely oligoclase. Together with the larger secretions of quartz occur numerous thin laminæ of biotite, in amount greatly in excess of that usually found in hornblende-andesite. Although of less frequent occurrence, occasional hypersthene crystals, similar to those found in the andesitic pearlite, may be recognized in the dacites and serve to show the dying out of ferro-magnesian minerals in the more acidic lavas. These glassy dacites are closely related to the andesitic pearlites, but occupy much smaller areas, their chief interest lying in the fact that they represent transition products from the andesitic to the rhyolitic lavas, sometimes associated with one, sometimes with the other, and not infrequently as lava flows connecting them both, in much the same way as the more crystalline dacites occur as transition products between the crystalline varieties of hornblende-mica-andesite and rhyolite. Near the entrance to Sierra Canyon, on both sides of the road, there is exposed a characteristic variety of gray dacite, and at Dry Lake and South Hill they occur with andesitic eruptions, but only in obscure low ridges and knolls, breaking through the Nevada limestone of the Devonian. Again some varieties of dacite are closely associated geologically with rhyolitic pumices and tuffs, but differ from them petrographically in having a predominance of triclinic instead of monoclinic feldspars.

Rhyolite.—The essential components of this natural group are restricted to orthoclase and quartz. Usually they carry more or less triclinic feldspars, in some cases almost equaling the monoclinic form, but they are rarely developed in as large individuals as the orthoclase. Biotite as an accessory mineral may be present in varying amounts, but is quite as likely to be wholly wanting. In chemical composition they form the most acid of all natural groups into which the lavas have been divided. In color and texture no rock surpasses the rhyolite in the endless modifications which it undergoes even within very limited areas. In crystalline structure it may vary from a rock possessing a holocrystalline groundmass, with or without large macroscopic secretions of the essential minerals, to one almost wholly made up of glass. Whether the rhyolite is crystalline or in large degree composed of glass, the sanidines occur in well developed crystals, frequently presenting the brilliant iridescent hues so often observed elsewhere throughout the Great Basin. The quartz occurs both as dihexahedral crystals and dark gray and black angular grains which stand out in strong contrast to the prevailing light tints of the inclosing groundmass.

At Eureka, where acid lavas are singularly well developed, among the many extrusions of rhyolite occur two principal varieties which cover large areas and embrace the greater part of the outbursts, and for the purposes of the present chapter may be designated by local names: one, the Rescue Canyon rhyolite, the other, the Pinto Peak rhyolite. In mineral and chemical composition they are closely allied. The Rescue Canyon rhyolite when fresh has a decidedly red color due to a considerable amount of iron oxide in the groundmass. It occurs only as a fissure eruption along the Rescue fault, the brilliancy of coloring causing it to stand out prominently in contrast with the inclosing dark gray limestones. It is largely composed of glass base in which are porphyritically imbedded exceptionally brilliant grains of dark quartz and tabular crystals of sanidine. The Pinto Peak rhyolite, on the other hand, is characterized by a more crystalline groundmass, much of it being holocrystalline. It is in general lighter in color, more varied in tint, carries less iron, and is almost wholly free from ferro-magnesian secretions. In places it disintegrates readily into loose quartz grains and feldspathic fragments. The name is taken from Pinto Peak, a prominent elevation, made up wholly of rhyolitic accumulations, lying between Spring Hill and Carbon Ridge, just east of the Hoosac fault. Similar rhyolites, singularly uniform in composition and crystalline structure, extend without a break in their continuity the entire distance from Pinto Peak to Gray Fox Peak. Nearly all the lesser outbursts of rhyolite scattered over the district and breaking out along fault planes belong to the Pinto Peak variety. It is characteristic of many volcanic centers in the Great Basin as well as Eureka, and may be considered as a typical rock over large areas.

Pumice and Tuff.—All rocks placed under this head are closely allied to the rhyolites in mineral and chemical composition and belong to the same natural group. The rhyolites and pumices break out under very similar geological conditions and frequently pass from one into the other, even more readily than the transition between the crystalline andesites and glassy pearlites. They cover much larger areas than the corresponding andesitic rocks and in their field occurrence offer such striking contrast to the more compact rhyolite that it is thought best to separate them, more especially as they exhibit definite characteristics sufficient to group them on the map by themselves, and in several localities the erupted material consists wholly of pumices and tuffs. Transitions from normal rhyolites into pumices are admirably shown along the base of Purple Mountain. The mass of the mountain rises 400 feet above the valley and is formed of a characteristic rhyolite, while the base spreads out in a great variety of pumices and tuffs, which stretch eastward beneath the town of Eureka as far as Richmond Mountain.

Similar transitions may also be seen in the neighborhood of Pinto Peak, although on a less extensive scale. It seems impossible for any region to exhibit a finer display of pumices and tuffs than those occupying the basin between County Peak and Richmond Mountain. Here, in the neighborhood of Hornitos Cone, a symmetrical hill of tuff 400 feet in height, these pumices are shown with every possible variation in color and texture, the results of alteration produced by the breaking through of basaltic masses. The color and density have undergone marked changes, but the mineral development remains much the same as in the normal rhyolite. Nothing could surpass the abrupt changes in physical habit which these rocks undergo.

Pyroxene-andesite (Augite-andesite).—Under pyroxene-andesite are included all those volcanic rocks whose essential constituents consist of triclinic feldspars and pyroxenes, the rock differing fundamentally from the hornblende-andesite in having the hornblende replaced by some form of pyroxene, usually a mingling of both hypersthene and augite. Hypersthene in most rocks of this group surpasses the augite in amount and in certain localities predominates to such a degree that the rock might properly be classed as hypersthene-andesite. Whether there exists any large body of extrusive lava in the Great Basin retaining the andesitic habit, in which the augite is the prevailing mineral, to the exclusion of hypersthene and without the accompaniment of olivine, is a matter of some doubt. The rock is rich in magnetite, disseminated throughout the mass, the mineral playing a far more important part than in hornblende-andesites. In addition to the essential mineral constituents which make up the rock, both biotite and black-bordered hornblende have been identified in the pyroxene-andesites from several localities in considerable quantity. Richmond Mountain is the only body of pyroxene-andesite in the Eureka District. It is well represented in the Cliff Hills just south of the Fish Creek basin, the northern end of which is shown on atlas sheet XII. It covers such an extensive area, presenting not only an important feature of the lavas of this region, but is such a typical rock of many other localities, that it requires to be described in detail.

Richmond Mountain.—The mountain lies in a region of profound disturbance and dislocation. Immediately to the west the depressed block of Spring Hill sinks beneath the plain, while to the south the broad elevated mass of County Peak rises abruptly above the lavas. The Pinto fault passes beneath Richmond Mountain and apparently connects with the Rescue fault, the great line of displacement which separates the County Peak block from the Diamond Range, but all structural features are obliterated by the pyroxene-andesite lava flows. The culminating point of Richmond Mountain, situated near its southern end, attains an elevation of nearly 2,000 feet above Diamond Valley. An abrupt wall, 800 feet in height, forms the southern end, and from its summit the mountain falls away to the north for nearly three miles, with an average slope of about 14°. Across its broadest expansion, in an east and west direction, the mountain measures three miles. For such an accumulated pile of lavas it presents a uniform, monotonous appearance, relieved by occasional shallow drainage depressions flowing northward, inclined with the natural slopes of its lava ridges. Its geological position with reference to the Carboniferous beds of the Diamond Range on the east, the Devonian on the south, and the Silurian and Cambrian beds on the west is shown in cross-section A-B, atlas sheet XIII.

Richmond Mountain is almost wholly made up of pyroxene-andesite, the prevailing colors of which are dark grayish purple varying to bluish black. In crystalline structure the rock varies from a microcrystalline groundmass to one rich in glass base, porphyritic crystals of light colored feldspars characterizing the rock through all degrees of crystallization. This range in crystallization produces marked variations in physical features, the lavas changing within short distances from a highly vesicular rock with angular fracture to a compact one weathering with rounded outlines. Varying proportions of the porphyritic constituents are found in all the rocks from the holocrystalline to those rich in glass base. Hypersthene is the prevailing pyroxenic mineral, always accompanied, however, by more or less augite. The feldspars are anorthite and labradorite. In addition to the essential minerals, well developed porphyritic crystals of hornblende occur in the less basic lava, but nowhere as shown by the microscope do they enter into the composition of the groundmass. Associated with the hornblendes are a few flakes of biotite, the latter mineral occasionally appearing scattered through the rock without the presence of the former. It is this association of hornblende and biotite in the pyroxene-andesite that relates it to the earlier hornblende-andesite. These relatively acid lavas are well shown in the neighborhood of Trail Hill. In all these rocks of Richmond Mountain the groundmass is made up of innumerable lath-shaped feldspars and microlites of pyroxene, producing that peculiar felt-like structure first described by Prof. Zirkel and since recognized by others as a characteristic of pyroxene-andesites. Two typical varieties occur here, extreme forms of the same lava: one, a rough, porous rock, dark purple in color and having what has frequently been called a trachytic texture; the other, a compact rock, bluish black in color and possessing an oily resinous luster which has been described as a characteristic of many pyroxene-andesites elsewhere. Both of these sharply contrasted rocks pass by insensible transitions, the one into the other, preventing the tracing out of separate flows in the field. There is, however, this marked peculiarity between them: the former has a laminated and fissile appearance, whereas the latter nowhere exhibits any tendency to such lines of parting.

Owing to the geological and petrographical importance of the Richmond Mountain rocks, Mr. Iddings has devoted much time to an investigation of the lime-soda-feldspars and ferro-magnesian-silicates, the results of which will be found in detail in his chapter on microscopical petrography. Mr Iddings has determined anorthite by its extinction angles and other optical properties as one of the prevailing feldspars which at the time of his work was the first recognition of this species as an essential constituent of the volcanic rocks of the Great Basin.

Within recent years investigations have demonstrated that hypersthene is the prevailing ferro-magnesian silicate of many pyroxene-andesites in volcanic regions throughout the world. The importance of hypersthene as an essential and controlling constituent of pyroxene-andesites in Colorado was first shown by Whitman Cross.[1] Soon after these observations were

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[1] Bulletin of the U. S. Geological Survey, No. 1, 1883.

confirmed and extended by an examination of the lavas from the volcanoes of the Pacific Coast[1] and those of the Great Basin.[2] In the investigations of these latter, the pyroxene-andesites of Richmond Mountain played an interesting part, all the more important as a large suite of rocks from one locality whose field relations were known were subjected to a most careful mineralogical study. The isolation of the hypersthene from augite was accomplished by means of a solution of cadmium-boro-tungstate having a specific gravity of 3·39. Repeated treatment with the solution yielded a brown hypersthene carrying a small amount of green augite. Under the microscope the former proved to be orthorhombic in form and strongly pleochroic, the latter monoclinic and without pleochroism. In the greater part of the pyroxene-andesites of Richmond Mountain the hypersthene was always found to be in excess of the augite, the prevailing minerals being hypersthene and anorthite, accompanied by labradorite and possibly other plagioclase feldspars, together with varying amounts of augite and magnetite.

Basalts.—Under basalts are included those volcanic rocks which have for their essential ingredients plagioclase augite and magnetite. Olivine, which occurs as a common accompaniment in varying proportions, in many varieties, is, however, too frequently wanting to be rigidly regarded as an essential constituent. The basalts form the most basic of all natural groups into which the volcanic lavas have been divided. At Eureka they present, for the wide field which they cover and the great number of their extrusions, a uniform appearance, and, although characterized by a large amount of glass base, may be regarded as typical of many localities in Nevada. It is fine grained and compact, frequently passing into vesicular forms, with but few macroscopic secretions, and by far the greater part of it grayish black in color. Olivine occurs in large grains and in such quantities as occasionally to modify the external character of the rock; yet over broad areas it is wholly wanting, the microscope failing to detect its presence in

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[1] Notes on the Volcanoes of Northern California, Oregon, and Washington Territory. Hague and Iddings. Am. Jour. Sci., September, 1883, vol. 26, pp. 222–235.

[2] Notes on the Volcanic Rocks of the Great Basin. Hague and Iddings. Am. Jour. Sci., June, 1884, vol. 27, pp. 453–463.

many thin sections. Hypersthene is wanting in the normal basalts, and if present is only recognized in the intermediate rocks between typical pyroxene-andesite and basalts. An exceptionally fine display of these intermediate rocks makes this group of special geological importance at Eureka. A discussion of these transition rocks is reserved till later in the chapter, when treating of the relations of the different groups to each other.

Manner of Occurrence of Volcanic Lavas.—In the Eureka District there are no grand craters through which the greater part of the lavas reached the surface and from which volcanic energy receding from centers of igneous action gradually decreased in intensity and finally died out altogether. On the contrary, the igneous rocks consist for the most part of extrusive lavas that have poured out through numerous vents scattered over the volcanic area, many of the outbursts being very limited in extent. At first sight it might seem impossible to recognize any order in their distribution, so irregularly do they appear to break out in most unexpected places. Further observation, however, shows how dependent these outbursts are upon the preexisting orographic structure a knowledge of which is absolutely necessary to a thorough understanding of the volcanic phenomena.

As regards their mode of occurrence, all the lavas may be classed under four heads: first, and most important, they break out along the three great meridional and approximately parallel lines of displacement, the Hoosac, Pinto, and Rescue faults; second, they border and almost completely encircle the large uplifted masses of sedimentary strata, like the Silverado and County Peak block; third, they occur in numerous narrow dikes penetrating the limestones, but for the most part confined to Prospect Ridge, and, fourth, they occur in one or two relatively large bodies, notably Richmond Mountain and Pinto Peak, along lines of displacement already mentioned. Richmond Mountain is situated at the junction of the Pinto and Rescue faults, while the lava of Pinto Peak has been piled up along an oblique fault, which runs from the Hoosac to the Pinto fault, and which separates Spring Hill from Carbon Ridge. It is along the lines of these latter faults that the most powerful volcanic activity has been displayed. As described elsewhere, these two faults are situated respectively on the east and west sides of the depressed block of Carboniferous rocks lying between the Cambrian and Silurian of Prospect Ridge on the one side, and the Silurian and Devonian of County Peak and Silverado Mountain on the other. These profound faults, as already described, show nearly 2½ miles of vertical displacement. Fissures accompany these faults and through them vast masses of lavas have reached the surface and poured out along both sides of the fault planes. In places the lavas are found only in narrow belts without any great accumulation of material and in others they are piled up in rounded hills and knolls of irregular outlines, concealing everything beneath them for long distances. In general acid lavas accumulate near their source of eruption while basic lavas, owing to their greater fluidity, show a tendency to flow from their vents in broad masses. Along the Hoosac fault from Fish Creek Valley to its junction with the Ruby Hill fault, a continuous body of acid lavas, either rhyolites or hornblende-andesites, follow the course of the fault, but beyond their junction no lavas come to the surface along the Hoosac, although they persistently follow the course of the Ruby Hill fault as described in detail in the chapter devoted to the discussion of the ore deposits of the District. Along the latter fault the rhyolites do not form a continuous surface overflow, but break out in isolated knolls all the way from its junction with the Hoosac to the Jackson fault, beyond which, on Ruby Hill, the lavas never reach the surface, although their presence is shown by underground mining galleries. Westward from the Hoosac fault volcanic energy slowly died out.

Following the trend of the Pinto fault from the southern end of the mountains, rhyolitic pumices and tuffs define the general course of displacement all the way to Dome Mountain. This light porous material has, by gradually welling out along the fissure, heaped up bosses and knolls of volcanic products, but owing to their peculiar physical habit they have eroded more easily than the denser rocks and present a more broken, undulating surface. Isolated outbursts of pumices occur, penetrating the sedimentary strata on both sides of the fault, and along Wood Valley extend far back into the Devonian limestones. Northward of Dome Mountain the pumices and tuffs again come in, but are finally lost beneath the imposing mass of pyroxene-andesites of Richmond Mountain. Along the Pinto fault only one occurrence of andesite is known, but on the other hand numerous rounded bosses of basalt occur on both sides of the fault line.

The Rescue fault, as regards the amount of displacement, is a less profound one than the others just mentioned, but it is as sharply outlined, and owing to the pre-Tertiary erosion of Rescue Canyon exhibits quite as striking an occurrence of volcanic outbursts. The erupted material does not follow the entire line of the fault, but is confined to its southern end, from Island Mountain southward, crossing Silverado Canyon and following along the east side of Rescue Canyon. It presents a most remarkable body of erupted material nearly 2 miles in length, seldom exceeding 200 or 300 feet in width. Starting in at the base of the escarpment upon the east side of Island Mountain, along which runs the fault plane, it descends gradually for 750 feet to the open country of Fish Creek Valley. The extravasated material is wholly composed of rhyolite so uniform in appearance and composition, and so characteristic of the region, as to well deserve the designation of the Rescue Canyon rhyolite. Rhyolitic pumices and tuffs, which occupy the valley near the base of the mountains, conceal the denser rock and obscure all structural features.

Subordinate to the eruptive outbursts along these three great fissures and to the west of the Hoosac fault, occur two other narrow belts of igneous rocks similar as to their geological position, but far less important as lines of eruptive energy. They are found on the west side of the southern end of Prospect Ridge and penetrate into the mountains from Fish Creek Valley. The most easterly outbreak occurs along Sierra Valley. Just west of it in Gray's Canyon, on the west side of South Hill, lies the second line of lava extrusions. The lava thrown out along these secondary faults is restricted in amount, bearing some relation to the importance of the orographic displacements.

Closely related to these north and south lines of eruption occur extravasated masses, completely surrounding the uplifted blocks. It is evident that they follow lines of orographic fractures, more or less profound, although the amount of displacement can seldom be determined. In some instances it is quite possible to estimate the faulting, but as a rule these lines of east and west orographic fractures are completely obscured by recent Quaternary accumulations or else buried beneath broad masses of lava. These latter overflows of lava, breaking out along the base of the escarpments, follow a somewhat sinuous course, yet cling most persistently to the border line of the uplifted area, and vary greatly in the amount of extravasated material and the manner in which they pile up at the surface along lines of fracture.

The most striking illustration of this mode of occurrence may be seen in the lavas surrounding the County Peak and Silverado block. Along the Pinto fault, which defines these mountains on the west, the lavas closely follow the fault, except for the short distance, already mentioned, northeast of Dome Mountain. Richmond Mountain encircles the block on the north, followed on the northeast by the broad basaltic flows of Basalt Peak and the Strahlenberg, which lie between County Peak and the Diamond Range. To the east every indication points to the occurrence of lavas beneath the alluvial deposits of Newark Valley, while the Rescue Canyon overflows continue southward to the open valley, completing the circuit in this direction. Facing Fish Creek Valley, bosses and knolls of both acid and basic lava stretch westward in sufficient number to plainly suggest a continuous outbreak of igneous material along the southern base of the uplifted block of Silurian and Devonian limestones.

In the case of the depressed Carboniferous area the bordering lines of lava following the Hoosac and Pinto faults are clearly made out. Between the Spring Hill and the Carbon Ridge bodies there is a sharp break in the Carboniferous strata, along which acidic lavas have broken out, crossing obliquely from the one great fault to the other. On the north side of the Spring Hill body, Richmond Mountain cuts off everything to the northeast. The volcanic pumices and tuff stretch westward under the town of Eureka and terminate finally in the rhyolites of Purple Hill. To the south of the Carboniferous area pumices and tuffs abut against the base of Carbon Ridge, skirting the foothills, unless concealed beneath recent deposits. South of Gray Fox Peak and Carbon Ridge there is a long line of secondary ridges, now completely covered by Quaternary deposits. It is easily seen that their trend is wholly out of accord with the line of the Paleozoic uplifts, but is precisely what we might expect to find if the lavas had poured out along the foothills and encircled the terminal spurs of the upturned Paleozoic beds. Pumices and tuffs again come to the surface along the southern end of the Pogonip beds, skirt Devonian limestone upon the south side of South Hill, and thence, penetrating the mountains, follow up Grays Canyon on the west side. By reference to the atlas sheets it will be readily seen that the lavas border the depressed areas of Carboniferous rocks lying between the two great faults in as forcible a manner as they do in the case of the elevated County Peak and Silverado orographic block.

Intrusive Dikes.—Dikes of andesite, rhyolite, and basalt penetrate the strata in a number of localities, for the most part, except in the case of rhyolites, in close proximity to the principal lines of volcanic activity. That they possess the same deep-seated origin with the larger bodies seems evident from their position and similarity of petrographical characters, their mode of occurrence clearly suggesting that they are merely offshoots from parent magmas. The erupted material was forced upward into narrow fissures and fractures, following lines of least resistance. In their geographical distribution they present some striking differences, andesitic dikes being found only to the west of the Pinto fault, and for the most part confined to Cambrian and Silurian rocks of the Prospect Ridge uplift, whereas basaltic dikes arrange themselves around the County Peak and Silverado Mountain body. Rhyolite dikes, while they may break out anywhere along lines of displacement, offer a marked geological feature of Prospect Ridge, the eastern slope being cut by a network of intrusive bodies. They vary from thirty feet to a few inches in width, and trend at all angles, some of them agreeing with the strike of the beds, while a few, notably the Geddes and Bertrand dike, cross the strata nearly at right angles to the course of the main ridge. The Ruby Hill fault-plane is coincident with a narrow fissure, into which the rhyolitic magma has forced an entrance for the greater part of its length, forming the most persistent dike of any in the region. In the neighborhood of the Dunderberg and Hamburg mines numerous outbursts of rhyolite have reached the surface. Notwithstanding, however, the great number of these dikes, none appear to have penetrated the strata along the top of the main ridge, and in no single instance have lavas built up any considerable knob or hill on the surface. It is quite impossible that such knobs should have been formed and later have been removed by erosion without leaving some evidence of overflow along the line of the dikes.

This system of dikes upon Prospect Ridge presents certain geological characteristics of interest bearing upon the mode of occurrence of erupted material. Throughout they show a great similarity in mineral composition and petrographical habit, and when fresh in every way resemble the unaltered rocks along the Ruby Hill fault. These latter lavas have been shown elsewhere to have been erupted at the same time and under similar conditions with the rhyolite of the Hoosac fault. Indeed, the Ruby Hill fault is simply a prolongation of the main fault. Evidences of alteration and metamorphism of the limestones and shales through which the erupted material passed are by no means easy to detect, the encasing walls showing scarcely any evidence of the effects of heat derived from ascending lava currents. These dike rocks being narrow bodies have cooled rapidly and imparted little heat to the limestones. Mining exploitations have frequently encountered these intrusive bodies hundreds of feet below the surface, but neither at the top nor underground do they exhibit structural features in any way different from the larger bodies. The only marked feature in which these dike rocks differ from the extrusive lavas of Pinto and Gray Fox peaks is shown by the absence of flow structure due entirely to their manner of occurrence, and in no way dependent upon either their chemical or mineralogical composition. As regards the degree of crystallization, they exhibit characters identical throughout and similar to the material erupted at the surface along the principal lines of faulting.

On all the great lines of orographic fracture along which both acid and basic lavas have emanated, the amount of volcanic material reaching the surface has varied greatly at different points. In certain localities they have piled up to such an extent as to form prominent hills and landmarks, but their mode of occurrence is precisely the same as those where the lavas have only accumulated in narrow belts along the fissures. Such masses as Pinto Peak, Purple Hill, and Gray Fox Peak are similar piles of lava, uniform in character, only varying in size according to the amount thrown out at each locality. In the same way Richmond Mountain is a vast accumulation of pyroxene-andesite similar in its geological occurrence to the smaller hills of basalt which have broken out at numerous points along the fractures caused by the elevation of the County Peak and Silverado block.

Mr. Clarence King, in summing up the observations of the geologists connected with the Geological Exploration of the Fortieth Parallel upon the mode of occurrence of the rhyolites between the Sierra Nevada and Wasatch ranges, makes the following concise generalization:

> Where a great mountain block has been detached from its direct connections and dropped below the surrounding levels, there the rhyolites have overflowed it and built up great accumulations of ejecta. Wherever the rhyolites, on the other hand, accompany the relatively elevated mountain blocks, they are present merely as bordering bands skirting the foothills of the mountain mass. There are few instances in which hill masses were riven by dikes from which there was a limited outflow over the high summits; but the general law was, that the great ejections took place in subsided regions.[1]

Nowhere within the Great Basin does this description hold true with greater force than in the Eureka District. It holds true, however, for the entire hornblende-andesite and dacite groups, as in their mode of occurrence they can not be separated from the more acidic lavas. It holds equally well for the pyroxene-andesites, since such broad masses as make up Richmond Mountain are simply relatively large accumulations of lavas at centers of great dislocation in highly disturbed regions in every way similar to those of other lavas. In the case of the hornblende-andesites and rhyolites they have poured over and nearly submerged a depressed sedimentary region, whereas the rhyolites, pyroxene-andesites, and basalts, which have broken out in proximity to the Silverado and County Peak region, appear more as an encircling belt to a relatively elevated country.

Relative age of Volcanic Rocks.—In the Eureka District the hornblende-andesite and the closely related hornblende-mica-andesite are the earliest of the Tertiary lavas, all others with which they are associated being found either to break through or overlie them. Hornblende-andesite, wherever it occurs in the district, is a crystalline rock and forms a central body, which, by insensible transitions, passes into a rock with a more and more glassy

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[1] U. S. Geol. Explor. 40th Par., 1878, vol. I, Systematic Geology, p. 691.

base until it becomes a characteristic andesitic-pearlite. As the andesites and pearlites become more and more acidic the rock gradually passes over into dacite, the eruptions of which usually occur in obscure hills and low ridges, and although covering comparatively restricted areas are clearly seen to overlie the hornblende-mica-andesite in all the local centers of eruption wherever the two rocks are observed together. In the neighborhood of South Hill, where the largest exposures of dacite have been observed, they rest superimposed against the andesite, and at Dry Lake, where, however, only a small body of dacite is known, it is evident that a similar sequence of flow was maintained.

In low hills near the entrance to Sierra Canyon northeast of South Hill instances may be seen of finely banded rhyolite lying in direct superposition upon good exposures of dacite. This dacite, though a moderately compact rock, possesses in places a pumiceous texture and in a marked degree strongly resembles many forms of rhyolite, but especially the variety with which it is here associated. Both rocks are highly acidic, but the dacite is richer of the two rocks in mineral secretions and is characterized by a great abundance of laminæ of biotite. In the few areas where both rocks occur together in such a way that their relations can be made out, the rhyolite has been the last to reach the surface.

The district affords abundant and frequent evidence of the relative geological position of andesite to rhyolite. Not only is this shown by the relationship between the rhyolites and dacites, but over much more extended areas the rhyolite encircles and overlies the andesite, filling in and smoothing out the accidented surface of the older rock, which in turn may occasionally be seen in isolated exposures rising above a broad expanse of superimposed rhyolite. Further and conclusive evidence is found in the frequent dikes of rhyolite penetrating the hornblende-mica-andesite in several places adjoining the Hoosac fissure. The rhyolitic pumices, tuffs and allied rocks appear in many instances to have preceded the more highly crystalline compact rhyolites represented by the typical Rescue Canyon and Pinto Peak rocks.

While it is by no means evident that all the overflows of pumice broke out before the denser rock, yet there is ample proof that long and continuous bodies spread out over wide areas of country, especially along the line of the Pinto fault, before the great bodies of the latter were forced to the surface. Rhyolites occur breaking through the pumices, overflowing and occasionally concealing them from view, except where the softer rock is exposed by deep cuts along drainage channels. In some instances the pumices lie superimposed upon denser rock, evidently of later age. It seems most probable that throughout the duration of rhyolitic eruptions conditions were at all times more or less favorable for the pouring out of pumices and tuffs, and that outbursts of similar material began and closed the rhyolite period. The conditions governing the physical characteristics of the erupted material seem in a great measure to have been dependent upon their relations to certain local centers of volcanic activity.

Along the Pinto fault, wherever the acidic lavas have piled up, pumices occur as the prevailing rock, and the same holds true along the lines of displacement bordering the elevated mountain masses. Normal crystalline rhyolite, on the other hand, characterizes the Hoosac fault and breaks out wherever these lavas penetrate into the interior of the mountains along fissures and lines of least resistance. They frequently reach the surface in small isolated bodies in the most distant and unlooked-for places. The Rescue fault is an instance of rhyolite penetrating into the very center of the mountains, and the pumices and tuffs on the south side of the Silverado Mountains offer a fine example of the pouring out of the latter along the outer edge of an uplifted orographic block. Following lines of least resistance they connect the rhyolites of the Rescue with those of the Pinto fault.

When it comes to determining the geological relations of pyroxene-andesite to hornblende-andesite and allied lavas, no direct superposition can be found, nor are there any instances of dikes of one rock breaking through an earlier body of the older rock. The main bodies of hornblende-andesite and pyroxene-andesite are, as regards geological position and geographical distribution, quite distinct.

Absence of direct evidence as to the relative age of the two large groups of andesite may be explained satisfactorily by the fact that only one body of pyroxene-andesite occurs in the district and this one, although covering an extensive area and of great thickness, has no outlying exposures. The Cliff Hills which lie beyond the limits of the Eureka Mountains, present a grand exposure of pyroxene-andesite, but as they stand alone afford no evidence as to the relations of the different lava flows to each other. Along the base of the escarpment, which forms the south side of Richmond Mountain, occurs a contact over a mile in length, between pyroxene-andesite and rhyolitic pumices, yet nowhere along this line has the sequence of eruption been definitely determined by actual contact. Evidence fails to show whether the pyroxene-andesite broke through the pumices, which, on account of their friable nature have suffered more or less erosion, or whether the latter banked up against a preexisting wall of the former. For the greater part of the distance the junction of the two rocks is completely obscured by both large and small blocks of andesite, which have fallen from the cliff above, and wherever these are wanting the contact is hidden by fine friable pumice and ash, which has accumulated in considerable thickness along the base of the escarpment, piled up by the prevailing westerly winds. Although no actual superposition is seen, all indirect evidences point so strongly to the true order of succession that the fact seems well established that the pyroxene-andesite followed the rhyolite.

Between the pyroxene-andesites and basalts there exists the closest possible relationship, so much so that it is by no means an easy matter to establish a sharp line between them, either in mineral composition or field occurrence. Unlike pyroxene-andesite, however, the outbursts of basalt present a considerable diversity in their mode of occurrence and distribution, forming broad table-like masses and numerous small extrusions in dikes and rounded knolls. Although the two rocks are closely related by transition products, extreme typical forms may easily be distinguished from each other by both geological and petrographical features of rock masses, and as to their order of succession there exists, fortunately, abundant proof to show that the pyroxene-andesite preceded the basalt. Evidences of their relative age may be seen on the summit of Richmond Mountain, where several dikes of dense glassy basalt cut the andesite in sharply defined lines of contact, and at several localities near the outer edge of the andesitic body, notably just east of the town of Eureka.

Now, the relationship as regards age between the basalts and rhyolites is placed beyond all question, numerous dikes of the former cutting the latter both along the Pinto fault and in the pumice basin southwest of Richmond Mountain. Hornitos Cone, about 400 feet in height, an isolated hill rising abruptly out of the basin, is an excellent instance of the cutting of rhyolite by basalt dikes. The cone is composed of light colored pumices, broken through and ribbed on all sides by black basaltic dikes, which have altered the siliceous rocks all along the lines of contact. Crater Cone, on the east side of Richmond Mountain, affords an equally good example of the relative position of the two rocks, the basaltic lavas which here form the Cone flowing for long distances over the earlier pumiceous beds. Magpie Hill, near the entrance to Rescue Canyon, affords still another equally as good an illustration of the relative position of the two rocks.

If the pyroxene-andesite overflows preceded the rhyolite it would hardly have been possible under the conditions of eruption for them not to have broken out along some of the hornblende-andesite centers before the appearance of the rhyolites. Again, if the rhyolites followed the pyroxene-andesite there should be found some field evidences of such eruptions between the pyroxene-andesite and basalt, whereas, on the contrary, there exists not the slightest evidence of an overflow of acidic lava intervening between the closely related basic lavas. It has already been pointed out that the acidic lavas hold the same close relationship to each other.

Field observations clearly show that the order of succession of these natural groups into which the lavas have been divided was as follows: First, that the hornblende-andesite was the earliest of all the erupted material; second, that the hornblende-mica-andesite followed the hornblende-andesite; third, that the dacite followed the hornblende-mica-andesite; fourth, that the rhyolite closely followed the dacite; fifth, that the pyroxene-andesite succeeded the rhyolite; sixth, that the basalt was the most recent of all volcanic products.

Two Magmas of Eruption.—A study in the field of the geological distribution and mode of occurrence of the igneous rocks, shows that they all belong to one or the other of two well defined groups, in each of which the lavas, although possessing a wide range in chemical composition, are so intimately related and so interdependent as to suggest that they must necessarily have been derived from some common source. In other words, all lavas at Eureka may be divided into two sharply contrasted groups, the one acid, and the other basic.

A microscopical examination in the laboratory of a large amount of material collected in the field in the opinion of the writer lends support to this view of two magmas. It is brought about by a study of the gradual transition in mineral composition and by certain peculiarities of structure and crystallization characteristic of each magma. The acid magma was the earlier in age, the eruptions beginning with hornblende-andesite and closing with the extreme acidic forms of rhyolite. In general the lavas of this acid series are light in color, the microcrystalline groundmass being composed for the most part of an aggregation of feldspar and quartz grains without the accompaniment of ferro-magnesian silicates. The hornblendes play no part in the composition of the groundmass, being present as porphyritic secretions, whereas the pyroxenes, in the few instances where they have been recognized, at the basic end of the series do not occur as porphyritic minerals, but only in minute microlitic forms developed in the groundmass. The glass is always highly acidic.

Sharply contrasted with these acidic lavas the basic lavas are characterized by a predominance of the pyroxenic minerals, the prevalence of lime-soda feldspars and the structural features of a groundmass peculiar either to pyroxene-andesite or to basalt. The basic magma came in with pyroxene-andesite and closed with numerous outflows of basalts. The two magmas so sharply defined by mineralogical and structural distinctions may be designated respectively as the feldspathic and pyroxenic magmas. A discussion as to their nature will bring out still more clearly their diagnostic points of difference and the importance of this division in its bearing upon the origin of the sequence of lavas. Further on in this chapter it will be maintained that both these magmas are simply differentiated products of an earlier homogeneous molten mass.

Feldspathic Magma.—Up to this point the composition of the rocks has been but little considered except as regards the mineral constituents of independent lava flows; it is necessary now, however, to look at them from the standpoint of a series of successive eruptions in order to understand their interdependence and geological relations. Normal hornblende-andesite, the earliest and most basic portion of the feldspathic magma, passes over without any recognizable physical break into hornblende-mica-andesite by the coming in of hexagonal plates of biotite which gradually increase in amount until they become the most prominent of the ferro-magnesian minerals and at the same time by insensible gradations the hornblendes decrease. Gradually the lava grows more and more acidic and quartz grains are developed in the groundmass, but at first not in sufficient force to be regarded as an essential constituent. The presence or absence of quartz is also governed in great measure by the degree of crystallization of the magma, a highly crystalline structure carrying more individual secretions than one where silica is largely absorbed in glass. With the increase of quartz the hornblende continues to diminish and the rock passes over into dacite, the biotite apparently holding its position with an occasional hornblende.

In dacite, quartz has become an essential mineral. With a still larger increase of the silica percentage orthoclase appears in broad and well developed crystals. Hornblende disappears entirely and in the normal varieties of rhyolite the biotite is rarely seen and then only as an accessory mineral; the ferro-magnesian minerals are wanting. At the basic end of the feldspathic series of lavas, labradorite and anorthite have been determined by their optical properties, but the predominating feldspars are apparently oligoclase. By insensible gradation the lime-soda feldspars pass away. Orthoclase, in most of the basic rocks, is entirely wanting, making its appearance by degrees until at the acid end of the series it occurs as the prevailing feldspar, although some species of plagioclase is nearly always present. At one end of this series of eruptive material the essential minerals are hornblende and one or more species of lime-soda feldspars; at the other, quartz and orthoclase.

Pyroxenic Magma.—The basic or pyroxene lavas began by the pouring out of large masses of the Richmond Mountain pyroxene-andesite. Successive changes in the mineral and chemical composition of this magma are by no means as easy to follow through the different flows as in the sequence of outbursts of the acidic products. Nevertheless, investigation shows as complete a range in composition of the erupted material, even where it is impossible to determine the relative age of the flows accompanying such changes. In some instances in the more crystalline acidic varieties it has been pointed out that both hornblende and mica occur as porphyritic secretions, although as accessory constituents, hypersthene being the predominant mineral. In lavas slightly more basic the former minerals are wanting; hypersthene still plays the part of the prevailing ferro-magnesian silicate, accompanied by relatively small amounts of augite, while in rocks still more basic augite is recognized as the predominant pyroxenic mineral, accompanied by an increasing development of magnetite. By insensible gradations a series of hand specimens and rock sections show that so far as mineral constituents are concerned the pyroxene-andesites pass over into basalts. While the rock masses of both lavas may be readily distinguished in the field by marked differences in physical aspect, it is by no means easy on a superficial examination to refer correctly from hand specimens certain varieties which approach each other in structure and composition. Mineralogically no sharp distinction can be drawn between intermediate varieties, but careful investigation of the Eureka rocks brings out certain differences which not only hold good for this region, but probably for other areas in the Great Basin. While observation, as already mentioned, offers abundant evidence as to the position of the pyroxene-andesite to the basalts and divides these closely connected rocks upon geological grounds, based upon their relative age, the microscope in a marked manner corroborates the distinctions made in the field. Mr. Iddings, who has submitted a large number of thin sections of both pyroxene-andesite and basalt to microscopical investigation, is able to substantiate by structural peculiarities of the groundmass the geological divisions observed. He finds that all those rocks which have been classed as pyroxene-andesite possess their own microstructure, characterized by the felt-like structure of the groundmass which has been so frequently noticed elsewhere. The typical basalts present in their structure a uniform groundmass made up of coarse-grained aggregations of feldspar and augite, imbedded in a globulitic glass base.

Nearly all the rocks of intermediate mineral composition possess the basaltic habit. Hypersthene is wanting in the normal basalts. Augite and magnetite, although essential minerals in the composition of both rocks, occur much more abundantly in basalts. With one exception the microscope has failed to detect olivine in any thin section of the lavas classed as pyroxene-andesite, the exception, however, furnishing quite a remarkable rock, and one that might with some reason be placed among the basalts. It occurs in an obscure exposure or knoll in Fish Creek Valley just west of Cliff Hills, and from its association, and still more from the fact that its groundmass structure bears the closest relation to adjoining rocks, it has been referred to the pyroxene-andesites. Although olivine is absent from the pyroxene-andesites of the district, it will not serve, as has been suggested, as a mineralogical distinction to separate the two natural groups, inasmuch as over large basaltic areas it is wholly wanting. Moreover, within limited areas, and apparently in the same flow, it may be present at one point and wanting in another, occurring so irregularly disseminated through the rock that any attempt to separate the basalts themselves into two divisions on a basis of olivine seems futile. In an abstract of the geology of the Eureka District published in 1883 this relationship between the olivine and basalt was clearly pointed out.[1] Since then it has been shown that olivine is absent in numerous basaltic lavas of the Great Basin.[2] Mr. George F. Becker[3] has recently arrived at the conclusion that olivine can not be used as a basis of division for the basalts along the sierra of California.

Characteristic Basalts.—It is well to mention two other marked peculiarities of these basalts—one, the very varying amount of silica which they carry; the other, the very high percentage of silica contained in the rock as compared with the most basaltic flows elsewhere. In their chemical composition nearly all these rocks possess far more silica

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[1] Third annual report of the Director of the U. S. Geological Survey, 1881-'82.

[2] Arnold Hague and Jos. P. Iddings: Notes on the volcanic rocks of the Great Basin. Am. Jour. Sci., June, 1884, p. 457.

[3] Geology of the quicksilver deposits of the Pacific Slope. Monograph XIII, U. S. Geol. Survey, 1888, p. 157.

than is ordinarily supposed to occur in normal basalt, the amount reaching as high as the percentage found in many andesitic rocks, and in some instances equaling the amount in the pyroxene-andesite of Richmond Mountain.

Olivine in Basalts.—In order to determine the amount of silica present in these rocks and its relationship to olivine, a number of chemical analyses were made from specimens which field observation and a study of thin sections had shown to belong to basalt. The subjoined table gives the result of ten such chemical examinations, arranged in order according to the silica percentage obtained. The presence or absence of olivine in the thin sections of the same rocks, as determined by the microscope, is also given in the table.

Number.	Silica.	Olivine.
1	49. 23	Rich in macroscopic secretions.
2	51. 86	Rich in microscopic secretions.
3	57. 42	Abundant in microscopic secretions.
4	58. 06	Easily recognized under the microscope.
5	58. 26	Only a trace.
6	58. 60	None detected.
7	58. 64	Detected under the microscope.
8	59. 51	None detected.
9	59. 64	None detected.
10	60. 11	None detected.

No. 1. South of Alhambra Hills.—This rock occurs as a low hill rising out of the Quaternary plain, and isolated from all other volcanic outbursts. It is a highly crystalline rock.

No. 2. Dike northeast of summit of Richmond Mountain.—An intrusive body penetrating the pyroxene-andesite.

No. 3. East of Basalt Peak.—A vesicular black basalt.

No. 4. Basalt Cone.—A compact dark rock characteristic of a large area of country.

No. 5. Basalt Peak.—A compact rock passing into vesicular varieties.

No. 6. West base of Richmond Mountain, near the town of Eureka.—A grayish red vesicular rock lying between pyroxene-andesite and earlier rhyolitic tuffs.

No. 7. West of Basalt Peak.—It occurs on the broad saddle just west of the peak, not far from the great body of Devonian limestone, and is a characteristic rock rich in glass base, black in color, mottled with gray.

No. 8. West base of Richmond Mountain, not far from the town of Eureka.—In its geological relations it is quite similar to No. 6. It is found breaking through rhyolitic tuffs and is a compact dark rock with a characteristic basaltic habitus.

No. 9. A dike from the summit of Richmond Mountain.—Under the microscope the rock resembles No. 2, which occurs not far distant, penetrating the same body of andesite under precisely similar geological conditions. This rock, however, is much richer in glass and correspondingly richer in silica. It is black in color, without macroscopic secretions, and has a decidedly conchoidal fracture.

No. 10. West of Toll Road, west of Dome Mountain.—It occurs as one of the largest extrusions of basalt along the Pinto fault. The broad mass lies in contact with hornblende-andesite, and flows from the same body are seen to directly overlie rhyolitic tuffs. It is exceedingly rich in glass, and so mottled as to present a gray color. Although the highest on the list in the percentage of silica, it possesses a strongly marked basaltic habitus, quite as characteristic under the microscope as in the hand-specimen.

It will be seen, with the exception of numbers one and two, that the silica percentage in all the rocks is higher than is usually found in basalts; they show between the two extremes on the list a variation in silica of 10·88 per cent.

Although olivine is not an essential constituent in the basalts, the above table shows how close a relationship exists between the olivine bearing and olivine free varieties, and a study of the localities and their mode of occurrence demonstrates how futile any attempt would be to try to separate them on the presence or absence of this mineral. In the hill south of Alhambra Hills, the silica is low, while the olivine is present in comparatively large secretions. In the dike from the summit of Richmond Mountain, the second in the table, there is an increase in the amount of silica of over 2·5 per cent, with a large falling off in olivine. From the rocks with 58 to 59 per cent of silica, there is only a small and varying quantity of olivine, while in the three specimens which gave over 59 per cent of silica the microscope failed to detect its presence.

Sufficient facts have been adduced to indicate how intricately the entire series of pyroxenic rocks are related to each other throughout a wide range in their composition. Throughout this entire group of extravasated lavas the essential minerals remain the same, the differences consisting for the most part in their relative proportions and the accompanying modifications of groundmass structure. This holds true in a still more striking manner if we exclude the extreme acidic end of the series where the hornblende and mica play the part of accessory minerals. Some of the basaltic masses determined as such by geological position and structural peculiarities have been found in several instances, usually the more glassy varieties, to be more acidic than the pyroxene-andesites, the two natural groups overlapping each other as regards their composition. The sudden changes which all these pyroxenic lavas apparently undergo from crystalline to glassy varieties is one of the marked peculiarities of the Eureka District and with these changes occur more or less variation in both mineral and chemical composition.

Age of Pyroxene-andesites Elsewhere.—Similar surface flows of pyroxene-andesites occur at numerous localities in the Great Basin, all the way from the Sierra Nevada Range to the Salt Lake Desert, although not always in as large bodies as Richmond Mountain, nor always associated with basalts. They are best shown along the Truckee Canyon in the Virginia Range, and in the Augusta, Cortez, and Wahweah ranges. In the Wahweah Range lavas which were considered by Prof. Zirkel as augite-trachytes can not be distinguished from the Richmond Mountain rock in any of their petrographical features. In the opinion of the writer many bodies of lava which formerly were classed as augite-trachytes, augite-andesites, and basalts, properly belong to this group of pyroxene-andesites, and in some instances rocks which had been determined as rhyolite from the fact that they were supposed to carry large amounts of sanidine have within recent years been shown to belong to this same natural group.

The Eureka District offers no positive direct evidence from superposition of the relative age of the hornblende-andesite and pyroxene-andesite, but this apparent break in the chain of evidence is more than made good elsewhere, inasmuch as pyroxene-andesites of the Richmond Mountain type have been observed breaking through hornblende-andesites not unlike those found along the line of the Hoosac fault. Similar volcanic rocks, as regards porphyritic secretions and groundmass structure, have been described by Mr. S. F. Emmons[1] as cutting through and overlying the hornblende-andesites in the Augusta Mountains, both in the region of Crescent Peak and Antimony Canyon. In the Truckee Canyon, rocks which have been called augite-andesites can not be distinguished from those of Richmond Mountain. They were observed by the geologists of the Fortieth Parallel Exploration to break through sanidine-trachytes (hornblende-mica-andesites) and were regarded by them at that time as an exception to the natural order of succession, all andesites being supposed to be older than the so-called trachytes. Along the walls of the same deep gorge and in its lateral

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[1] U. S. Geol. Explor. 40th Par., vol. II, p. 654.

branches pyroxene-andesite is exposed overlying rhyolite[1] and for the same reason was regarded as an anomalous occurrence, whereas it is now evident that it belongs more properly to that group of pyroxene-andesite which is found associated with and passing over into basalt. Inasmuch as it distinctly overlies the adjoining rhyolite it was designated on the geological maps of the Fortieth Parallel Exploration as basalt, although in the text mention was made of its andesitic character. At Jacob's Promontory, in the Shoshone Range, a body of lava which had been determined as rhyolite has also proved on further examination to be allied to pyroxene-andesite, and here, as at Eureka, it is found associated with basaltic flows, although of earlier age but overlying typical rhyolite. Numerous localities might be mentioned where similar pyroxene-andesites occur, but their relationship with neighboring rhyolites is obscure. Nearly similar pyroxene-andesites occur throughout California, according to the descriptions given by Mr. George F. Becker,[2] who has also identified these lavas from the west side of the Sierras with similar andesites in the neighborhood of Steamboat Springs, Nevada, which closely resemble those of Truckee Canyon. Quite recently Mr. H. W. Turner[3] has reported the occurrence of basic andesite overlying rhyolite at a number of localities along the western Sierra foothills.

These instances suffice to show that this type of rock occurs over widely separated areas, but it should, however, as regards its geological position, in no way be confounded with an older body of pyroxene-andesite of somewhat similar composition, such as is well represented in the Washoe District on the slopes of Mount Davidson, in the Virginia Range. The latter in general present a high degree of crystallization, carrying more porphyritic secretions and consequently less glass. On the other hand, the former present all those characters which ordinarily characterize surface flows, and are for the most part darker in color, as they carry fewer well developed feldspars. The hornblende and pyroxene-andesites of Washoe have been well described elsewhere in numerous publications upon that much discussed region. In the opinion of the writer the geologists of the

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[1] U. S. Geol. Explor. 40th Par., vol. II, p. 830.

[2] Geology of the quicksilver deposits of the Pacific Slope, Mon. U. S. Geol. Surv. vol. XIII.

[3] Mohawk Lake Beds. Phil. Soc. of Wash., Bull. XI, pp. 385-410.

Fortieth Parallel Exploration were led into error in supposing that all the rocks classed as pyroxene-andesite in the Great Basin belong to the same time period and were identical as regards their geological position in the order of succession, whereas there are two distinct periods, the earlier of which is represented by the pyroxene-andesites of Washoe and preceded the hornblende-mica-andesites, dacites, and rhyolites, and the latter by the pyroxene-andesites which followed the rhyolites, as developed on so grand a scale at Richmond Mountain.

Accessory Minerals.—Disseminated through the lavas at Eureka four minerals have been recognized, which in all cases occur simply as accessory constituents, as in no single instance do they enter largely into the composition of the rocks. These minerals are apatite, zircon, garnet, and allanite. Apatite and zircon in a perfectly unaltered condition have been determined in every type rock of both feldspathic and pyroxenic magmas. The apatites are much like those described in volcanic rocks elsewhere, with well developed terminations and a characteristic basal cleavage. Zircons in both long, slender prisms and short, stout, colorless crystals are by no means uncommon, and, judging from their distribution, occur apparently uninfluenced by the nature of the lava, notwithstanding their high specific gravity. They are found especially well developed in the andesitic pearlites, the crystalline forms, as drawn by Mr. Iddings, having already been employed as illustrations of microscopic zircons in recent text-books.

The presence of apatite is indicated by analyses in the determination of phosphoric acid, but the amount of zirconia present has not yet been estimated in any of these lavas. Judging from the analyses, the phosphoric acid increases with the basicity of the lava, starting in with only ·06 per cent in the rhyolite from Rescue Canyon and reaching ·29 per cent in the basalt from the summit of Richmond Mountain. The two silicates, garnet and allanite, have been detected only in the acidic magmas, but both of them have apparently been developed in the same type of rocks. The garnets, although minute, may be easily recognized by the naked eye, standing out as brilliant dark red crystals in contrast with the light colored pumices, tuffs, and pearlites which carry them. They occur in both the Rescue Canyon and Pinto Peak rhyolites. They are well developed at

Gray Fox and in the porous white tuffs south of Richmond Mountain. Microscopic individuals of brown and reddish brown allanite have been determined, almost invariably in an unaltered state, in andesitic pearlite, Rescue Canyon rhyolite, and in other very glassy varieties of rhyolite. The determination of allanite by its optical and crystallographic properties, its separation by chemical analyses, and its occurrence in widely separated localities prove that the mineral may claim recognition as an accessory constituent in recent volcanic rocks.[1]

In addition to the above minerals it may be well in this connection to mention two nonessential constituents occurring in the pyroxenic lavas—tridymite and quartz—which, although of interest from a petrographical point of view have almost no bearing upon the ultimate composition of the original molten mass. Tridymite is easily recognized under the microscope in the vesicular rocks of Richmond Mountain in thin tabular crystals lapping over each other in the manner so frequently observed elsewhere. These leaf-like crystals arrange themselves in clusters lining the cavities. Identical occurrences of tridymite may be observed in similar pyroxene-andesites from other localities in the Great Basin, notably in this type of lava in the Wahweah Range northwest of Richmond Mountain.

Quartz as an accessory constituent has been recognized in the basalts from a number of localities and apparently bears no relation to the chemical composition, being quite as apt to be developed in the normal olivine basalts as in the more siliceous flows. It is as characteristically displayed in the basic rock of Magpie Hill as in any other, occurring in isolated irregularly shaped grains encircled on all sides by minute augite crystals. Under the microscope they have all the appearance of being of primary origin. Similar quartz grains have been described by Mr. Iddings[2] from New Mexico and Arizona, their origin being referred by him to physical causes attending an earlier stage of the magma. He regards the exceptional development of the quartz in these basic rocks as comparable to the crystallization of fayalite in the lithophysæ of rhyolitic obsidian. Similar quartz grains in basalts have been described by Mr. J. S. Diller, from the base of

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[1] Joseph P. Iddings and Whitman Cross: Widespread occurrence of allanite as an accessory constituent of many rocks. Am. Jour. Sci., Aug., 1885, vol. xxx, pp. 108-111.

[2] Bull. U. S. Geol. Survey, No. 66, 1890.

Lassen Peak in northern California and are also regarded by him as of primary origin.[1]

Chemical Composition.—During the progress of the investigation upon the erupted material, analyses were made of several of the more characteristic rocks, which are presented here in tabular form arranged in the order of their basicity.

	1	2	3	4	5	6	7	8	9
Silica	75.69	73.91	73.09	67.83	67.03	65.13	61.58	56.54	50.38
Alumina	12.26	15.29	14.47	15.02	16.27	15.73	16.34	14.75	19.83
Ferric oxide	....	....	....	....	....	2.24	....	....	6.05
Ferrous oxide	2.93	0.89	2.99	5.16	3.97	1.86	6.42	9.29	2.00
Manganese	....	....	....	....	....	trace	....	....	0.38
Nickel	....	....	....	....	....	0.07	....	....	....
Lime	1.13	0.77	1.13	3.07	3.42	3.62	5.13	7.80	10.03
Magnesia	....	....	....	0.29	1.19	1.49	2.85	6.51	5.36
Soda	3.01	3.62	2.77	2.40	2.71	2.93	2.69	2.07	2.15
Potash	4.74	4.79	5.07	3.20	3.60	3.96	3.65	2.96	1.76
Lithia	....	....	....	....	....	....	....	....	trace
Phosphoric acid	0.06	0.07	....	0.26	....	0.23	0.28	0.29	....
Titanic acid	....	....	....	1.04	1.07	0.58	0.68	0.55	....
Sulphuric acid	....	....	....	....	....	....	....	....	0.83
Loss in ignition	....	1.19	....	1.11	1.56	2.43	0.64	....	1.37
Total	99.82	100.53	99.52	99.38	100.72	100.27	100.26	100.76	100.14

1. Coll. No. 163.—Rhyolite from Rescue Canyon. Analysis by R. W. Mahon. 1883.

2. Coll. No. 121.—Rhyolite from top of Pinto Peak. Analysis by Dr. Edward Hart, of Lafayette College. 1883.

3. Coll. No. 175.—Rhyolite overlying dacite from northeast of South Hill. Analysis by R. W. Mahon. 1883.

4. Coll. No. 35.—Hornblende-mica-andesite from hill northeast of Hoosac Mountain. Analysis by R. W. Mahon. 1883.

5. Coll. No. 69.—Dacite, small canyon northeast of South Hill. Analysis by R. W. Mahon. 1883.

6. Coll. No. 71.—Andesitic-pearlite, south of Carbon Ridge. Analysis by W. H. Melville. 1890.

7. Coll. No. 79.—Pyroxene-andesite, Richmond Mountain. Analysis by Dr. Thomas M. Drown, Institute of Technology. 1883.

8. Coll. No. 284.—Basalt from saddle east of Basalt Peak. Analysis by Dr. Edward Hart. 1883.

9. Coll. No. 269.—Basalt, summit of Richmond Mountain. Analysis by J. Edward Whitfield. 1886.

These nine analyses of carefully selected material represent the composition of the entire mass of extravasated lavas at Eureka and show a range in their tenure of silica of over 25 per cent. Lavas from 1 to 6, inclusive, belong to the feldspathic magma, and those from 7 to 9,

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[1] Am. Jour. Sci., 3d ser., 1887, vol. XXXIII, pp. 45–50.

inclusive, to the pyroxenic magma. Analyses numbered 2, 4, 7, 8, and 9 give the composition of typical rocks from different natural groups and of the most extensive bodies of rhyolite, hornblende-mica-andesite, pyroxene-andesite, acidic basalt, and normal basalt. Each of these five rocks carries about 6 per cent more silica than the one standing next below it in the series.

All the vast accumulation of lavas may be regarded either as belonging to, or as variations from, these main types, or else as transition products between two closely related natural groups.

Along the Hoosac fault, where the most basic unaltered rocks of the feldspathic magma are best developed, solfataric action has so decomposed them that it becomes a matter of much difficulty to determine even approximately their original basicity, as they all show more or less evidence of infiltration of siliceous material. The oldest lavas occurring in any extensive body and still preserved in a fresh condition consist almost wholly of hornblende-mica-andesite, represented by the rock northeast of Hoosac Mountain, carrying, according to analysis, 67·83 per cent of silica. The fine rhyolite from Pinto Peak, free from ferro-magnesian silicates and rich in well developed orthoclase, is typical as regards chemical composition of the acidic end of the feldspathic magma along the same great line of displacement.

It will be noticed that the dacite from northeast of South Hill carries ·8 per cent of silica less than does the hornblende-mica-andesite, whereas on theoretical grounds it would be expected to show an amount somewhat in excess, owing to the presence of quartz secretions. The rock was selected on account of its well recognized geological relations with an overlying rhyolite body, an analysis of which, for comparison, will be found in the table. Normal dacite of the Great Basin usually carries about 70 per cent of silica, whereas this rock stands as an intermediate variety between it and the andesite. A study of the chemical analysis explains the mineral composition. The large amount of iron and magnesia in excess of that found in the rhyolite and the falling away in the percentage of potash are sufficient to account for both the predominance of biotite and the absence of sanidine. The plagioclastic nature of the prevailing feldspar assigns the rocks to the andesites, while the presence of quartz as an essential constituent places it more correctly among the dacites. For the erupted material of Eureka it stands as one of the most basic rocks of the feldspathic magma, rich in porphyritic quartz secretions.

The most basic of the feldspathic lavas analyzed is an andesitic pearlite, very limited in extent, containing 65·13 per cent of silica, the complete analysis of which will be found in column 6 of the table. It carries well developed feldspars, with some hornblende and biotite, but is especially noticeable for the numerous pyroxene microlites which enter into the structure of the very glassy groundmass. The rock, although belonging to the acidic lavas, is allied to the basic magma by the coming in of these microlites of pyroxene, which more or less modify the nature of the glassy groundmass and relate it in structural habit to the rocks of Richmond Mountain. It is doubtful if any fresh rock of the feldspathic magma would fall much below 65 per cent in silica. An analysis of a typical rock from Richmond Mountain, given in column 7 of the table, yielded 61·58 per cent of silica. The most acidic rocks derived from the pyroxenic magma, as shown by a series of silica determinations in partial analyses, is 62·41 per cent. As these analyses are only partial, they are not published. They show variations from 49 to 62 per cent of silica, with a gradual falling off in soda and potash as the rocks develop more and more magnetite and olivine. The most basic basalt examined yielded about 49 per cent of silica.

By reference to the table of complete analyses it will be seen that the lime, magnesia, and oxides of iron increase from the acidic to the basic end of the series. Of these bases, lime is the most regular in its behavior and presents the widest range, starting with less than 1 per cent in the rhyolite of Pinto Peak and reaching over 10 per cent in the dike of intrusive basalt which cuts the pyroxene-andesite near the summit of Richmond Mountain. It should be borne in mind that the Pinto Peak rock carries no ferro-magnesian minerals and the feldspars are for the most part sanidine. Magnesia stands second in this uniform increase, but is wholly wanting in the rhyolites, coming in with the first appearance of the ferro-magnesian-silicates and increasing rapidly with the development of pyroxene and olivine. In general both alkalies may be said to decrease from the acidic toward the basic end, and, except in the more basic basalt, the potash exceeds the soda in amount.

There is a much greater range throughout the entire series of lavas in the percentage of potash than in that of soda, the former showing a variation of over 3·25 and the latter of only 1·50 per cent. The greatest interruption in the regularity of the potash is shown along the line where the sanidine disappears and some one or more of the lime-soda feldspars become the predominant species, whereas with the soda no such break is noticeable. In the liquid mass, under influences very little understood, the material forming ferro-magnesian minerals draws apart from the alkalies and excess of soda, the result of which is to produce separate magmas differing widely in chemical composition.

Common Source of Lavas.—In the preceding pages all the extravasated lavas have been considered as belonging to one or the other of two distinct magmas, yet it is impossible, notwithstanding they are so sharply contrasted in certain fundamental structural characters, not to recognize the fact that both magmas stand in the closest relationship to each other. The similarity in mineral development as they approach each other in chemical constitution, the gradual changes in the relative proportions of the oxides of the different elements throughout the entire range of lavas, show how close a connection exists between them. An equally strong argument is found in their geological distribution, where the rhyolite occurs closing up the vents occupied by the feldspathic magma and at the same time breaking out as the earliest eruptions along fissures which later served as channels for the pyroxenic magma. The loci of eruption of both magmas have been shown to be in close proximity to each other, and some of the most acid and most basic lavas, so far as external evidence can determine, not only reached the surface along the same great fractures, but actually used the same conduits at a number of localities.

To the writer, after studying all the facts, it seems impossible to regard these differentiated volcanic products otherwise than as belonging originally to one and the same body of molten material; in other words, they were derived from a common reservoir. To conceive of such a separation from an earlier primordial molten mass is no more difficult than to conceive of the breaking up of the feldspathic magma into a hornblende-mica-andesite and a rhyolite group, and the latter has been shown to take place, so far as it is possible to demonstrate it from surface evidences, along fissure planes through which the lavas issued. The original magma separated into a heavier and a lighter portion, the groundmass structure of the two being fundamentally different. It will be borne in mind that the earlier magma consisted of a groundmass made up of an aggregation of feldspar and quartz grains, through which were disseminated porphyritic secretions of hornblende and mica, but no pyroxene, except in a few instances of pyroxene microlites in the groundmass of some varieties of andesite. The later magma consisted of a groundmass composed of lath-shaped lime-soda feldspars and pyroxene microlites, so intricately interwoven as to form the so-called felt-like structure characteristic of pyroxene-andesite, through which were scattered the heavier ferromagnesian minerals already described.

History of Volcanic Action.—The geological history of volcanic action at Eureka during Tertiary time is in many respects simple and, after a careful study of its details, easily deciphered. There are among the lavas no masses of coarsely crystalline rocks slowly cooled beneath the surface under physical conditions different from those usually found accompanying extrusive flows. No powerful displacements have brought into juxtaposition igneous rocks of different ages, crystalline structure and mineral composition, and although faulting attending extravasation doubtless did occur it was not of a kind to obscure geological structure. Again, the sequence of events was not complicated or broken by long intervals of activity and rest through successive geological epochs during which an older and a younger series of eruptions took place; but on the contrary the lavas were apparently poured out under very similar physical conditions from the beginning to the end of volcanic action. In coming to the surface these lavas were not forced upward as one continuous eruption or rapid series of eruptions, but were the result of a succession of overflows accumulating slowly, although at times spasmodically, along lines of volcanic activity coincident with lines of orographic displacement. The material thus poured out gradually underwent changes in mineral composition offering a great variety of volcanic products of which the relative age and order of succession of typical lava flows have been clearly established. It has also been demonstrated that throughout this entire series of lavas the range in silica amounts to about 25 per cent, a range which is quite as wide as is ordinarily found in most centers of eruption, even where the volume of lavas thrown out has been vastly greater and the duration of volcanic energy far longer. The succession of events throughout the volcanic period presents a continuous chapter of geological history complete in itself with the rise, culmination and dying out of eruptive energy. So far as ultimate chemical composition of both acid and basic rocks is concerned it furnishes a complete cycle of volcanic products.

Probably the feldspathic and pyroxenic lavas do not approach each other in their tenure of silica within 2·25 per cent, at least no body of rock or lava stream is known which indicates a closer coming together of the two magmas. In chemical composition and mineral development the earliest eruptions of both magmas resemble each other closest, but from this common ground they differentiate steadily until the feldspathic lavas reach the extreme acidic and the pyroxenic the extreme basic end of their respecive series. The former and earlier magma exhibits in the overflows a constantly increasing acidity through a range of 11 per cent of silica, and the latter an increasing basicity with a falling away in silica of 13 per cent, the point of separation of the two magmas being nearly midway between the extremes in composition.

Exceptional lavas in other localities may carry somewhat more silica than those thrown out at Eureka, but it is doubtful if flows of any considerable size exceed those of Rescue Canyon in acidity by more than 2 per cent unless accompanied by secondary alterations or infiltration products. Obsidians are reported as carrying 78 per cent of silica, but for the most part these highly acidic glasses fall within the limits assigned to normal rhyolites. Basalts somewhat richer in olivine and magnetic iron are by no means uncommon elsewhere, but these extreme basic varieties have not as yet been recognized within the Great Basin. Not only as regards the range in silica, but for all other essential elements entering into the original composition of magmas, this series of lavas may be taken as representative of many others in widely separated regions throughout the world. To the lavas of Hungary they show very close resemblance.

Beginning with the hornblende-andesite the feldspathic magma became gradually more siliceous until the close of the rhyolitic eruptions without any abrupt break in the outpourings or the intervention of any perceptible change in geological conditions. It seems impossible, therefore, to consider these lavas in any other light than as a continuous succession of flows, interrupted only by time intervals of longer or shorter duration. Notwithstanding these gradual transitions, certain type rocks prevail to a far greater degree than others, both as regards bulk and distribution, notably the hornblende-mica-andesite and the Pinto Peak variety of the rhyolite, the two standing out prominently as the principal eruptions of the feldspathic series. The dacites are greatly limited in their bulk, and the same is true of all rocks of intermediate composition, the greater part of them being easily classed under one or the other of the natural groups.

The earliest outbursts along different profound fissure planes have not necessarily been identical in composition or synchronous in time. Along some of these the first overflows observed are hornblende-mica-andesite, in others highly siliceous andesitic pearlites, in still others dacites, and in several of them rhyolites, but in no single instance, whatever may have been the nature of the earliest lava poured out, has a more basic member of the feldspathic series been recognized as breaking out along the same fissure. It is as if certain of these fissures were opened by the forcing upward of the lavas at different periods of eruptive energy and the vents filled by a magma of definite composition at that time coming to the surface simultaneously through all the fissures. It is also worthy of note that along the meridional faults the andesitic material for the most part broke out at the northern ends, the lavas in general growing more acidic toward the south. Furthermore, certain fissures becoming filled and choked by cooling and crystallization have prevented the more acidic lavas from finding an outlet at the surface along the same line where the earlier portions of the molten mass broke out.

When it comes to the pyroxenic magma it is found to break out and follow the sinuous lines of fracture previously followed by rhyolitic lavas. In some instances they present the appearance of actually employing the identical conduits used by the feldspathic magma. In this way the rhyolite plays a most important part, not only as a connecting link between the feldspathic and pyroxenic magmas in respect to sequence of flow, but still more as regards geological distribution and mode of occurrence. Too much stress can not be laid upon the fact already mentioned, that the rhyolites were the last to break out along the vents occupied by the hornblende-andesite and the first to reach the surface along the same lines of fracture which were afterward used by the basalts of the pyroxenic magma. That these basic lavas may have occasionally forced open new vents for themselves is quite possible, but the greater number of outbursts followed the same grand fractures as the earlier highly acidic magmas which border the elevated orographic block of Silverado and County Peak. Richmond Mountain, as already pointed out, may have reached the surface through a separate and wholly independent vent, but it is so vast and its overflows cover so large an area that it is impossible to determine the position of its vent or vents and their precise relation to the earlier rhyolite. It must be borne in mind, however, that it breaks out at the junction of two grand lines of faulting, coming up from the south on opposite sides of a great uplifted mountain mass. The earliest flows of the pyroxenic magma resembled those of the feldspathic magma, in so far as they carry the same ferro-magnesian silicates as porphyritic secretions. On the other hand, they are sharply contrasted by an andesitic habitus of the groundmass, which, however, had been slightly foreshadowed by a groundmass carrying pyroxene microlites, shown in the basic pearlite from the south end of Carbon Ridge, where the rock occurs as the earliest eruption at that locality, followed by a series of feldspathic lavas, closing with rhyolite.

Following the great body of pyroxene andesite came lavas intermediate in composition between them and basalt, breaking through and overlying the less basic varieties. Some of these are allied to the earlier flows, while others show a decided tendency to transition into basalt. Most of them are related geologically either with the later basaltic eruptions or stand alone, having broken through rhyolite. A large portion of the rock masses designated as pyroxene-andesite would hardly be classed as typical rock of that natural group, and the same may be said of many of the basaltic flows which are far too rich in silica and wanting in olivine to be regarded as normal basalt. It is probable that many modern volcanoes would show the same wide range in basic lavas as is developed in the region of Richmond Mountain.

Throughout a wide range in composition and over an extended geographical area the pyroxenic magma fails to show the tendency, so strongly marked in the feldspathic magma, to separate into well defined natural groups, nor is the evidence by any means clear that during the period of extravasation a steady increase in the basicity of the lava took place without occasional oscillations in composition. Nevertheless, it is evident that whatever oscillations there were must have been confined within very narrow limits and restricted to lavas of intermediate composition between pyroxene-andesite and basalt. No pyroxene-andesite dikes have been observed penetrating either the basalts or the intermediate lavas.

It seems evident from field observations that there were no abrupt alterations of feldspathic and pyroxenic lavas after the appearance of the earliest pyroxene-andesite.

Speculative Theories.—It does not come within the scope of this chapter, which is mainly devoted to a presentation of observed facts, to enter upon a full discussion of the speculative theories advanced by geologists to account for the condition of the molten masses beneath the surface, nor the physical causes leading to their separation into the varied products found either as interbedded sheets and laccolites within the superficial crust of the globe, or poured out upon the surface as extrusive lavas. Yet, at the same time, after having devoted so much study to the constitution of the different lavas and their order of succession, this chapter would be incomplete without calling attention to the importance of the phenomena presented at Eureka and pointing out the bearing of the observed facts upon the problems offered in volcanic regions elsewhere. Without entering upon a review in detail or a critical discussion of the opinions held by others who have considered these speculative matters, it is necessary to recall, briefly, the views expressed in the more important contributions to the literature on the subject.

Bunsen's Views.—Bunsen, after a visit to Iceland, where he laboriously studied the volcanic phenomena displayed on a grand scale, conceived the idea of two distinct bodies of lava, one acid and the other basic, the former of which he designated as the normal trachytic, the other as the normal pyroxenic magma. He was disposed to regard all volcanic products intermediate in composition between these types as admixtures in varying proportions derived from two distinct foci of eruption, the relative proportions of each depending in great part upon the intensity of eruptive energy. He sought to apply his views to all other volcanic regions, citing as an identical mode of occurrence the table-land of Armenia.[1] The grand division of volcanic products into acid and basic lavas has been received by most vulcanologists, but his theories to account for the very varied constitution of volcanic rocks has not obtained the same general acceptance. In this chapter the writer adopts the views of Bunsen as regards two great groups of lavas, but differs with him as to the origin of the varied transition products of eruption.

The writer has used the expression feldspathic magma in preference to trachytic magma, as the former is a mineralogical term contrasting sharply with the expression pyroxenic magma. This is rendered all the more necessary since the word trachytic now possesses a different signification from what it did at the time when it was first employed by the German scientist. Typical trachytes are somewhat rare and confined to restricted areas, since many of the rocks formerly considered as trachyte have been found to be characterized by plagioclastic feldspars, and hence more properly come under the head of andesite. This is the case with the feldspathic rocks of Iceland, which Bunsen investigated and upon which he bases his conclusions.

Durocher's Theories.—Durocher,[2] after studying the composition and petrographical characters of a large number of crystalline rocks, endeavored by ingenious and somewhat complex theories to establish universal laws to account for the variations observed in crystalline rocks of all ages and

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[1] Ueber die Processe der vulkanischen Gesteinsbildung Islands. Poggendorf's Annalen, 1851, Band 83, pp. 197-272.

[2] Essai de pétrologie comparée. Ann. d. mines, Paris, 5th ser., 1857, Tome XI, pp. 217-259.

of every possible mode of occurrence. He followed Bunsen in accepting the theory of both an acid and basic magma, but regarding them as parts of the same body of lava. In an appendix to his paper[1] he admits the possibility in certain cases of a mingling of both types, but objects to the hypothesis of Bunsen as altogether too broad a generalization. That part of Durocher's hypothesis which possesses the most originality and upon which he places the most stress to account for the differences in the mineralogical character of lavas has been designated the liquation process applied to igneous rocks. His conclusions, based largely upon chemical analyses, were not substantiated by any array of facts or observations from any one center of volcanic energy. Durocher was disposed to regard certain lavas as differentiated products obtained by the breaking up of a magma by processes comparable to the separation and segregation of metals in a bath containing several metallic substances in a state of fusion, the theory being based upon well recognized processes employed in metallurgical establishments for the concentration of gold and silver in molten lead. The views enunciated by Durocher have met with slight recognition, but, although containing much that with the advancement of knowledge has been shown to be based upon error, they are, in the opinion of the writer, full of the most valuable suggestions bearing on the origin of lavas, and entitled to far more consideration than has generally been accorded them.

Roth's Views.—In 1861 Justus Roth[2] published his hypothesis of "Spaltung und Differenzirung," in which he elaborated similar views, although by no means identical with those held by Durocher. For the purposes of this chapter it is sufficient to say that the two authors are in accord so far as believing in the power of a magma to split up during crystallization into secondary magmas of different mineralogical composition. Roth regarded large bodies of crystalline rocks as "Spaltungsproducte," the result of the separating out of certain groups or association of minerals from and dependent upon the composition of a primary liquid lava, but governed by varying conditions of pressure and temperature. His views are derived

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[1] Op. cit., p. 677.

[2] Tabellarische Uebersicht der Gesteins Analysen und mit kritischen Erläuterungen. Berlin, 1861.

from a careful study and comparison of a large number of chemical analyses of crystalline rocks gathered from all parts of the world, differing widely in their mineralogical development and structural habit.

Besides these references to original contributions the reader who desires to pursue the subject still further will find an excellent summary of the views of Bunsen, Durocher, Roth, and others, published by Ferdinand Zirkel in his text-book of petrography.[1]

Waltershausen's Conclusion.—Sartorius von Waltershausen, after a careful investigation of the lavas of Sicily and Iceland, published the results of his researches in an elaborate memoir in which he presented his conceptions of the physical condition of the interior of the earth. His conclusions, so far as they relate directly to subjects considered here, stated briefly, were that between a superficial cool crust and a solid interior there existed a broad belt of fused material of undetermined thickness which furnished the source of supply for the lavas poured out upon the surface. This material arranged itself approximately according to its density. The most acid lava, being the lightest, was situated nearest the surface, followed by that of intermediate composition characterized by minerals of somewhat higher specific gravity, and terminating finally with the heaviest, and consequently most basic, lavas—basalts—carrying large amounts of magnetite and other iron minerals. He concludes that in most instances the lavas were ejected in the order of their position, the lightest being first thrown out, imperfect separation by specific gravity being sufficient to account for all exceptional occurrences. This simple and regular order of succession met nearly all the requirements of Waltershausen's personal observations and were in accord with his theories.[2]

Richthofen's Views.—Baron von Richthofen accepted the main conclusions of Waltershausen regarding the physical conditions of the globe, agreeing with him as to the evidences of a liquid mass lying between a solid interior and a superficial outer crust. This liquid mass was acid near the surface, basic beneath, with the intermediate transition lavas between them. He traveled extensively in the volcanic regions of Europe

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[1] Lehrbuch der Petrographie. Bonn, erster Band, 1866, pp. 453–473.

[2] Ueber die vulkanischen Gesteine in Sicilien und Island und ihre submarine Umbildung, Göttingen, 1853.

and western America, studying the development of volcanic rocks. He devoted special attention to the laws governing the mode of occurrence of the different natural groups into which he divided all igneous rocks, and the relations of these groups to each other, being more interested in the geological problems than in the precise chemical composition of the extruded products. As a result of his observations in the field, he was impressed by the great similarity in the nature of lavas in widely separated regions and the uniformity in the order of their succession. He found, however, that this succession was by no means as simple as suggested by Waltershausen, nearly every volcanic region which he visited presenting abrupt, but similar, alternations from acid to basic rocks, at first sight not readily explained. Richthofen's final conclusions were published in an admirable and remarkably suggestive memoir presented to the California Academy of Sciences,[1] in which he gives what he considers to be the natural law of the sequence of massive eruptions applicable to all centers of volcanic energy. As his conclusions were based largely on observations made in California and the western edge of the Great Basin, they are of more than ordinary interest for purposes of comparison with results since obtained by the investigations at Eureka.

The natural order of succession of massive eruptions as laid down by Richthofen is as follows:[2]

1. Propylite.
2. Andesite.
3. Trachyte.
4. Rhyolite.
5. Basalt.

This law of succession as enunciated by Richthofen is far more complex than the simple regular order suggested by Waltershausen, as it supposes the breaking out, first of all, of intermediate lavas represented by propylites and andesites, followed by others of varying composition, but more acidic than the latter and belonging to the order trachytes. The trachytes were succeeded by a still more acid series of lavas, and then the closing of eruptive energy by an abrupt change from the most acidic of all

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[1] Natural system of volcanic rocks. Memoirs of the California Academy of Sciences, 1867, vol. I, p. 36.

[2] Op. cit., p. 29.

lavas, the rhyolites, to the most basic of all, the basalts. From this order he nowhere recognized any deviation. Accepting the hypothesis of Waltershausen as regards a liquid interior and the nature of the molten mass, he seeks to account for the remarkable alternations observed in lavas upon the surface of the globe by supposing changes to take place in the physical conditions governing the emission of lavas which would from time to time elevate or depress the loci of eruption. These changing conditions were universal, producing similar results in volcanic centers all over the world, but not necessarily contemporaneous in time. He says:

> It appears that after the ejection of the chief bulk of andesite, when other processes ending in the opening of fractures into the basaltic region were being slowly prepared in depth, the seat of eruptive activity ascended gradually to regions at less distance from the surface.[1]

Clarence King's Views.—As a part of the report upon the Geological Exploration of the Fortieth Parallel, Mr. Clarence King published in 1878 the results of his researches upon the genesis of lavas as shown by their occurrences in the field of his observations in the Great Basin. As regards the law of succession, his views are for the most part in accord with those of Richthofen, he going, however, still further and finding a much more intricate system in the alternations from acid to basic rocks. He finds an acid, a neutral, and a basic member in each natural group or order which he designates by specific names, each member having a definite mineral composition and a fixed place in the order of succession. To these modifications proposed to Richthofen's order he adds another still more radical, in respect to classification, uniting rhyolite and basalt under one head, to which he applies a new designation, "Neolite," these two types of lava constituting the acid and basic subdivisions of this natural group, having the same relative value as andesite and trachyte. The sequence of lavas as recognized by Mr. King is as follows:[2]

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[1] Op cit., p. 58.

[2] U. S. Geol. Explor. of the Fortieth Parallel, vol. I, Systematic Geology, p. 690.

Natural succession of volcanic rocks.

Order.	Subdivision.
1. Propylite	*a*. Hornblende-propylite.
	b. Quartz-propylite.
	c. Augite-propylite.
2. Andesite	*a*. Hornblende-andesite.
	b. Quartz-andesite (Dacite).
	c. Augite-andesite.
3. Trachyte	*a*. Hornblende-plagioclase-trachyte.
	b. Sanidine-trachyte (quartziferous).
	c. Augite-trachyte.
4. Neolite	*a*. Rhyolite.
	b. Basalt.

This presents a much more complex system and could hardly be accepted upon the simple conditions of a uniform and widespread liquid mass, as held by Waltershausen and modified by Richthofen, in requiring frequent elevation and depression of the loci of eruption in accord with the changes in the composition of the lava thrown out at the surface. Mr. King is fully aware of the many physical obstacles encountered, and explains the many oscillations and abrupt alternations in the volcanic products which his system calls for by a carefully considered hypothesis of his own, quite at variance with the views advanced by his predecessors. In place of a broad belt or magma of liquid lava encircling the earth beneath the sedimentary crust, he holds to the opinion of local reservoirs of molten matter within the superficial crust, each of his orders being the product derived from one of these reservoirs, or, as he calls them, "extremely localized and only temporarily existing pools of fusion." He says:

> Under my hypothesis, by which fusion is the temporary result of erosion, each one of Richthofen's orders, with its acidic and pyroxenic members, would be considered as the product of a single ephemeral lake. A period of erosion under this conception would result in the formation of a lake. The cessation of erosion, either from climatic causes or from the degradation of centers of erosion, would place a limit to the expansion in depth of fusion; in other words, would define the time limits and the vertical expansion of the lake.[1]

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[1] Op. cit., p. 716.

His views, which can not well be abridged here, will be found admirably stated in his chapter devoted to a discussion of the genesis of volcanic species, in which he treats of geological causes leading to the formation of local lakes of lava.

Later Observations.—Since the publication of King's memoir the study of volcanic rocks has progressed with rapid strides, and nowhere have they been investigated with more untiring energy than in the Cordillera of North America. Notwithstanding our knowledge of the rocks of the Washoe District and the Comstock Lode, derived from the works of Richthofen and King, later study of them, aided by methods of microscopical research, has developed fresh points of interest bearing upon their order of succession and mutual relations. After a thorough examination of the propylites, Mr. George F. Becker[1] has shown that they can not be separated from the andesites as an independent rock species based upon any mineralogical distinctions, since the peculiar habitus of the propylite is due to chemical change and decomposition of the constituent minerals. Moreover, the propylites and andesites are found to pass into each other by gradual transitions.

Hague and Iddings,[2] in the course of their examination of the Washoe rocks, confirmed the results of Mr. Becker so far as the identity of the propylite and andesite is concerned, and also failed to see any geological evidences of a preandesitic eruption.

Similar views as regards the independence of propylite are now maintained by nearly all petrographers who have given much thought to the subject or who attempt to classify volcanic rocks upon either a structural or mineralogical basis.[3]

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[1] Geology of the Comstock Lode and the Washoe District, Washington, 1882.

[2] On the development of crystallization in the igneous rocks of Washoe, Nevada; with notes on geology of the district. Bull. U. S. Geol. Survey, No. 17, Washington, 1885.

[3] Since this chapter was written Prof. J. W. Judd has published an admirable paper on "The Propylites of the Western Isles of Scotland, and their Relation to the Andesites and Diorites of the District." He revives the use of the term propylite, but in the strict sense suggested by Rosenbusch, regarding it simply as a "pathological variety" of andesite. His detailed descriptions identify the Scottish rocks with similar rocks found in Hungary. From his description it would be difficult to distinguish them in any particular from the altered andesites of the Washoe District in the Virginia Range. They even show the development of metallic sulphides. Quart. Journ. Geol. Soc., vol. XLVI, pp. 341-382. London, 1890.

The same writers have demonstrated the nonexistence of trachyte as one of the natural divisions of volcanic lavas in the Great Basin, the occurrence of orthoclase rocks free from quartz secretions being almost unknown in that region. These recent advances in our knowledge of volcanic rocks tends to simplify the law of sequence so far as their occurrence in the Great Basin is concerned, since two of the groups, the propylite and the andesite, as laid down by Richthofen, have been merged into one, and the trachytes either relegated to some variety of andesitic lavas or placed among quartz-bearing rocks, either dacite or rhyolite. The importance of these observations lies in the fact that there is no interpolation of a strongly alkaline magma in the series of lavas, and that andesitic lavas pass over directly into rhyolite. Not only in the Great Basin but in many other regions as well, rhyolite is far more closely related to andesites derived from a feldspathic magma than to trachytes.

Having thus briefly reviewed the literature bearing upon the genesis of lavas and their order of succession, it becomes a matter of much interest to see how far the facts observed in a carefully studied and surveyed region like Eureka are in accord with the views expressed by the eminent writers quoted, since it is only by the accumulation of vast amount of evidence from many widely separated fields that we can hope to attain anything like definite laws governing the mutual relations of igneous rocks.

In only one other region of the Great Basin have volcanic phenomena been investigated in a manner at all comparable with Eureka and that one the much discussed area of the Washoe District. At Washoe the conditions are in some respects very different, volcanic activity having extended through a longer period of time. The coarse crystalline rocks which form the long slopes of Mount Davidson do not make their appearance at Eureka, and for that matter are wanting over the greater part of the Nevada plateau. They belong to an earlier period, forming a distinct chapter in the Tertiary history of volcanic action.

The earliest eruptions at Eureka may be correlated with the hornblende-mica-andesite of Washoe (trachytes of Richthofen and King and later hornblende-andesites of Becker) in mineral composition and structural features. They may be regarded from the point of view of this chapter as synchronous in age, since the succession of all subsequent lava-flows for the feldspathic rocks in both localities may be said to be the same—hornblende-mica-andesite, dacite, rhyolite. Analyses show the hornblende-mica-andesite rocks of Eureka to carry slightly more silica than the corresponding rocks at Washoe, the most acid members of this group from the latter locality. coming just within the range of the basic members of the series at Eureka.

When it comes to the pyroxenic rocks following the rhyolite the sequence of events does not appear so clearly established at Washoe, as there no such grand exposures occur as at Eureka. In the immediate region of the Comstock Lode only a few isolated patches of basalt are exposed. Small outbursts of pyroxene-andesite, similar to those of Richmond Mountain, have broken out only a short distance from Mount Davidson, but the relations between these two pyroxenic lavas are unknown. A few miles northward in the same range of mountains large flows of both pyroxene-andesite and basalt may be seen superimposed upon hornblende-mica-andesite and rhyolite. Taken together the Washoe District and the region of Truckee Canyon present a sequence of lavas and a geological history of volcanic events similar to that found at Eureka.

The subjoined table presents a series of twelve chemical analyses representing the volcanic rocks of Washoe arranged according to their basicity:[1]

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[1] **On the development of crystallization in the igneous rocks of Washoe, Nevada; with notes on the geology of the region. Bull. U. S. Geol. Survey, No. 17, p. 33.**

Analyses of Washoe Rocks.

Number.	Determination.	Locality.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	Na_2O	K_2O	Other components.	Ignition.	Total.	Analyst.
I	Basalt	North of American Flat Creek.	47·91	2·70	14·26	1·05	7·80	trace.	9·60	10·83	3·01	1·89	Li_2O . . trace	0·37 H_2O	100·02	Samuel L. Penfield.
II	Granular pyroxene-andesite.	Eldorado outcrop	56·71	......	18·36	......	6·45	......	6·11	3·92	3·52	2·38	....	1·94 H_2O	99·39	R. W. Woodward.
III	Pyroxene-andesite	Sutro tunnel, foot-wall, Savage connection.	56·40	1·14	15·99	3·26	3·82	0·12	6·98	3·54	3·83	1·91	P_2O_5 . . . 0·32	2·47	99·78	Gideon E. Moore.
IV	Hornblende-andesite	Center of Cedar Hill ridge.	58·55	0·83	15·48	3·03	2·07	0·11	6·44	3·60	3·99	1·69	P_2O_5 . . . 0·30	3·62	100·61	Do.
V	Pyroxene-andesite (herblende bearing).	Ridge northeast of American Flat.	58·44	......	18·17	......	6·03	......	6·19	2·40	3·20	1·97	CO_2 . . . 2·87	0·76	100·03	W. G. Mixter.
VI	Pyroxene-andesite (hornblende bearing).	Silver terrace	59·22	......	18·20	......	6·69	......	5·51	2·90	3·31	1·39	....	2·80 H_2O	100·02	Do.
VII	Hornblende-andesite	Cross Spur quarry below Graveyard.	60·82	......	17·54	......	5·42	......	5·65	1·76	3·71	1·41	CO_2 . . . . 1·41	2·31	100·13	Do.
VIII	Hornblende-mica-andesite.	Mount Rose	63·30	......	17·81	3·42	0·83	......	5·12	2·07	4·27	2·26	Li_2O . . trace	0·88 H_2O	99·96	R. W. Woodward.
IX	Hornblende-mica-andesite.	Cross Spur quarry	63·13	......	16·00	4·34	1·52	......	4·45	2·07	3·87	2·65	....	2·00 H_2O	99·54	Do.
X	Mica-andesite	800 feet east of Waller Defeat shaft.	65·68	0·98	15·87	1·78	1·25	......	3·50	1·79	3·20	3·37	P_2O_5 . . . 0·23	3·10	100·75	Gideon E. Moore.
XI	Dacite	Spur northeast of McClellan Peak, near American Flat road.	69·96	......	15·79	2·50	......	......	1·73	0·64	3·80	4·12	....	1·53	100·07	F. A. Gooob.
XII	Rhyolite	South-southeast of McClellan Peak..	73·07	......	11·78	2·30	......	......	2·02	0·39	1·19	6·84	....	2·24	99·83	Do.

Analyses Nos. II to VII, inclusive, represent Tertiary rocks older than any found at Eureka, but from Nos. VIII to XII, inclusive, together with No. I, they correspond fairly well to similar lavas at the latter locality. In this table, however, pyroxene-andesites similar to those of Richmond Mountain and of the same geological position, associated with basalts and later than the rhyolites, were not shown, for the reason already stated: that they lie beyond the limits of the mining districts.

Nowhere else between the Wasatch and Sierra have the lavas been so carefully mapped, and only in a few places do they appear so varied and complete. In many centers of eruption, even where the amount of lava poured out is large, certain types of rock are wanting, and in others their relative position can not well be determined owing to frequent breaks in the continuity of exposures.

The history of volcanic action may be fragmental and only partially recorded in any one locality, but throughout the Great Basin, where the physical and geological conditions were much the same during the volcanic period, it is probable that the sequence of lava will be found to be in accord in many places with the observed facts at Eureka. As a center of eruptive energy in Tertiary time the Great Basin stands out as a geological unit.

The earliest lavas erupted at Eureka carry from 65 to 67 per cent of silica and are of intermediate composition, in accordance with the broad generalization of Richthofen and the facts observed by others elsewhere. From this middle ground, however, the lavas increase in acidity until they attain the composition of the extreme acid types. The latter are in turn followed by lavas that are also intermediate in composition, but which increase in basicity until they attain the extreme basic type found in the later basalt.

Starting from a magma closely related in composition, they differentiate in opposite directions from this common ground until they reach the extreme type. It will be borne in mind that the existence of both an acid and a basic magma at Eureka have been clearly established, and to this extent conform to the views held by Bunsen. Nowhere are the two magmas better exhibited, as shown in their distribution, mode of occurrence, and even in the outlines of the lava masses, both types of rock being sharply contrasted in their surface features. In the opinion of the writer, however, there are too many insurmountable physical obstacles and too few established facts to warrant the acceptance of any theory which attempts to account for the varied products of eruption by supposing them to be admixtures from wholly distinct reservoirs. The observed geological phenomena at Eureka tend to controvert such a theory where the two magmas, although in close proximity, fail to show any mingling of products from separate reservoirs.

Furthermore, there are no evidences of any alternating flows of feldspathic and pyroxenic magmas, nor of oscillations in relative acidity within any acid magma, which would certainly be the case had there been any basic material injected into the feldspathic lava. Within limited range any large outburst of lava doubtless may display slight variations in composition, but this also holds true for different parts of the same flow, and is still more noticeable in pyroxenic magmas owing to the greater liquidity of basic lava streams and the consequent tendency of the basic mineral secretions to lag behind. The first violent explosions after cessations of activity might readily throw out a lava slightly different in composition from the regular even flow of the mass, and again the last portions might vary somewhat in character from the great bulk of molten material.

Evidence is wanting at Eureka that the lavas were thrown out, geologically speaking, from great distances below the surface or from very varying depths; at least the lavas themselves do not indicate that there were any profound orgraphic movements during the eruptions. Nor is there any evidence of oscillation in depth from which the material was derived, even if we accept differences in specific gravity as evidence of increase of distance from the surface. There was one, and only one, great break in the mineralogical character of the lava. Changes in specific gravity were gradual, but at the same time they covered nearly the entire range of variation ordinarily found in volcanic lavas. Such heavy minerals as zircon, allanite, and garnet occur in the rocks of the lowest specific gravity, and in the case of zircons they are nowhere found better developed than in the glassy rocks which must have cooled near the surface. As these heavy infusible minerals were the first to crystallize out, they should have sunk to the bottom if their position in the molten mass was mainly a question of specific gravity. The writer can not but regard the lavas as derived from a local reservoir, all the ejected material having had a common source in some primordial magma. The order of succession is governed by far-reaching physical forces which may vary greatly in different volcanic areas, dependent on conditions of heat and pressure. A powerful orographic movement such as frequently happens during a period of volcanic action may be sufficient to affect the entire geological conditions in any eruptive center. In widely separated parts of the world the extravasated products are singularly alike, yet the sequence of lavas within restricted limits show very considerable variation.

Supposing the products of eruption and order of succession to have been much the same over the geological province of the Great Basin, it does not follow that the same succession of events took place in another region where the geological conditions were obviously different. Within the observations of the writer instances are known outside the Great Basin where such an order of events not only did not take place, but where the mutual relations of nearly identical lavas exhibit a succession strikingly at variance with the sequence of flow as found at Eureka. The Yellowstone Park may be cited as an instance where the succession of lavas is somewhat different. In the latter locality the earliest eruptions were of intermediate composition, consisting of hornblende-andesite and hornblende-mica-andesite. While the sequence of lavas may vary owing to geological conditions, the laws governing the differentiation of lava hold good everywhere.

Basalt and Rhyolite.—The writer accepts, with some important modifications, the views of Mr. Clarence King regarding rhyolite and basalt, not only as geologically closely related rocks, but also as extreme members of the same primordial magma. He differs from Mr. King as to the manner in which these extreme products were derived from an earlier molten mass. It is nothing against this view of their common origin that rhyolitic outbursts frequently occur unaccompanied by basalt, or that basaltic exposures abound without any evidences of the presence of acid lavas. Both rocks break out in the closest proximity and not infrequently through the same fissures, under precisely similar geological conditions, in too many localities not to realize their mutual relations. Such occurrences appear far too common the world over to permit us to suppose them to be derived from wholly independent reservoirs, yet everywhere occupying the same relative positions with the basalt superimposed upon the rhyolite. Basalt and rhyolite may be the final products from the same common source, but not necessarily differentiated by a simple process of specific gravity separation as demanded by Mr. King.

Within the area of the Great Basin there does not appear to be any rock whose composition is due to a mingling of minerals characteristic of both basalt and rhyolite. Both rocks, while they exhibit considerable range in chemical composition, always remain sharply contrasted as regards mineral constituents. Variations from normal rhyolite carrying orthoclase and quartz in most instances show a transition toward hornblende-mica-andesite through dacite, and never toward a pyroxenic magma, which could hardly be the case if the process was due wholly to the dropping out of the heavier minerals. Plagioclastic feldspars may be developed in large numbers, but they belong to less basic species than those which characterize normal basalt. In like manner variations from normal basalt tend toward pyroxene-andesite and do not carry orthoclase. The process by which the two magmas are formed is more in the nature of a differentiation by molecular change and changes of density in the molten mass under varying conditions of pressure and temperature than by a separation of minerals during crystallization based upon differences of specific gravity. In the Great Basin and probably all through the northern Cordillera conditions were favorable in many localities for a complete differentiation of a normal magma to its final products, rhyolite and basalt.

Now, if we suppose a magma of intermediate composition, from which the necessary material to form rhyolite has been withdrawn, the chemical constitution of the residue will depend largely upon the quantity of rhyolite produced. If the quantity of rhyolitic magma thus formed is relatively large, the remaining basaltic magma may be correspondingly small and necessarily basic in composition. Again, if the bulk of acid or feldspathic magma which separated out is small, there will remain a relatively large quantity of pyroxenic magma, but less basic. If the lava which crystallized out from this latter magma upon cooling is forced upward to the surface, it may consist of both pyroxene-andesite and basalt, as at Eureka. It may be wholly a normal basalt, as shown in a number of localities in the Great Basin, or it may be largely made up of magnetite and other iron minerals, forming a basic rock not yet recognized in the Great Basin, but known elsewhere at several widely separated places in the world. It is a matter of observation in many localities that where the bulk of rhyolite is excessive the basalt outflows frequently occur in small bodies, and it will probably be found that where there are relatively large basic flows a portion of them will at least show an andesitic habit.

Differentiation of Lavas.—The existence at Eureka of two groups of lavas, differing primarily in structure and the chemical nature of their transition products, has been clearly demonstrated and evidence has been advanced to show that they were derived from a still earlier molten mass. Processes of differentiation similar to those by which the molten material beneath the surface is supposed to be capable of breaking up into rhyolite and basalt, are sufficient not only to account for the breaking up of a primordial mass into a feldspathic and pyroxenic magma, but also to account for the existence of partial magmas and an entire series of transition lavas such as found at Eureka. The first products of such a molten mass would naturally, but not necessarily, be a lava of intermediate composition, such as are often seen as the earliest eruptions in volcanic centers. The first eruptions at Washoe being earlier than those at Eureka were consequently more uniform in composition. Differentiation in the magma had taken place only to a limited degree, and it is by no means easy to distinguish hornblende-andesite from pyroxene-andesite. The splitting up of both the feldspathic and pyroxenic magmas, the former into hornblende-mica-andesite, dacite, and rhyolite, and the latter into pyroxene-andesite and basalt, has already been described. It is difficult to conceive a controlling physical force acting upon one magma which could not under similar conditions of heat and pressure exert the same influences upon fractional magmas, the differentiated products of a primordial molten mass.

In applying this hypothesis of differentiation to molten masses the question naturally arises, What would have resulted at Eureka if the slow processes of differentiation going on in a magma before final crystallization had either terminated earlier or progressed still further? On the one hand, supposing a separation less complete than that at Eureka, a stage in the development would be reached when a feldspathic magma would form consisting of hornblende-mica-andesite or dacite, or more probably both, followed by pyroxene-andesite without the interpolation of any body of rhyolite. On the other hand, if the segregation of feldspathic magma had gone on more completely than we find it at Eureka, there might have been formed the same sequence of feldspathic lavas, only with a much larger extravasation of rhyolite, in turn followed by basalt, without the interpolation of pyroxene-andesite. Again, the earliest rock might have been hornblende-mica-andesite of the feldspathic magma, succeeded rapidly by pyroxene-andesite. If this series of lavas had been followed by a cessation of volcanic energy and a long interval of rest, and then by a renewal of activity, the final product, after a still further separation of the magma, would result in the extravasation of rhyolite and basalt. This latter sequence of lavas gives the order of succession so frequently met with throughout the Great Basin. At Eureka, as already described, no long-time interval, geologically speaking, is recognized between the andesites and rhyolites, while the dacites and rhyolites frequently present the appearance of continuous flows.

In considering these phenomena it is important to bear in mind the facts so frequently observed elsewhere in the Great Basin, that a crystalline lava derived from a feldspathic magma of intermediate composition is, in many instances, as shown by Richthofen and King, followed by a pyroxene lava, and the latter is almost invariably of intermediate composition; a lava still more acid by one correspondingly basic, and the extreme acid type by the extreme basic type. A rhyolite may be followed by pyroxenic lavas varying in composition, but the writer knows no instance in the Great Basin where a rhyolite is succeeded by a more basic feldspathic rock, nor where a basalt is followed by a less basic pyroxenic lava.

This hypothesis of the progressive differentiation by molecular changes in a fluid or a molten mass under varying conditions of temperature and pressure is offered to explain the variations in chemical and mineralogical composition of lavas. It is offered tentatively and with much hesitation, the writer knowing the many difficulties involved in the problem. It is based upon and is in accord with the facts seen at Eureka and confirmed by observations in many volcanic areas elsewhere. It at least has the merit of accounting for nearly all variations in the sequence of lavas which have from time to time been noted in the Great Basin. It offers a rational explanation for the recurrence of lavas in certain localities and accounts for their absence in others. The pyroxene-andesite furnishes a marked instance of such a recurrence. Occurrences of lava which have been regarded as exceptional and difficult to explain by any general law are now seen to fall within the prescribed limits of variation as laid down here. Nothing seems more clear than that there are certain laws determining the sequence of flow that govern the extravasation of lavas in every great volcanic center, notwithstanding the fact that we may still be a long way from the correct interpretation in all its details.

Summary.—The Eureka District presents a most instructive volcanic region standing quite apart from all other centers of similar eruption, yet typical in the nature of its extravasated material of many localities in the Great Basin.

The region offers no direct proof of the age of volcanic energy, yet all evidence points to the conclusion that the eruptions belong to the Tertiary period and for the most part to the Pliocene epoch. They may have extended well on into Quaternary time, although there is no reason to suppose that eruptions took place within historic periods.

As regards their mode of occurrence the principal eruptions may be classed under four heads: First, they broke out through profound fissures along the three great meridional lines of displacement, the Hoosac, Pinto, and Rescue faults, and to some extent along the lesser parallel faults; second, following the lines of orographic fracture, they border and almost completely encircle the large uplifted masses of sedimentary strata like the

Silverado and County Peak block and the depressed Carboniferous block between the Hoosac and Pinto faults; third, they occur in numerous dikes penetrating the limestones; fourth, they occur in one or two relatively large bodies, notably Richmond Mountain and Pinto Peak, along lines of displacement already mentioned.

All the lavas may be classed under the heads: hornblende-andesite, hornblende-mica-andesite, dacite, rhyolite, pyroxene-andesite, and basalt. They pass by insensible gradations from one to the other. All division lines are more or less arbitrary; they are necessary for the purposes of classification, although they may not exist in nature.

Field observations clearly show that the order of succession of these natural groups into which the lavas have been divided was as follows: First, that the hornblende-andesite was the earliest of all the erupted material; second, that the hornblende-mica-andesite followed the hornblende-andesite; third, that the dacite followed the hornblende-mica-andesite; fourth, that the rhyolite closely followed the dacite; fifth, that the pyroxene-andesite succeeded the rhyolite; sixth, that the basalt was the most recent of all these volcanic products.

In chemical composition this entire series of lavas shows a range in silica amounting to about 25 per cent, a range which is quite as wide as is usually found in most centers of eruption even where the volume of lavas thrown out is vastly greater and the duration of volcanic energy far longer. Analyses show endless transition products between the extreme basic and acidic lavas, with a tendency of the alkalies and silica to accumulate at the acidic end and the material forming the ferro-magnesian minerals at the basic end.

It is maintained in this work that all the varied products of eruption are derived from a common source, a homogeneous molten mass. Under a process of differentiation this earlier mass split up into two magmas, designated as a feldspathic and a pyroxenic magma. The lavas at Eureka are the result of the same process of differentiation derived from one or the other of these magmas. Beginning with hornbende-andesite, the earliest lava, the feldspathic magma became more siliceous until the close of rhyolitic eruptions. The rhyolite was followed by pyroxene-andesite and the eruptions became more and more basic until the close of the volcanic period. The feldspathic and pyroxenic lavas do not approach each other in their tenure of silica within 2·25 per cent. In chemical composition the earliest eruptions of both magmas resemble each other, but from this common ground they differentiate steadily until the feldspathic reaches the extreme acidic, and the pyroxenic the extreme basic end of their respective series. The extreme products of differentiation in any volcanic center in the Great Basin are rhyolite and basalt.

CHAPTER IX.

ORE DEPOSITS.

Geological History.—It is not the intention to enter into a detailed description of the various ore deposits of this region or of their mode of occurrence. An excellent monograph upon the mines and ores of Ruby Hill has been published by Mr. J. S. Curtis,[1] in which he gives in much detail the results of his studies of the silver-lead deposits of the Richmond and Eureka mines.

This report, however, would be incomplete if the writer, after devoting much time to an investigation of the structural features of the Eureka Mountains, constantly keeping in mind the relationship between the ore bodies and the sedimentary and igneous rocks, should fail to state his conclusions as to the geological position of the ores, their age, and origin. Moreover, as many geologists do not care for the details of mining developments, but feel a keen interest in all questions relating to mineral deposition, it seems desirable to state here, for the use of the general reader, such facts as bear directly upon the geological occurrence of the Eureka ore bodies.

It has been demonstrated beyond all question, from the facts presented in the preceding chapters, that the Eureka Mountains are formed of orographic blocks of Paleozoic strata made up of quartzites, limestones, and shales. These blocks, strongly contrasted by their orographic structure, are separated from each other by profound north and south faults. Along the lines of these displacements east of Prospect Ridge enormous masses of igneous rocks have been poured out, which have tended still more sharply to intensify the lines of demarcation between the individual blocks. The entire thickness of Paleozoic sediments can not be far from

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[1] Silver-lead deposits of Eureka, Nevada. Mon. U. S. Geol. Survey, VII, Washington, 1884.

30,000 feet. Between the close of the Carboniferous and the close of the Jurassic period dynamic action folded and faulted the strata, producing the present complex structure and outlining the configuration of the mountains much as they are found to exist to-day except such changes as have been produced by denudation. Soon after the coming in of Tertiary time the volcanic period began in the Great Basin, and probably not long after it volcanic energy manifested itself in the Eureka Mountains. Evidence seems to show that the profound displacements were augmented by intrusive rocks, and in many instances fissures were formed along the fault planes. Accompanying the fissuring of these faults by volcanic lavas was the forming of lateral and oblique secondary faults, cross fissures, and fractures, complicating the already disturbed sedimentary beds.

After the outbursts of andesites and rhyolites, and possibly in part subsequent to the basalts, the deposition of the ores took place. The basalt is known to follow the rhyolite. As regards the relative age of the ores and basalt, there is no direct evidence other than that in the region of ore bodies the andesites and rhyolites show the action of steam and solfataric agents, whereas the basalts are for the most part comparatively fresh and unaltered. In a number of instances it is clearly evident that the ores followed the rhyolite intrusions, the former being found to lie wholly undisturbed upon the latter rock. It is true that over the greater part of the region the ores do not come in direct contact with the rhyolites, but, on the other hand, all evidences of pre-rhyolite ore deposits are wholly wanting, and it is hardly conceivable that there could have been such deposits without some evidence of movement at a time when the region was undergoing strain and dislocation on all sides. Furthermore, nowhere, so far as known, does the network of dikes on Prospect Ridge cut any earlier ore body.

Since the intrusion of the innumerable rhyolite dikes there is no evidence of any orographic movement of sufficient intensity to disturb or dislocate them by faulting of the strata, and the same may be said of the ore deposits. This gives both to the dikes and ores a comparatively recent origin in the geological history of the region. As regards the ores it should be stated that they have undergone alteration and oxidation since their deposition, and, as much of the loose, friable material occurs in limestone chambers and cavities, it is quite likely to have undergone some movement by earthquake shocks during Quaternary time, but this is quite another matter from profound orographic displacement of beds. To-day there is absolutely nothing positively known as to the source of the rhyolite material nor the deep-seated centers from which it originated, and this is equally true as to the source of the heavy metals. With our lack of knowledge on these matters it seems out of place to speculate in the present volume as to their ultimate source. Probably no geologists, however, would question the statement that the volcanic products came from below.

The writer, after a careful study of the facts observed at Ruby Hill and Prospect Mountain, as well as of the entire Eureka region, is forced to the conclusion that there exists the closest relationship between the rhyolites and the formation of the ore deposits, although they have been observed in actual contact in only one or two localities in the larger mines. In almost all cases where mineral deposits are found, rhyolite intrusions are known to penetrate the limestone in close proximity to the ores, and it is presumable that in many instances the presence of such ore bodies might be detected without the discovery of any intrusive rock. No theory of the ore deposits seems applicable to this region that does not carry with it the fundamental proposition that the ores came from below, as the result of solfataric action which accompanied volcanic energy. Evidence shows that the centers of greatest deposition of ores were not the same as those of greatest eruptive energy, but that the latter are associated with the secondary dikes and offshoots rather than with the great lines of volcanic outbursts. Solfataric action may have continued and probably did continue for a long period after the rhyolite eruptions had altogether ceased, during which metallic sulphides filled certain preexisting fissures, cracks, chambers, and crevices in the limestone. After the deposition of the sulphides came the period of oxidation which, so far as can be told, lasted throughout the greater part of Quaternary time.

Ores of the Cambrian.—In regard to the distribution and geological position of the ores in the Paleozoic strata all evidence shows that although the most remunerative mines and those explored to a great depth occupy somewhat restricted limits, ores of similar mode of occurrence and composition as those so successfully worked on Ruby Hill, are found throughout a wide vertical range of sedimentary beds. No ore deposits are known below the contact between the Prospect Mountain quartzite and the overlying limestones upon Ruby Hill. As will be shown later these limestones on Ruby Hill carry deposits of ore throughout their entire thickness from the quartzite to the overlying Secret Canyon shale.

Along the slopes of Prospect Mountain from Mineral Hill southward to Surprise Peak, the crushed and brecciated limestones have undergone considerable local disturbance and are honeycombed throughout by fissures, seams, and irregular crevices of various width and length. Many of these openings lie parallel with the stratification; others cut across the beds, occurring in the limestone anywhere between the quartzite and shale without any recognized order. Oxidized ore bodies occupy these openings, many of them being connected by narrow channels and seams more or less filled with mineral matter. The Williamsburg mine on the west side is a good example of the ore found deposited in characteristic chambers, while on the east side at the extreme southern end of the ridge the Geddes and Bertrand mine appears to be a well defined north and south fissure carrying much rich ore. Among others of the larger bodies of ore may be mentioned those of the Silver Connor and Banner mines, the latter a good example of a fissure which occurs on the summit of the ridge. In but few of these ore bodies, at least on the surface, have any rhyolites been recognized. A marked instance, however, may be seen in the case of the Geddes and Bertrand mine, where a powerful east and west dike cuts the limestone and overlying shale in close proximity to the north and south ore channel.

Nowhere along the grand exposures of Secret Canyon shales have the ores penetrated to the surface, the pliable, argillaceous clays flexing and folding instead of fissuring, and everywhere serving as an impervious barrier to the ascending currents. Fine examples of dike cutting are shown near the Geddes and Bertrand Mine and again on the summit of the watershed between New York Canyon and Secret Canyon shales, but at the latter locality, so far as known, wholly unaccompanied by important mineral matter.

The beds of the Hamburg limestone are similar in their structural features to those of Prospect Mountain, the resemblance holding equally good for the ore bodies. On Adams Hill the Price and Davies mine lies in this formation in close contact with the Secret Canyon shales, whereas the Wide West occurs near the summit just below the Hamburg shales. Other localities where more or less work has been done were sufficient to indicate the existence of mineral deposits across the intervening belt of limestone from one shale belt to the other. Along Hamburg Ridge the limestones are not so much disturbed as on the steeper mountain slopes, and fissures and seams of ore are by no means as common, but on the other hand mines like the Dunderberg and Hamburg have produced large bodies of ore, second in quantity to none in the district outside of Ruby Hill, and these stand in the closest connection with intrusive masses of rhyolite. Dikes and irregular shaped bosses of rhyolite along the summit of Hamburg Ridge indicate a network of eruptive rocks between the two great shale belts. Like the underlying Secret Canyon shale horizon, the Hamburg shales, although of much less thickness, are impervious to ascending mineral currents, and neither along the front of the mountain or north of Adams Hill is there the slightest evidence of ore bodies penetrating it.

Ores of the Silurian.—Coming to the Pogonip horizon, ore bodies occur all the way from the north end of Adams Hill southward to Roundtop Mountain, at the extreme southern end of the region, with, however, considerable intervals where none have been exposed near the surface. Numerous mining claims have from time to time been recorded, but most of the ground proved unprofitable and unproductive. On the other hand, such mines as the Bullwhacker and Williamsburg, northwest of the town of Eureka, and the Page and Corwin, southwest of Pinto Peak, have yielded large quantities of mineral matter and may be said to exhibit well its mode of occurrence in the limestone of this horizon. In the Williamsburg Mine a well defined quartz-porphyry dike penetrates the limestone, and dikes of similar rock come to the surface near the Bullwhacker. The Page and Corwin was not being worked at the time of the writer's visit, and it is impossible to say whether any intrusive dikes have broken through the strata in close connection with the ore, but the limestones are much disturbed and faulted and rhyolite has reached the surface only a short distance from the mining property.

In the Eureka quartzite the only instances known of mineral deposition are those found on Hoosac Mountain, a description of which is given elsewhere. They have been worked extensively and have yielded considerable ore. Here they are intimately associated with intrusive dikes of both andesite and rhyolite offshoots from the great bodies which forced their way upward along the Hoosac fault.

Throughout the Eureka Mountains the Lone Mountain horizon has here and there shown evidences of mineral deposits when found in the neighborhood of rhyolite outbursts, but over the greater part of the area they exhibit no surface signs of ore-bearing material. An interesting example of ore in the Lone Mountain horizon may be found at the Seventy-six mine, in hard, flinty limestone on the northwest side of McCoy's Ridge. While it can not be looked upon as remunerative property, from the point of view of the present description it serves as an instructive link in the chain of facts bearing upon the geological position of the Eureka ore bodies. This is the only body of Lone Mountain limestone lying in close proximity to the Hoosac fault, and, in consequence, partially explains the occurrence of ore.

Ores of the Devonian.—Passing upward, without any intervening lithological break, the Nevada limestones are in like manner frequently found to carry oxidized, argentiferous lead ores in fissures and crevices in the regions of profound faults. It by no means follows that rhyolites necessarily accompany the ore at the surface, and still less that the latter occurs wherever rhyolite penetrates the Nevada limestone through fissure planes. Instances may be cited in the case of the Reese and Berry mine, just north of the canyon of the same name, and again on the summit of Newark Mountain, both localities indicating disturbances of strata without any assignable cause on the surface. The dislocation of beds may be due to intrusive rocks which failed to penetrate the surface, the fissuring being filled by mineral matter.

Along Rescue Canyon, where there is such a continuous and powerful mass of rhyolite under geological conditions similar in many respects to those observed along the Hoosac fault, mineral deposits are found identical in mode of occurrence with those found on Prospect Mountain, although less productive. A line of ore deposits follows Rescue Canyon on the east side in the highly inclined strata of Century Ridge. The Rescue mine is the most important property, exploration having developed several small, but rich, chambers of ore in following down the shaft between 400 and 500 feet below the surface. Other mines on Century Ridge are the Queen and Maryland, both of which resemble the Rescue mine.

In the Alhambra Hills a shaft has been sunk in the Fairplay mine, 85 feet in depth, following down a clay seam between well defined walls of limestone. It carries a good deal of galena. The White Rose mine closely resembles the Fairplay and lies in nearly the same geological horizon.

Crossing to the Mahogany Hills, on the opposite or west side of the Eureka Mountains, we find mining properties on the southeast side of Brush Peak at localities designated as the Mountain Boy and Kentuck mines. They show that mineral matter was deposited under geological conditions similar to those found elsewhere. Again, at the head of Browns Canyon there is a very decided break in the limestone, accompanied by a sharp anticlinal fold, along the axis of which occurs an outflow of rhyolite presenting geological conditions that might readily lead one to look for ore. Indications of mineral deposits were found at the surface sufficient to warrant mining exploration, and an ore channel followed for considerable distance into the limestone. A study of the geological position of these different ore bodies makes it clear that they occur throughout the Nevada limestone, being found near the base of the epoch and again not far below the summit. With the coming in of the White Pine shales all the characteristic oxidized and unoxidized ores of the district cease, and they fail to reappear in any of the higher geological horizons.

No Ores in the Carboniferous.—Nowhere within the district have ores been recognized in any of the grand divisions of Carboniferous time. In the Diamond Range northward and westward of Newark Mountain the strata seem to be entirely free from mineral matter. It is possible that mining claims may have been recorded along some superficial outcrop or some segregation of mineral matter, but these are so obscure and unpromising and usually without any indication of the precious metals that they may be wholly discarded. The same may be said of the entire area of the Carboniferous block lying between the Hoosac and Pinto faults. It is somewhat remarkable that in this latter block, which lies in the very center of volcanic action, no mineral occurrences of any importance are known. Along the two great meridional faults enormous masses of igneous rocks have been poured out, notwithstanding which no ore deposits have been reported either on the east side of the Hoosac fault or on the west side of the Pinto fault.

Geological Range of Ore Deposits.—It will be seen from these facts that the ore deposits of Eureka are found throughout a wide vertical range, extending from the base of the Prospect Mountain limestone to the summit of the Nevada limestone, occurring in every grand division of the Cambrian, Silurian, and Devonian periods, with the exception of the two great shale belts—the Secret Canyon and Hamburg shales. From the base of the Prospect Mountain limestone to the top of the Hamburg shale it is estimated that there are 6,200 feet of strata; the Silurian rocks measure 5,000 feet and the Nevada limestone of the Devonian 6,000 feet. This gives from the base to the summit of the included strata over 17,000 feet of sedimentary rocks, through which argentiferous lead ores have been deposited on a sufficiently extensive scale to encourage more or less expensive outlays for mining exploration.

From the rapid review of these facts it is evident that within the area of the Eureka District the ores are by no means restricted to any definite geological horizons and have been deposited in siliceous as well as calcareous strata. Notwithstanding that the ore bodies occur through a great thickness of rock, it still remains true that the greater part of the mineral deposits and probably all those which have proved remunerative to the investor, lie within restricted limits. The most productive mines, those carrying the largest and richest bodies of ore, are found in Cambrian strata. This is owing to orographic and structural conditions rather than to the geological age of strata or the chemical nature of sediments. A study of the structural features of the mountains together with the mode of occurrence of the rhyolite eruptions shows that the age of the rock has but little, if anything, to do with the occurrence of the deposits. They depend more upon the fissuring and fracturing of the mountain uplifts and the relations of the accompanying faults to the outbursts of rhyolite.

A study of the mountain blocks and distribution of ores brings out the fact that what has been designated the Prospect Mountain uplift, lying between the Hoosac fault on the east side and the Sierra and Spring Valley faults on the west, embraces pretty much all the valuable mineral deposits which have as yet been successfully developed. Within the limits of these lines of faulting are embraced all the mining properties extending from Adams Hill southward to Surprise Peak, including those on the west side of Prospect Mountain, together with the Dugout mine at the southwest base of the peak on the west side of the anticlinal fold. In preceding chapters the structural features of Prospect Mountain Ridge and relations between the sedimentary beds and intrusive dikes have been described with some detail. As has already been shown, the strata between these faults belong to the Cambrian and Silurian periods up to and including the lower portion of the Lone Mountain horizon exposed on the north side of McCoy's Ridge. The principal overflows of rhyolite have been along the line of the Hoosac fault, the two most powerful centers of extravasation being located at Pinto Peak and Purple Mountain. Purple Mountain lies in the angle between the Hoosac and Ruby Hill faults, and it is along this latter fault that rhyolites come to the surface all the way from New York Canyon to the Jackson fault, thence crossing the latter fault, fill the fault-fissure for a considerable distance along the north slope of Ruby Hill, but without building up any accumulation of rhyolite on the surface.

While it can not be absolutely demonstrated, all evidence bears out the assumption that the dikes penetrating Prospect Mountain Ridge have a deep-seated connection with the source of the rhyolite material which has furnished the surface outflows all along the line of faulting. It can hardly be doubted that both forms of the same eruptive rock mass have had an identical deep-seated origin. It should be also borne in mind that it is only in exceptional instances that dikes and off-shoots from any parent body of lava can be traced to their source step by step in the field without any break in continuity.

Ruby Hill Ore Deposits.—Mr. J. S. Curtis, in his elaborate monograph upon the ore deposits of Ruby Hill, has embodied the results of much careful investigation of the underground exploitations of the mines. His work is accompanied by numerous vertical and cross sections, compiled from the original mine surveys, indicating the positions of the different ore bodies and their mutual relations. It is unnecessary, therefore, to enter into the details of the economic geology, and only such facts will be given as will enable the reader to form a correct conception of the geological position and mode of occurrence of the ore bodies, not only upon Ruby Hill but those found throughout the district. Ruby Hill, from a geological point of view, may be taken as typical of the deposits in what has been designated as the Prospect Mountain uplift. For the details of the mines, and their extensive underground workings the reader is referred to Mr. Curtis's report. In chapter v, of this report, upon the descriptive geology, there will be found an account of the geological structure of Ruby Hill and Adams Hill.

By reference to the accompanying map (Pl. I,) and section (Fig. 3, Pl. II,) it will be seen that Ruby Hill is made up of the three underlying formations of the Cambrian. They possess a fairly uniform dip, although presenting occasional abrupt changes due to faults and fractures. This dip along the surface may be taken at 40°, and in the lowest workings of the Richmond mine, which have reached a depth of over 1,200 feet, this angle of inclination is still maintained. At the surface the line of contact between the quartzite and limestone is easily made out all the way from the Jackson fault to the west base of Ruby Hill. Near this latter fault the contact is first observed just west of the American shaft and the Jackson mine. It crosses the summit of the spur on which the Phœnix mine is situated and follows along the southern slope of Ruby Hill, the quartzite at one point rising to within 160 feet of the summit. In the underground workings the plane of contact between the quartzite and limestone has been exposed in all the mines and at very many of the levels, the latter frequently running along the contact of the two formations and occasionally cutting the quartzite where it projects to the north beyond the course of the drifts. Numerous cross-cuts have also been run into the underlying rock.

These workings, although they do not offer a continuous exposure, are sufficient to give the course of the quartzite all the way from the Jackson to the Albion. Beginning with the Jackson mine, the plane of contact has a course a little east of north, gradually turning more and more to the west until at the Albion it curves slightly south of west. In the lower levels of the mines this contact plane, as mapped by the underground surveys, presents roughly a concave outline curving outward toward the north or away from the granite mass of Mineral Hill. This curve, however, is by no means symmetrical, the tendency of the quartzite in making so sharp a bend being to break abruptly and irregularly and for short distances to be forced outward, assuming directions quite at variance with the general course; the dip frequently changing with the strike. This tendency of the quartzite in fracturing to be forced outward beyond the line of the curve is well shown just west of what is known as the compromise line between the Eureka and Richmond mines. It may be seen all the way from the surface down to the ninth level of the Richmond. Mr. Curtis has carefully mapped the underground contacts, not only between the quartzite and limestone but for all three formations. By reference to his map[1] both the concave outline of the beds and the irregularities of strike and dip may be seen at a glance.

The overlying limestone and shale conform in their general outline with the quartzite, the shale, however, exhibiting a decided tendency, as is usually the case with argillaceous strata, to bend and fold rather than to break abruptly.

Across the limestone on the east slope of Ruby Hill runs a profound fault which, on account of its bearing upon the geology of the region, has been designated the Ruby Hill fault. It is a continuation of a line of faulting coming up from the southwest. From New York Canyon, where the Ruby Hill fault leaves the Hoosac fault, to its intersection with the Jackson fault the nearly straight course is easily followed by a chain of rhyolite outbursts as well as by the conformity of strata Where it crosses the Jackson fault its direction is somewhat disturbed and is not so readily made out, but near the American shaft it reappears, with a course a

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[1] Op. Cit., Pl. III.

few degrees west of north, passing just west of the Jackson shaft. From this point westward it is difficult to follow the Ruby Hill fault on the surface, as it lies wholly in limestone more or less concealed by soil and débris, and the rhyolite which to the southeast of the Jackson fault materially aids in tracing the displacement nowhere comes to the surface after crossing the latter fault. At the time the accompanying map was printed the line of the Ruby Hill fault had not been followed west of the Jackson mine, but since then Mr. Curtis has traced it through the underground workings of all the mines as far as the extreme limit of exploration in the Albion.

According to the investigations of Mr. Curtis the fault after leaving the Phœnix mine runs in a nearly northwest direction, agreeing closely with its course on the east side of the Jackson fault. It passes just to the northeast of the KK shaft and southwest of the Richmond office. It persistently cuts all formations, quartzites, limestones, and shales alike, scarcely deviating from a straight line and apparently uninfluenced by the physical conditions of the rock. In like manner the fractures and displacements produced by the earlier orographic changes which elevated the region have exerted but little influence on the course of the Ruby Hill fault. A study of the disturbances and dislocations of the strata point to the conclusion that this fault, with its accompanying fissure, was the last dynamic movement in the history of Ruby Hill. Wherever underground explorations admitted of observation the average dip of the fissure plane was found to be about 70° to the northeast. Southeast of the Jackson fault the width of the fissure and the dip of its plane are unknown.

Subsequent to the formation of the fissure and probably nearly coincident with it was the filling of the wider portions with intrusions of rhyolite, notwithstanding the fact that they nowhere quite reach the surface on Ruby Hill.

Evidence goes to show that the volcanic energy displayed along the fault line expended the greatest activity near its junction with the great Hoosac fault, the powerful extravasations of rhyolite gradually dying out toward the northwest, and beyond the intersection with the Jackson fault failed to overflow the top of the fissure walls. The rhyolites exposed in the mines rarely attain an average width of more than 15 to 20 feet across the broadest expansions, although instances of much greater width occur in the Phœnix. Decomposed rhyolite is recognized along the fissure in both the Jackson and Phœnix mines. It is intersected by the Jackson shaft above the third level, and the cross-cuts from the old Jackson shaft on both the third and fourth levels expose the rhyolite body on the main fissure. In the Phœnix, rhyolite is found on all the lower levels wherever they intersect the fissure. Proceeding westward the fissure narrows, but the rhyolite may still be detected on the sixth level of the KK, although so thoroughly altered as to have lost the distinctive characters of a lava. In the Richmond mine no rhyolites nor rhyolitic clays are recognized, nor have they been observed anywhere along the fissure to the northwest. The fissure gradually narrows and finally dies out and the fault is lost where the rocks pass beneath Spring Valley, a short distance beyond the Albion mine.

Transition products from unaltered lava to highly kaolinized rhyolite are found along the fissure in every stage of decomposition. In the Jackson mine the rhyolite origin of much of the filling of the fissure is determined by the presence of mica flakes and quartz grains imbedded in blue clay. These transition products grade off into nearly pure clays holding grains of quartz still unaltered, whereas the feldspars and glass base have undergone such complete kaolinization that the volcanic origin of much of this material could not be made out but for its association with fresher rock. In places the entire filling between the walls of the fissure, which may be only a few inches in width, is composed of rhyolite clays, the extreme product of the action of steam and solfataric fumes upon injected volcanic rock. They have all the physical properties of and behave like ordinary clays. Between the Phœnix and the Richmond occur bodies of clay which are undoubtedly derived from the rhyolite, with an admixture of more or less calcareous material. Such material abounds where the fissure walls stand only a few inches apart, and a movement has pulverized the limestone along the fault plane, producing an admixture of rhyolitic clay with comminuted siliceous limestone. In the Richmond the filling of clay between the fault planes is derived solely from attrition of the walls; at least, no rhyolite can be detected. It is possible that the crack became too narrow to permit of the forcing upward of the liquid lava without sufficient power to widen the space between the inclosing walls. Here the volcanic quartz grains are wanting, the calcareous nature of the material determining its origin.

In following its northwest course the main fissure crosses the entire width of the limestone of Ruby Hill, which, by means of the network of underground workings, may be easily studied and compared from base to summit with the same horizon on Prospect Ridge. Near the American shaft the distance from the main fissure to the underlying quartzite is only a few feet. This distance increases in the Phœnix and Jackson mines as proved by the crosscuts on different mining levels, the limestone belt gradually becoming wider toward the west. Near the Richmond mine the main fissure, having traversed the limestone, follows the contact between Prospect Mountain limestone and Secret Canyon shale for a considerable distance, beyond which it is lost. In the Jackson mine a shale belt is exposed which, although fairly persistent in the underground workings of the KK, Eureka, and Richmond mines, never reaches the surface, owing to the fault across the limestone. Without much doubt the shale corresponds with the broad irregular shale belt found on Prospect Ridge and designated the Mountain shale. To the south of this main fissure, along the contact of the Prospect Mountain quartzite and the Prospect Mountain limestone, occurs a line of faulting which, although of less magnitude than the Ruby Hill fault, is, on account of its relation to the ore bodies, quite as important from an economic point of view. Like the Ruby Hill fault it was formed subsequent to the minor displacements connected with the earlier orographic movements. Evidence seems to show that this faulting took place contemporaneously with that of the Ruby Hill fault and has been named the secondary fissure. This secondary fissure possesses an average dip of 40°, coinciding with the contact plane between the two formations, and as the angle of inclination of the main fissure uniformly stands at 70°, the two faults might naturally be expected to come together at no great distance from the surface. Exploitation confirms this supposition and in the lower workings of the mines the secondary fissure is easily traceable into the Ruby Hill fault, but has nowhere been observed to cross it. Indeed, this secondary fissure may be considered as an offshoot from the more persistent and profound Ruby Hill fault. Where the quartzite and limestone show a tendency to curve to the south and southwest, following around the spur of the mountain, the secondary fissure abandons the contact plane and with a northwest course enters the limestone, leaving a block of the latter rock between it and the quartzite.

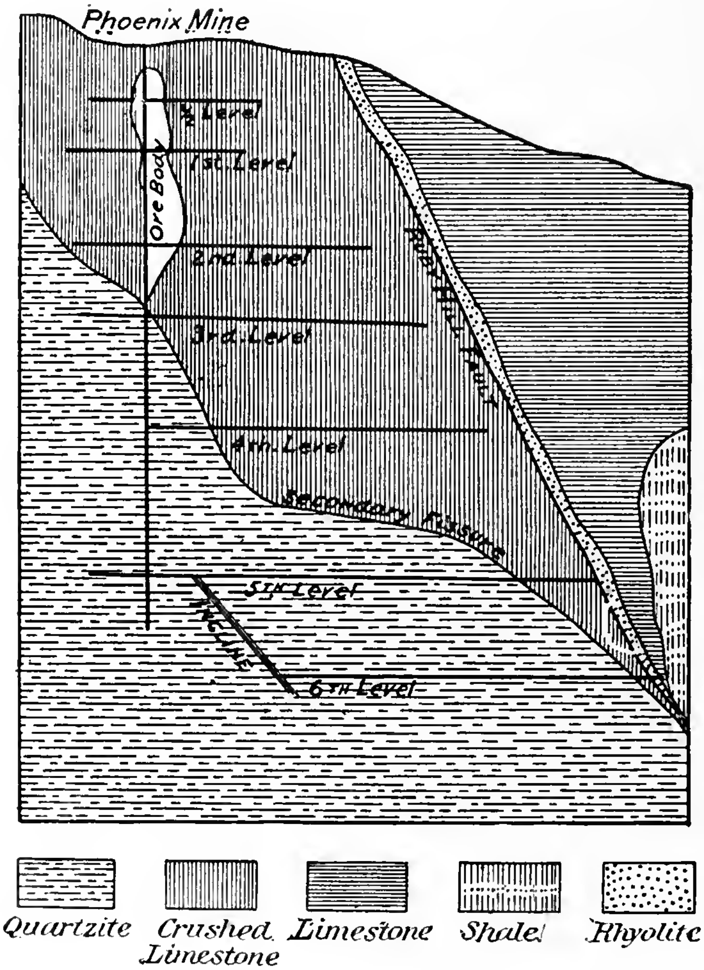

FIG. 6.—Cross-section in Phœnix mine.

Within the wedge-shaped limestone body included between the Ruby Hill fissure and the secondary fissure have been found all the deposits of ore which were of sufficient value to repay extraction. Up to the time of the present investigation all exploitations by crosscuts from the main levels outside these limits have failed to discover any accumulations of ore. The limestone on the north side of the Ruby Hill fault presents a fairly compact uniform appearance occasionally well stratified. Between the two fissures the limestone is crushed and broken, everywhere showing the effect of great pressure accompanied by movement. Much of this rock indicates alteration by chemical process since the fracturing and displacement. The limestone south of the secondary fissure is for the most part black in color, siliceous in composition, and in distinction to the limestone between the fissures uniform in structure. It is more easily recognized than the other belts and resembles the lower strata of limestone on Prospect Ridge. By the miners the limestone beneath the secondary fissure is known as the back limestone; that found between the two fissures is called either the crushed or mineral limestone, while the beds overlying the main fissure are referred to usually as the front limestone.

Figure 6 represents the relative position of the Ruby Hill fault, along which the main fissure has been formed, to the secondary fissure as shown by a vertical cross-section in the Phœnix mine. It will be seen that the two fissures come together just below the sixth level of the mine. The rhyolite dike follows the Ruby Hill fault, and nowhere deviates to the southward in its upward course. In the ground shown by the section the secondary fissure adheres closely to the line of contact between the quartzite and limestone. The ore body is cut by the shaft extending from the surface nearly down to the point of contact between the formations. Near the third level the shaft enters the underlying quartzite and has been sunk only a short distance below the fifth level, the sixth being reached by an incline.

Preexisting Caves and Crevices.—It has been stated that the fissure which accompanies the main fault on Ruby Hill has been the principal channel through which the intrusive rhyolites have been forced upward to within a short distance of the surface, if, indeed, they have not accumulated on top and subsequently been removed by erosion. On the other hand, the secondary fissure carries no rhyolite, but, accompanying it, especially along the contact of rhyolite and limestone, are large and valuable bodies of ore. Between these two fissures the crushed limestone shows the evidence of faulting approximately parallel with the Ruby Hill fault, and due to forces acting at the time the main ridge was uplifted. Other faults indicate lateral thrust, but they are less effective than the former and may be of later origin, due to subterranean forces connected with the period of volcanic energy. Accompanying these are innumerable small fissures, seams, crevices, chambers and channels of varied shapes and sizes. Many of these owe their origin simply to the dynamic effects of upheaval. Others are best explained on the theory of surface waters percolating downward along lines of least resistance, widening fissures and enlarging cavities. If these waters were charged with carbonic acid, chambers and irregular shaped galleries and drainage channels must necessarily have been dissolved out of the limestone. A study of these channels and their intricate connections tends to the belief in the theory of preexisting caves and underground water courses before the introduction of ore.

Filling of Fissures.—The coming in of the volcanic period would be quite likely to disturb and dislocate any previous system of subterranean drainage, in some places completely closing and in others opening new channels by the formation of fresh cracks and crevices. Subsequent to the penetrating of the main fissure by rhyolite came the filling of minor fissures and other openings in the limestone by the ascending mineral solutions and gaseous currents. Wherever the narrow fissures admitted of it these openings and chambers were more or less filled with mineral matter precipitated from solution, the passage ways in many instances being left nearly barren or only carrying stringers and slight indications of earthy, ocherous material probably deposited before the dying out of the active mineral currents. In some instances the narrow connecting channels between the larger openings are richer in mineral matter than the chambers themselves. It would be useless to speculate on the reasons why certain fissures and chambers carried ores and others were left barren. The freaks of deposition from ascending currents—in some places rapid, in others slow—and the varying conditions of temperature and pressure brought about by the varying intensity of solfataric action would produce endless differences in the mode of occurrence. Channels which at one time presented conditions most favorable for deposition might at a later period become entirely cut off from ascending currents. Anyone who has observed carefully the apparent freaks in the deposition of mineral matter in such centers of thermal activity as the Yellowstone Park realizes how little it takes to deflect the course of ascending aqueous or gaseous currents and how, under varying conditions, mineral deposition is liable to undergo change within restricted areas. The occurrences of ore bodies on Ruby Hill and Prospect Mountain are variable and uncertain, but such as one might anticipate from their mode of formation.

Relative Age of Rhyolite and Ore.—The best example on Ruby Hill showing direct contact between the ores and rhyolite bodies was observed in the Jackson mine, but probably a still finer illustration of the relationship between the two with the ore lying undisturbed along the under side of a highly inclined dike was seen in the Dunderburg mine on Hamburg Ridge. It was exposed on the third level of the mine near the main shaft which had been sunk all the way in hard limestone. The rhyolite dike varied from 1 to 8 feet with an average width of a little more than 2 feet. The strike of the dike was approximately east and west with a dip to the north, whereas the course of the ore channel stood nearly at right angles to it. The ore never penetrated the rhyolite, its course being deflected on approaching the intrusive dike. At the shaft house the ore body measured 50 feet in thickness. Opportunity for examining the contact was excellent as much of the ore still remained in place, while over other areas along the contact the ore had been stripped off, rendering it possible to observe the relationship between it and the dike, as well as the position of both to the inclosing limestone. Nowhere did the ore penetrate the rhyolite, and nowhere had any ore been found inclosed within the dike. In like manner the ore was wholly free from rhyolite. Nothing could seem more clear than that the mineral matter had been quietly deposited from solution along the under side of a highly inclined dike, neither could anything be seen suggesting a replacement of rhyolite by ore, although immediately along the contact there is considerable kaolinization of rhyolite. Such instances as the Jackson mine on Ruby Hill, the Dunderberg on Hamburg Ridge, and the position of the rhyolite and ore at the Geddes and Bertrand mine in Secret Canyon, furnish strong proof corroborating other evidence that the ore followed the rhyolite.

Kaolinization of Rhyolite.—A careful study of the transition products of kaolinization of the rhyolite shows how complete the decomposition has been along the Ruby Hill fissure west of the Jackson fault. Equally complete and impressive are the evidences of similar kaolinization in the Dunderburg and on the summit of Hamburg Ridge above the Dunderburg and Hamburg mines wherever the rhyolites offer good exposures on the surface. Along the line of contact on the summit of the ridge between the thoroughly whitened rhyolite and the dark limestone there has been considerable prospecting for ores, but without success. Perhaps the best instance of the alteration of the rhyolite is found where the drainage channel of New York Canyon in coming down from Prospect Ridge has worn a deep passage through the Hamburg limestone ridge. It is seen in the limestone bluff on the south side where an exploring tunnel was run into the hill following the contact between the nearly vertical rhyolite dike and the inclosing limestone. There is exposed here a fine example of completely kaolinized rhyolite possessing all the properties of an ordinary clay, except that the quartz grains of rhyolite still remain unacted upon with here and there a little unaltered sanidin. This is an instance of thoroughly kaolinized rhyolite without the presence, so far as known, of any ore body as far as the tunnel was run. Finding no indication of ore, the tunnel had been abandoned after running a long way into the hill along the contact of the two formations.

Ores Deposited as Sulphides.—Solfataric action which accompanied the filling of the intricate net-work of openings in the limestone may have continued throughout a long period of time, the mineral matter accumulating slowly. That the ores were originally deposited as sulphides there seems no good reason to doubt, an opinion probably held by all geologists who have examined the district and who believe that the ores came from below.

The enormous amount of oxidized products indicates that the original ore was mainly galena and pyrites. Evidence that such was the case on Ruby Hill is shown by the discovery of fragments of galena and pyrites found in a perfectly fresh state scattered throughout the ore bodies near the surface as well as at great depths. These fragments are frequently surrounded by partially oxidized material showing a nucleus or kernel of still unaltered sulphide. Assuming it to be correct that the ores were originally deposited as galena and pyrites, it is most difficult to see how such vast accumulations of these sulphides could have been formed in any other way than in the preexisting caves and openings. Any theory with which we are acquainted of chemical and physical replacement of the limestone or dolomite seems wholly inadequate to meet the necessary conditions. Pseudomorphs of galena and pyrites after calcite have been described as mineralogical curiosities and possibilities, but nowhere have they been found in large quantities in any mine, and so far as the writer is aware they have never been recognized at Eureka. On the other hand, underground drainage channels probably existed before the deposition of the ore bodies, and with the coming in of the ascending mineral currents it is most natural that they should have followed these channels in their upward course.

The Ores.—After the deposition of the metallic sulphides came the period of oxidation, which probably continued throughout the greater part of Quaternary time and was due to atmospheric agencies, mainly percolating surface waters. On Ruby Hill this oxidation may be said to be nearly complete, unaltered galena and pyrites being exceptional occurrences above water level. It has produced a great variety of secondary minerals, but such as it might be anticipated would follow the complete alteration of an admixture of argentiferous galena and auriferous pyrites accompanied by compounds of arsenic and molybdenum. Mr. Curtis has devoted considerable time to an investigation of the mineralogical character of the ore and has published a catalogue of the minerals known to occur on Ruby Hill. The secondary products of oxidation include a long list of carbonates, sulphates, arseniates, molybdates, and chlorides. The ore is exceptionally rich in gold. Wulfenite occurs in brilliant transparent crystals, varying in color from lemon-yellow to bright orange, and is found in large clusters filling cavities or incrusting other minerals. Since the opening of the mines the wulfenite of Eureka has been much sought after by mineral-collectors both in this country and in Europe. It appears to be the only species which Ruby Hill has developed that has any exceptional value from a mineralogical point of view.

The following analysis of a sample of all the ores smelted at the

Richmond furnace for the year 1878 was made for the company by Mr. Fred Claudet, of London:

Lead oxide	35·65	Lead	33·12
Bismuth	.....		
Copper oxide	·15	Copper	·12
Iron sesquioxide	34·39	Iron	24·07
Zinc oxide	2·37	Zinc	1·89
Manganese oxide	·13		
Arsenic acid	6·34	Arsenic	4·13
Antimony	·25	Antimony	·25
Sulphuric acid	4·18	Sulphur	1·67
Chlorine	.....		
Silica	2·95		
Alumina	·64		
Lime	1·14		
Magnesia	·41		
Water and carbonic acid	10·90		
Silver and gold	·10		
	99·60		

Silver, 27·55 troy ounces per ton of 2,000 pounds. Gold, 1·59 troy ounces per ton of 2,000 pounds.

The analysis is taken from the records of the Richmond company. It is reproduced here, as it gives the average composition of a large quantity of ore probably derived from the same ultimate source, and is therefore not without scientific value, although it cannot be considered as representing any definite deposit or the product of any special mode of formation.

The method of stating the present composition of the ore is somewhat misleading. All the lead is estimated as lead oxide, whereas a very appreciable amount of lead sulphide must have been present, as is shown by the examination of any ore pile. It indicates, however, how completely the ore body has undergone oxidation since deposition. No determination was made of the molybdic acid, yet it is hardly possible that none was present when it is easily detected in almost any ore sample. The low percentage of base metals other than lead and iron shows the great uniformity and simplicity of the original sulphides. That the ores vary in composition within certain limits, dependent upon the position of the ore chamber and their connection with the fissures and pipes, is admitted by all who have carefully studied the deposits. Occasionally the ore contained in small pockets in the limestone will present a fairly uniform composition, but differing widely from that found in adjacent bodies, and in some of these zinc and copper accumulate in relatively large quantities as compared with the entire mass of ore. Such variations appear to be much more common on Prospect Ridge than on Ruby Hill.

Two of the most singular and interesting of these isolated deposits were found near the summit of Prospect Ridge, on two adjoining mining properties, known as the Lord Byron and Kelly mines. They resemble each other so closely that they may very properly be considered as having a common origin and possibly filling the same fissure, the connection between them being concealed beneath the surface.

The following analyses of these complex ores were kindly made for the writer by Dr. W. F. Hillebrand, of the U. S. Geological Survey:

	Lord Byron.	Kelly.
Bismuthous oxide	29·54	40·023
Lead oxide	1·97	....
Tin oxide	....	0·273
Telluric acid	12·69	1·077
Antimonious oxide	Not determined.	0·752
Copper oxide	1·00	0·559
Ferric oxide	15·30	0·713
Ferrous oxide	....	1·350
Alumina	0·23	0·259
Zinc oxide	5·54	0·350
Uranium oxide	Not determined.	0·081
Lime	2·77	20·650
Magnesia	Trace.	5·691
Carbonic acid	2·56	25·002
Chlorine	Not determined.	0·047
Phosphoric acid	0·24	0·079
Sulphuric acid	2·41	0·520
Silica	15·31	1·402
Water	3·39	0·913
Silver	1·01	0·034
Gold	0·001	0·002
Total	93·961	99·777

Dr. Hillebrand regards the greater part of the tellurium as occurring in the state of telluric acid, because in boiling with hydrochloric acid much chlorine is evolved, although there is no manganese present, and on reducing it with sulphurous acid the tellurium is immediately precipitated. Dr. Hillebrand notes the absence of all sublimation products of tellurium, antimony, and arsenic on heating the ore in an open tube, indicating the previously complete oxidation of these substances. The telluric acid is nearly sufficient in the Lord Byron ore to combine with the bismuth, leaving enough over to combine with the small amount of silver present. Some silver in both ores probably exists in combination with tellurium as a telluride. These ores possessed no commercial value on account of the exceedingly small amount of them obtained. In the case of the ore from the Kelly mine it will be seen that there is a large amount of carbonate of lime present, but it is not possible to say whether this occurred as calcite, a secondary product, or as limestone derived from the country rock.

Occasional pockets or crevices in the limestone are characterized by the deposition of wad and other compounds of manganese. Silica is rarely found in the fissures and chambers in the Richmond and Eureka mines, but, on the other hand, most of the deposits on Prospect Ridge carry more or less quartz, and associated with it there appears to be, judging from the assay reports, an increase in the amount of gold. Silica also characterized the mines of the Hamburg Ridge, as is shown not only in some of the larger deposits, but in such properties as the Connolly and California mines. Variations in silica present no greater range than other mineral matter deposited under conditions of solfataric action. It is known as one of the most common products from deep-seated sources. The noticeable feature about the silica is not its occurrence on Prospect Ridge, but rather its absence from the Ruby Hill fissure and connecting chambers.

As has been previously mentioned, the mines of Ruby Hill have yielded up to the time of the present investigation gold and silver to the value of $60,000,000, accompanied by over a quarter of a million tons of commercial lead. The large amount of iron contained in the ores has never been estimated. These enormous products of the heavy metals, deposited in small openings in the Ruby Hill limestone, within a very limited area, through narrow fissures, from some deep-seated source, certainly present, in their scientific aspects, most interesting problems to the geologist.

Recent Changes.—Following the oxidation of the sulphides and in some degree associated with it, came the partial rearrangement of the oxidized material under the influence of percolating surface water, in some instances removing the ore from narrow passageways and fissures and sweeping it into larger receptacles, where, together with ore already deposited, it was piled up on the limestone floors This rearrangement of the oxidized material, seen upon opening several chambers on Ruby Hill in the course of mining exploration, appeared so self-evident that no other theory of their formation seems adequate to account for all the observed facts. Such ore receptacles, although more frequent near the surface, were opened at different depths, but usually along lines that gave every appearance of having been ancient water courses. On opening a chamber the tops of the ore piles would be found covered by an accumulation of dust, fine sand, and material foreign to the ore body. The stratification of material shown in cross section and the settling of the heavier particles under the action of water were too convincing to admit of any other mode of formation. Many of the pipes coming down from the surface would be found wholly barren of ore, yet carrying fragments of limestone rounded and worn smooth by he action of percolating subterranean waters charged with carbonic acid. Such recent drainage channels and pipes are by no means restricted to Ruby Hill, but occur equally well preserved on Prospect Mountain, and may be seen with more or less distinctness in some of the tunnels cutting the ridge. They are well shown in both the Eureka and Prospect Mountain tunnels and are so large as to serve the purposes of ventilation, and in one instance, at least, so straight as to admit light from the surface. Many of the tunnels suggest the existence of subterranean water courses at a time when the country was less arid than at present.

Dr. J. S. Newberry[1] has cleverly suggested that climatic changes, with alternating wet and dry periods, within Quaternary time in the Great Basin, may have had much to do in determining water levels in deep mines. If

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[1] School of Mines Quarterly, March, 1880.

this is true, the action of percolating waters in underground drainage channels would be influenced in like manner. During the present period of excessive dryness these channels in the limestone carry no water, and consequently exert but little solvent power. If, however, subterranean chambers can be worn in the limestone since the deposition of the ore; it seems but logical to assume that on the identical ground, under nearly similar conditions, caves should have been formed before the deposition of sulphides.

Since the formation of these more recent water courses nothing of any moment occured on Ruby Hill until historical time, when man, in his eager search for wealth, excavated in a few years, by means of modern mechanical appliances, the enormous mineral product which required untold ages to deposit by natural process.

Conclusions.—The conclusions reached after an investigation of the Eureka Mountains with regard to the geological position, age, and origin of the ore deposits may be briefly stated as follows:

The rocks in which the ores occur are sedimentary beds belonging to the Cambrian, Silurian, and Devonian periods.

The ores were deposited after the eruption of the rhyolite, and consequently they are of Pliocene or post-Pliocene age.

In their mode of occurrence the ores are closely associated with the dikes of rhyolite, although there is no evidence to show that they were derived from them.

The ores came from below.

They were for the most part deposited as sulphides in preexisting caves and cavities.

They were oxidized by atmospheric agencies, mainly surface waters percolating through the rocks.

APPENDIX A.

SYSTEMATIC LIST OF FOSSILS

OF

EACH GEOLOGICAL FORMATION IN THE EUREKA DISTRICT, NEVADA.

BY

CHARLES DOOLITTLE WALCOTT.

APPENDIX A.

SYSTEMATIC LIST OF FOSSILS FOUND AT EUREKA, NEVADA.

By Charles D. Walcott.

In the monograph of Mr. Arnold Hague the grouping of the different genera and species and their stratigraphical succession and relations throughout the great thickness of sediments at Eureka are given with considerable detail in the discussion of the Paleozoic rocks. For the student of general geology the vertical range of species and their geographical distribution are clearly brought out.

For the purpose of bringing together in tabulated form all the genera and species of each important group into which the rocks have been divided, the following systematic list was originally published in the Paleontology of the Eureka District,[1] and is reproduced here in order that the student may see at a glance the life of each geological horizon.

Invertebrate life is well represented throughout the entire series of rocks from the base of the Prospect Mountain limestone to the summit of the Upper Coal-measure limestone, a thickness of over 28,500 feet of sediments.

In the list all the Cambrian fauna is included under the head of Prospect Mountain group, embracing the Prospect Mountain limestone, Secret Canyon shale, Hamburg limestone, and Hamburg shale.

Since the publication of the Paleontology the Cambrian fauna has been divided into three subfaunas: Lower, Middle, and Upper. Under this classification the Lower Cambrian or *Olenellus* fauna is included in the quartzites and immediately superjacent shales beneath the Prospect Mountain limestone; the Middle Cambrian fauna in the Prospect Mountain limestone and Secret Canyon shales, and the Upper Cambrian fauna in the Hamburg limestone and Hamburg shales. As the monograph of Mr. Hague does not deal with these faunal subdivisions in detail no further reference will be made to them.

A number of generic references will be changed in a forthcoming review of the Middle and Upper Cambrian faunas, but it is not thought best to anticipate these changes in the present systematic list.

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[1] Paleontology of the Eureka District, Nevada. Mon. U. S. Geol. Surv., vol. VIII, 1884.

The Lower Silurian embraces the fauna of the Pogonip limestone beneath the Eureka quartzite, and the Silurian fauna above the quartzite is represented by the meager collections obtained from the Lone Mountain limestone.

Under the grouping of Carboniferous fossils are included the fauna from the great belts of limestone both above and below the Weber conglomerate.

Included in the list is the collection obtained from the White Pine Mountains, situated about 40 miles southeast of Eureka. The fauna from the base of the Pogonip to the summit of the Devonian is so closely related to that of the Eureka District that they may well be studied together, and in the tables are arranged in parallel columns.

The reader who desires more detailed information in regard to the specific character of the fauna is referred to the descriptions given in the Paleontology of the Eureka District, above mentioned.

SYSTEMATIC LIST OF FOSSILS OF EACH GEOLOGICAL HORIZON.

CAMBRIAN.

PROSPECT MOUNTAIN TERRANE.

[The double multiple (××) denotes that the species passes to the group above.]

Genera and species.	Eureka.	White Pine.	Remarks.
Porifera.			
Protospongia fenestrata Salter	×	....	Type from the Cambrian of Wales.
sp. ?	....	×	
Brachiopoda.			
Discina sp. ?	×	....	Fragment.
Lingulepis mæra H. & W	××	....	Types from Eureka and White Pine districts, Nevada.
? minuta H. & W	××	×	Type from Eureka District.
Lingula? manticula White	××	....	Type from Schell Creek Range, Nevada.
Obolella discoidea H. & W	××	....	Type from Eureka District.
sp. ?	×	....	Like O. pretiosa Billings.
Acrothele? dichotoma Walcott	×	....	
Acrotreta gemma Billings	××	....	Type from Calciferous formation in Newfoundland.
Kutorgina prospectensis Walcott	×	....	
sculptilis Meek	×	....	Type from Gallatin River, Montana.
whitfieldi Walcott	×	....	
Leptæna melita H. & W	××	....	Type from Eureka District.
Orthis eurekensis Walcott	×	....	
sp. ?	×	×	
Pteropoda.			
Stenotheca elongata Walcott	×	....	
Hyolithes primordialis Hall (sp.)	×	....	Type from St. Croix (Potsdam) sandstone of Wisconsin.
Scenella? conula Walcott	×	....	

CAMBRIAN—Continued.

PROSPECT MOUNTAIN TERRANE—Continued.

Genera and species.	Eureka.	White Pine.	Remarks.
Pœcilopoda.			
Agnostus bidens Meek	××	×	
communis H. & W	××	×	Type from White Pine District, Nevada.
neon H. & W	××		Type from Eureka District.
prolongus H. & W	×		Type from Eureka District.
richmondensis Walcott	×		
seclusus Walcott	×		
Olenellus gilberti Meek	×		Type from Pioche, Nevada.
howelli Meek	×		Type from Pioche, Nevada.
iddingsi Walcott	×		
Olenoides? expansus Walcott	×		
Dicellocephalus? angustifrons Walcott	×		
? bilobatus H. & W	×		Type from Eureka District.
flabellifer H. & W		L.	Geol. Expl. Fortieth Par., vol. IV, p. 227.
iole Walcott	×		
marica Walcott	×		
Ptychoporia (?) angulatus H. & W		×	Geol. Expl. Fortieth Par., vol. IV, p. 220.
?richmondensis Walcott	×		
anytus H. & W	×		Type from Schell Creek, Nevada.
(S.) breviceps Walcott	×		
? granulosus H. & W	××		Type from Eureka District.
haguei H. & W. (sp.)	××		Type from White Pine District, Nevada.
læviceps Walcott	×		
(?)linnarssoni Walcott	×		
?maculosus H. & W (sp.)	××		Geol. Expl. Fortieth Par., vol. iv. p. 215.
nitidus H. & W (sp.)	×		Type from Eureka District.
occidentalis Walcott	×		
oweni M. & H (sp.)	××		Type from Big Horn Mountains, Montana.
(?) prospectensis Walcott	×		
(?) similis Walcott	×		
(?) similis, var. robustus, Walcott.	×		
(?) unisulcatus H. & W	××		Type from Eureka District.
(Euloma?) affinis Walcott.	××		
(Euloma?) dissimilis Walcott.	×		
(P.) laticeps H. & W	××		Type from White Pine District, Nevada.
(P.) occidens Walcott	×		
sp. ?		×	
Anomocare ?parvum Walcott	×		
? pernasutus Walcott			
nasutus Walcott	×		
osceola Hall	×		Type from St. Croix (Potsdam) sandstone of Wisconsin.
? quadriceps H. & W	×		Type from Ute Peak, Wasatch Range, Utah.
Ptychaspis minuta Whitfield	×		Type from St. Croix (Potsdam) sandstone of Wisconsin.
pustulosa H. & W		L.	Geol. Expl. Fortieth Par., vol. iv, p.223.
Chariocephalus ? tumifrons H. & W	×	L.	Type from White Pine district, Nevada.
Agraulos? globosus Walcott	×		
Arethusina americana Walcott	××		
Ogygia? problematica Walcott	×		
? spinosa Walcott	×		
Illænurus sp.?		×	

NOTE.—Species from White Pine District occur at the base of the Pogonip group and are doubtfully referred to the Cambrian.

LOWER SILURIAN (*Ordovician*).

POGONIP TERRANE.

[The letter C in the first column denotes that the species also occurs in the Cambrian.]

Genera and species.	Eureka Lower.	Eureka Upper.	White Pine, Lower and Upper.	Remarks.
Rhizopoda.				
Receptaculites ellipticus Walcott	......	×	......	
elongatus Walcott	......	×	......	
mammillaris Newberry	......	×	U.	
Hydrozoa.				
Graptolithus sp. ?	......	×	......	Like G. bifidus Hall.
Actinozoa.				
Monticulipora sp. ?	......	×	......	
Polyzoa.				
Ptilodictya, sp. ?	......	×	......	
Brachiopoda.				
Lingulepis mæra H. & W	C	......	......	Types from Eureka and White Pine districts.
?minuta H. & W	C	......	......	Type from Eureka District.
Lingula ? manticula White	C	......	......	Type from Schell Creek Range, Nevada.
sp. ?	......	......	L.	
Obolella ? ambigua Walcott	×	......	......	
discoidea H. & W	C	......	L.	Type from Eureka District.
Acrotreta gemma* Billings	C	......	L.	Type from Calciferous formation in Newfoundland.
sp. ?	......	×	......	Like A. subconica Kutorga.
Schizambon typicalis Walcott	×	......	......	
Leptæna melita H. & W	C	......	......	Type from Eureka District.
Strophomena nemea H. & W	×	......	L.	Type from White Pine District, Nevada.
Orthis hamburgensis Walcott	......	×	......	
lonensis Walcott	......	×	......	
perveta Conrad	......	×	U.	Trenton of Wisconsin, Chazy of Canada.
pogonipensis H. & W	......	×	U.	Geol. Expl. Fortieth Par., vol. IV, p. 23.
testudinaria Dalman	......	×	U.	Trenton group species of New York, Canada, etc.
tricenaria Conrad	......	×	U.	Trenton group species of New York, Canada, etc.
sp. ?	×	......	......	
sp. ?	......	×	U.	
Streptorhynchus minor Walcott	......	×	......	
Porambonites obscurus H. & W	......	×	......	Geol. Expl. Fortieth Par., vol. IV, p. 234.
Triplesia calcifera Billings	×	......	......	Calciferous formation of Canada.
Lamellibranchiata.				
Tellinomya contracta Salter ?	......	×	U.	Trenton group species.
? hamburgensis Walcott	......	×	......	
Modiolopsis occidens Walcott	......	×	U.	
pogonipensis Walcott	......	×	U.	
sp. ?	......	......	U.	

* Identified by Mr. Meek, from Malade City. Hayden's Report for 1872, p. 464.

LOWER SILURIAN (*Ordovician*)—Continued.

POGONIP TERRANE—Continued.

Genera and species.	Eureka Lower.	Eureka Upper.	White Pine, Lower and Upper.	Remarks.
Gasteropoda.				
Bellerophon (Bucania) bidorsata Hall			U.	Trenton group species in New York, Canada, etc.
sp. ?		×		Like B. allegoricus White.
Straparollus sp. ?			U.	
Raphistoma nasoni Hall (sp.)		×		Trenton group of Wisconsin.
sp. ?		×		
Murchisonia milleri Hall			U.	Trenton group species in New York, Canada, etc.
sp. ?		×		
sp. ?			U.	
Pleurotomaria lonensis Walcott		×	U.	
sp. ?		×		
Helicotoma sp. ?		×		
Maclurea annulata Walcott		×	U.	
carinata Walcott		×		
subannulata Walcott		×		
sp. ?		×		
Metoptoma ? analoga Walcott			U.	
phillipsi Walcott			U.	
Cyrtolites sinuatus H. & W		×		Type from the White Pine District, Nevada.
Pteropoda.				
Coleoprion minuta Walcott		×	U.	
Hyolithes vanuxemi Walcott		×		
sp. ?			U.	
Cephalopoda.				
Orthoceras multicameratum Hall		×	U.	A sp. of the Lower Trenton in New York.
4 sp. ?			U.	
Endoceras (like E. multitubulatum)		×		Species of Lower Trenton in New York State.
proteiforme Hall		×		Trenton group sp.
Crustacea.				
Leperditia bivia White		×		Type from the Schell Creek Range, Nevada.
sp. ?		×		
Beyrichia sp. ?		×		
Plumulites sp. ?		×		
Pœcilopoda.				
Agnostus bidens Meek	C.			Type from Gallatin River, Montana.
communis H. & W	C.			Type from White Pine District, Nevada.
neon H. & W				
tumidosus H. & W	×			Geol. Expl. Fortieth Par., vol. iv., p. 231.
Dicellocephalus inexpectans Walcott	×			
finalis, Walcott		×		
multicinctus H. & W	×			Geol. Expl. Fortieth Par., vol. iv., p. 226.

LOWER SILURIAN (*Ordovician*)—Continued.

POGONIP TERRANE—Continued.

Genera and species.	Eureka Lower.	Eureka Upper.	White Pine, Lower and Upper.	Remarks.
Pœcilopoda—Continued.				
Ptychoparia annectans Walcott	×			
granulosus H. & W. (sp.)	C.			Type from Eureka District.
haguei H. & W. (sp.)	C.			Type from White Pine District.
maculosus H. & W. sp	C.			Geol. Expl. Fortieth Par., vol. iv., p. 215.
oweni Meek	C.			Type from Big Horn Mountains, Montana.
unisulcatus H. & W (sp.)	C.			
(Euloma?) affinis Walcott	C.		L.	
Arethusina americana Walcott	C.			
Bathyurus ? congeneris Walcott		×		
pogonipensis, H. & W			U.	Geol. Expl. Fortieth Par., vol. iv., p. 243.
? simillimus Walcott		×		
? tuberculatus Walcott		×	U.	
? sp. ?			U.	
Cyphaspis ? brevimarginatus Walcott		×		
Amphion nevadensis Walcott		×	U.	
sp. ?		×		
sp. ?			U.	
Ceraurus sp. ?		×		
Symphysurus ? goldfussi Walcott		×		
Barrandia ? maccoyi Walcott		×		
? sp		×		
Illænurus eurekensis Walcott	×		L.	
Illænus crassicauda Wahlenbergs (p.)			U.	Very abundant in Upper Pogonip.
sp. ?		×		
Asaphus caribouensis Walcott		×		
curiosus Billings		×		Type from Quebec group of Canada.
3 sp. ?		×		

LONE MOUNTAIN SILURIAN.

Genera and species.	Lower Silurian.	Upper Silurian.	White Pine.	Remarks.
Actinozoa.				
Streptelasma Walcott	×			
sp. ?	×			
Zaphrentis ? sp. ?		×		
Halysites catenulatus Linn (sp.)		×	U	
Monticulopora, sp ?	×			
Echinodermata.				
Cystid	×			Separate plates.

LONE MOUNTAIN SILURIAN—Continued.

Genera and species.	Lower Silurian.	Upper Silurian.	White Pine.	Remarks.
Brachiopoda.				
Leptæna sericea Sowerby	×			
Orthis	×			Like O. plicatella.
Cephalopoda.				
Orthoceras sp.?	×			
Cyrtoceras sp.?	×			
Pœcilopoda.				
Ceraurus	×			
Dalmanites	×			
Trinucleus concentricus Murch	×			
Illænus				
Asaphus platycephalus Stokes	×			

DEVONIAN.

[Abbreviations.—Up. Held. = Upper Helderberg. Ham. = Hamilton group. Ch. = Chemung group of the Devonian series of the Geological Survey of New York. H. & W.=Hall & Whitfield, Geol. Expl. Fortieth Parallel, vol. IV, 1877.]

Genera and species.	Lower.	Upper.	White Pine, Upper.	Remarks.
Porifera.				
Palæomanon roemeri Walcott	×			
Astylospongia sp?	×			
Stromatopora, sp?	×	×		
Actinozoa.				
Fistulipora, sp?	×			
Favosites hemispherica Y. & S	×			Up. Held. and Ham. of New York and Canada; Up. Held., Falls of Ohio.
basaltica, var	×			
n. sp	×			
Alveolites multilamellata Meek			×	Geol. Expl. Fortieth Par., vol. IV, p. 25.
rockfordensis Hall?		×		Type from Devonian of Iowa.
Cladopora prolifica Hall			×	Up. Held. of New York and Falls of Ohio.
pulchra Rominger?		×		Up. Held. of New York and Falls of Ohio.
sp.?	×			Up. Held. of New York and Falls of Ohio.
Thecia ramosa Rominger?	×			Up. Held. of New York and Falls of Ohio.
Syringopora hisingeri Billings		×		Up. Held. of New York and Falls of Ohio.
perelegans Billings	×	×		
Aulopora serpens Goldfuss	×			Ham. of Michigan.
Cyathophyllum corniculum M. Ed		×		Up. Held. of New York. Canada. Falls of Ohio, etc.
rugosum M. Ed. & Haine.	×			Up. Held. of New York, Falls of Ohio, etc.

DEVONIAN—Continued.

Genera and species.	Lower.	Upper	White Pine, Upper.	Remarks.
Actinozoa—Continued.				
Cyathophyllum davidsoni M. Ed	×			Ham. of Iowa.
2 n. sp	×			
sp. ?			×	
Acervularia pentagona Goldfuss		×	×	Identified by Meek from White Pine District, Nevada.
Smithia hennahii Lonsdale (sp)			×	Geol. Expl. of Fortieth Par., vol. IV., p. 32.
Pachyphyllum woodmani White, sp		×		Devonian of Iowa.
Diphyphyllum simcoense M. Ed	×		×	Up. Held. of New York, Falls of Ohio, etc.
Ptychophyllum ? infundibulum Meek			×	Geol. Expl. Fortieth Par., vol. IV, p. 28.
Cystiphyllum americanum M. Ed	×			Up. Held. of New York and Falls of Ohio; Ham. of New York, etc.
2 n. sp	×			
Polyzoa.				
Fenestella, 2 sp. ?	×			
Thamniscus ? sp ?	×			
Brachiopoda.				
Lingula alba-pinensis Walcott			×	
læna Hall	×			Ham. of New York.
ligea Hall		×		Ham. of New York.
ligea, var. nevadensis Walcott		×		
lonensis Walcott	×			
melie Hall	×			Pal. of New York, vol. IV, p. 14.
whitei Walcott	×			
sp. ?			×	
Discina lodensis Hall			×	Ham. of New York.
minuta Hall ?		×		Ham. of New York.
sp. ?	×			
Pholidops bellula Walcott	×			
quadrangularis Walcott	×			
Orthis impressa Hall	×		×	Ch. of New York.
macfarlanei Meek	×		×	Type from Mackenzie River, British America.
tulliensis vanuxem		×		Ham. of New York.
Skenidium devonicum Walcott	×			
Streptorhynchus chemungensis Conrad (sp.)	×			Up. Held., Ham., and Ch. of New York.
chemungensis, var. pandora Billings.	×	×		Up. Held. of New York and Canada.
chemungensis, var. perversa Hall.	×			Up. Held. and Ham. of New York.
Strophomena rhomboidalis Wilckens, (sp.)	×			Up. Held. New York, Falls of Ohio, etc.
Strophodonta arcuata Hall	×			Devonian of Iowa.
calvini Miller	×			Devonian of Iowa.
canace H. & W.	×		×	Geol. Expl. Fortieth Par., vol. IV, p. 246, 1877.
demissa Conrad (sp.)	×			Devonian of Iowa, New York, etc.; Mackenzie River, British America.
inequiradiata Hall	×		×	Up. Held. of New York.
patersoni Hall	×			Up. Held. of New York.
perplana Conrad (sp.)	×	×		Throughout the Devonian of New York.
punctulifera Conrad (sp.)	×			Throughout the Devonian of New York.

DEVONIAN—Continued.

Genera and species.	Lower.	Upper.	White Pine, Upper.	Remarks
Brachiopoda—Continued.				
Chonetes deflecta Hall	×	×	......	Ham. of New York.
filistriata, Walcott	×	......	......	
hemispherica Hall	×	......	......	Up. Held. of New York.
macrostriata Walcott	×	......	......	
mucronata Hall	......	×	......	Up. Held. of New York, etc.; Great Bear Lake, British America.
setigera Hall	×	......	......	Ham of New York.
sp.?	......	......	×	
Productus (P.) hallanus Walcott	×	×	......	Devonian of Iowa.
(P.) hirsutiforme Walcott	......	......	×	
(P.) lachrymosus Conrad (sp.)	......	×	......	
(P.) lachrymosus var. limus Conrad (sp.)	......	×	......	Ch. of New York.
(P.) lachrymosus, var. stigmatus Hall.	......	×	......	Ch. of New York.
(P.) navicellus Hall	×	......	......	Up. Held. and Ham. of New York.
(P.) shumardianus Hall	×	×	......	Devonian of Iowa.
(P.) shumardianus var. pyxidatus Hall.	×	×	......	Devonian of Iowa.
(P.) speciosus Hall	......	×	......	Ch. of New York.
(P.) subaculeatus Murch	×	×	×	Up. Held. of Falls of Ohio.
(P.) truncatus Hall	×	......	......	Ham. of New York.
sp.?	......	......	×	Of the type of P. semireticulatus.
Spirifera alba-pinensis H. & W	......	......	×	Geol. Expl. Fortieth Par., vol. IV, p. 255.
disjuncta Sowerby	......	×	×	Ch. of New York, Mackenzie River, British America, etc.
englemanni Meek?	......	×	×	Type, Eureka and White Pine Districts, Nevada.
parryana Hall?	×	......	......	Devonian of Iowa and Canada.
piñonensis Meek	×	×	×	Type, Piñon Range, Nevada.
raricosta Conrad (sp.)	×	......	......	Up. Held. of New York, Falls of Ohio, etc.
strigosus Meek	......	......	×	Geol. Expl. Fortieth Par., vol. IV, p. 43.
varicosa Hall	×	......	......	Up. Held. of New York, Falls of Ohio, etc.
sp. undt.	×	......	......	
(M.) glabra, nevadensis Walcott.	......	×	......	
(M.) maia Billings	×	×	......	Up. Held. of New York and Canada.
(M.) undifera Roemer	×	......	......	
Spiriferina cristata Schlotheim (sp.)	......	......	×	Also in Carboniferous.
Ambocœlia umbonata Conrad (sp.)	......	......	×	Ham. of New York.
Cyrtina davidsoni Walcott	......	......	×	
hamiltonensis Hall	......	×	......	
Nucleospira concinna Hall	×	......	......	Up. Held. and Ham. of New York.
Trematospira infrequens Walcott	×	......	......	
Retzia radialis Phillips (sp.)	......	......	×	
Athyris angelica Hall	......	×	......	Ch. of New York.
sp.?	......	......	×	Of the type of Athyris planosulcata.
sp.?	×	......	......	
Meristella (W.) nasuta Conrad (sp.)	×	......	......	Up. Held. of New York.
Atrypa desquamata Sowerby	×	......	......	Devonian of England.
reticularis Linn. (sp.)	×	×	×	Devonian of America, Europe, etc.
Rhynchonella castanea Meek	×	×	......	Type from Mackenzie River, British America.
duplicata Hall	......	×	×	Ch. of New York.
emmonsi H. & W	......	......	×	Geol. Expl. Fortieth Par., vol. IV, p. 247.
horsfordi Hall	×	......	......	Ham. of New York.

DEVONIAN—Continued

Genera and species.	Lower.	Upper.	White Pine, Upper.	Remarks.
Brachiopoda—Continued.				
Rhynchonella pugnus Martin		×		Devonian of Ohio, New York, and England.
? occidens Walcott	×		×	
quadricosta Hall			×	Genesee Slate of New York.
tethys Billings	×			Up. Held. of Canada and Falls of Ohio.
(L.) laura Billings		×		Ham. of Canada and New York.
(L.) nevadensis Walcott		×		
(L.) sinuatus Hall		×		Ch. of New York.
Leptocœlia sp. ?	×			Not unlike L. acutiplicata Hall.
Pentamerus comis Owen (sp.)	×			Ham. and Ch. of Iowa.
lotis Walcott			×	
Tropidoleptus carinatus Hall	×			Found in Piñon Range, Nevada.
Cryptonella ? circula Walcott	×		×	
piñonensis Walcott		×		
Terebratula, sp. ?			×	
Lamellibranchiata.				
Aviculopecten ? catactus Meek			×	Geol. Expl. Fortieth Par., vol. IV, p. 93.
Pterinopecten, sp. ?			×	
Glyptodesma, sp. ?		×		
Pterinea newarkensis Walcott		×		
flabella Conrad	×			Upper Held. to Ch. of New York.
Actinopteria boydi Conrad (sp.)	×			Ham. group of New York.
Leiopteria rafinesquii Hall	×			Ham. group of New York.
Leptodesma transversa Walcott		×		
Limoptera sarmenticia Walcott	×			
Mytilarca dubia Walcott	×			
chemungensis Conrad (sp.)		×		Ch. of New York.
sp. ?	×			
(Plethomytilus) oviformis, Conrad (sp.).	×			Ham. of New York.
Modiomorpha altiforme Walcott	×			
obtusa Walcott	×			
Goniophora perangulata Hall	×			Schoharie Grit of New York.
Palæoneilo, sp. ?		×		
Nucula resenensis Walcott		×		
sp. ?		×		
Nuculites triangulus H. & W			×	Geol. Expl. Fortieth Par., vol. IV, p. 248.
insularis Walcott	×			
Megambonia occidualis Walcott	×			
Nyassa parva Walcott	×	×		
Grammysia minor Walcott		×		
Edmondia piñonensis Meek	×			Geol. Expl. Fortieth Par., vol, IV, p. 46.
Sanguinolites ? combensis Walcott	×			
? gracilis Walcott	×			
(Spathella) ventricosus White & Whitfield (sp.).		×		Ch. of New York; Burlington sandstone of Iowa.
(Spathella) oblonga Walcott.	×			
Glossites ? sanduskyensis Meek	×			Up. Held. of Ohio.
Sphenotus contractus Hall		×		Ch. of New York; Burlington sandstone of Iowa.
Conocardium nevadensis Walcott	×			
sp	×			
Lunulicardium fragosum Meek (sp.)			×	Geol. Expl. Fortieth Par., vol. IV, p. 92.

DEVONIAN—Continued.

Genera and species.	Lower.	Upper.	White Pine, Upper.	Remarks.
Lamellibranchiata—Continued.				
Paracyclas occidentalis	×	×		
peroccidens H. & W.			×	Geol. Expl. Fortieth Par., vol. IV, p. 248.
Posidonomya devonica Walcott	×			
lævis Walcott	×			
Cypricardella macrostriatus Walcott	×			
Cardiomorpha missouriensis, Swallow			×	Geol. Expl. Fortieth Par., vol. IV, p. 277.
Anadontopsis amygdalæformis Walcott	×			
Schizodus (Cytherodon) orbicularis Walcott.	×			
Cypricardinia indenta, Conrad (sp.)	×			Upper Held. of New York and the Falls of the Ohio.
Gasteropoda.				
Platyceras carinatum Hall	×			Up. Held. and Ham. of New York.
conicum Hall	×			Up. Held. and Ham. of New York, and Up. Held. of Falls of the Ohio.
conradi Walcott	×			
dentalium Hall	×			Up. Held. of New York.
nodosum, Conrad	×			Up. Held. of New York.
thetiforme Walcott	×			
thetis Hall	×			Up. Held. and Ham. of New York.
undulatum Walcott	×			
Platyostoma lineatum Conrad	×			Up. Held. and Ham. of New York, Canada, etc.
sp. ?		×		
Euculiomphalus devonicus Walcott	×			
Euomphalus eurekensis Walcott	×			
(P.) laxus Hall		×	×	Up. Held. and Ham. of New York.
sp. ?	×			
sp. ?			×	
Sratparollus newarkensis Walcott		M.		
Plaurotomaria, sp. ?			×	
Platyschisma ? ambiguum Walcott		M.		
? maccoyi Walcott		M.		
sp. ?			×	
Calonema occidentalis Walcott	×			
Loxonema approximatum Walcott	×			
eurekensis Walcott	×			
nobile Walcott	×			
? subattenuatum Hall	×			Up. Held. of New York.
(2 sp. ?)	×			
sp. ?			×	
Bellerophon combsi Walcott	×			
leda Hall		M.		Ham. of New York.
lyra Hall		M.		Ham. of New York.
mæra Hall		×		Ch. of New York.
neleus H. & W	×			Geol. Expl. Fortieth Par., vol. iv, p. 250.
pelops Hall		M.		Up. Held. of New York.
perplexa Walcott	×			
Scoliostoma americana Walcott	×			
Naticopsis (like N. æquistriata)		×		
sp. ?		×		
sp. ?			×	
Metoptoma ? devonica Walcott	×			

DEVONIAN—Continued.

Genera and species.	Lower.	Upper.	White Pine Upper.	Remarks.
Pteropoda.				
Tentaculites attennatus, Hall	×			Ham. of New York and Canada.
bellulus, Hall?	×			Ham. of New York and Canada.
gracilistriatus Hall	×			Ham. of New York and Canada.
scalariformis Hall	×			Up. Held. of New York.
Styliola fissurella Hall	×	×		Ham. of New York and Canada.
var. intermittens Hall		×		
Conularia (sp.?)	×			
Coleolus lævis Walcott		×		
Hyolithes (like H. aclis Hall	×			
Cephalopoda.				
Orthoceras (5 sp.?)	×			
Gomphoceras suboviforme Walcott		×		
Cyrtoceras cessator, H. & W			×	Geol. Expl. Fortieth Par., vol. iv, p. 278.
nevadense Walcott	×			
Goniatites desideratus Walcott	×			
kingi, H. & W			×	Geol. Expl. Fortieth Par., vol. iv. p. 279.
sp.?		×		Like (G. discoidus Hall).
Crustacea.				
Beyrichia occidentalis Walcott	×			
Leperditia rotundata Walcott	×			
Pœcilopoda.				
Phacops rana Green (sp.)	×			Up. Held. and Ham. of New York, Canada, etc.
Dalmanites meeki Walcott	×			
sp.?	×			
Proetus nevadae Hall		M.		Ham. of New York, Pal., N. Y., vol. vii, p. 129, 1888.
marginalis Conrad (sp.)	×			Up. Held. of New York.
sp.?			×	
Phillipsia coronata, Hall ?		M.		Ham. of New York.

CARBONIFEROUS.

Genera and species.	Lower.	Upper.	Remarks.
Rhizopoda.			
Fusilina cylindrica Fischer	×	×	
robusta Meek	×	×	
Porifera.			
Stromatopora sp.?	×		
Actinozoa.			
Zaphrentis sp.?		×	
Syringopora multattenuata?	×		McChesny, sp.
Chætetes 3 sp.?		×	

CARBONIFEROUS—Continued.

Genera and species.	Lower.	Upper.	Remarks.
Echinodermata.			
Archæocidaris 2 sp. ?	×	....	
Polyzoa.			
Polypora, sp. ?	....	×	
sp. ?	×	....	
Ptilodictya (S.) carbonaria Meek ?	....	×	Coal-measures of Ohio.
(S.) serrata Meek ?	....	×	Coal-measures of Ohio.
(sp. ?	×	....	
Fenestella 3 sp. ?	×	....	
Brachiopoda.			
Discina connata Walcott	×	....	
newberryi Hall	×	....	Species of the Waverly sandstone of Ohio.
nitida Phillips (sp.)	×	....	
sp. ?	×	....	
Lingula mytiloides Sowerby ?	×	....	
Chonetes granulifera Owen	×	....	U. S. Geol. Surv., Nebraska, p. 170, 1872.
verneuiliana N. & P	×	....	U. S. Geol. Surv., Nebraska, p. 170, 1872.
Productus costatus Sowerby ?	×	....	Geol. Expl. Fortieth Par., vol. iv., p.69,1877.
elegans McCoy	×	....	
longispinus Sowerby	×	×	Geol. Expl. Fortieth Par., vol. iv., p.78,1877.
longispinus, var. muricatus N. & P.	×	....	
nebrascensis Owen	×	×	Expl. and Surv. W. 100th Merid., vol. iv., Pal. p. 116, 1875.
prattenianus Norwood	×	×	Geol. Expl. Fortieth Par., vol, iv., p.72,1877.
punctatus Martin (sp.)	....	×	Expl. and Surv. W. 100th Merid., vol. iv, Pal. p. 114, 1875.
semireticulatus Martin (sp.)	×	×	Geol. Expl. Fortieth Par., vol. iv, p. 69, 1877.
subaculeatus Murch	×	....	Also in Devonian.
Strophomena rhomboidalis Linn (sp.)	×	....	
Streptorhynchus crenistria Phillips (sp.)	×	....	
Orthis pecosi Marcou	....	×	Expl. and Surv. W. 100th Merid., Pal., vol. iv, p. 125, 1875.
resupinata Martin (sp.)	×	....	Geol. Expl. Fortieth Par., vol. iv, p. 265, 1877.
Spirifera annectans Walcott	×	....	
camerata Morton	×	×	Geol. Expl. Fortieth Par., vol. iv, p. 91, 1877.
desiderata Walcott	×	....	
leidyi N. & P	×	....	
neglecta Hall	×	....	
rockymontana Marcou	×	×	Expl. and Surv. W. 100th Merid., vol. iv, Pal., p. 134. 1875.
striata Martin	×	....	Geol. Expl. Fortieth Par., vol. iv, p. 269. 1877.
trigonalis Martin (sp.)	×	....	
(Martinia) setigera Hall	×	....	Geol. Expl. Fortieth Par., vol. iv, p.270. 1877.
Syringothyris cuspidatus Martin (sp.)	×	....	Davidson's Monograph, Carb. Brachiopoda.
Spirifera cristata Schlotheim (sp.)	×	×	Also in Devonian.
Retzia radialis Phillips	×	×	
veneuiliana Hall	×	....	L. Carb., Eureka District, Nevada.
Athyris royssii L'Eveille (sp.)	×	....	Geol. Expl. Fortieth Par., vol. iv, p. 82, 1877.
hirsuta Hall	×	....	
subtilita Hall (sp.)	×	×	
Rhynchonella eurekensis Walcott	×	....	
thera Walcott	×	....	
sp. ?	×	....	Leiorhynchus-like.
Camarophoria cooperensis Shum	×	....	
Terebratula bovidens Morton	....	×	Expl. and Surv. W. 100th Merid., vol. iv, Pal., p. 144, 1875.
hastata Sowerby	×	....	

Systematic list of fossils of each geological horizon—Continued.

CARBONIFEROUS—Continued.

Genera and species.	Lower.	Upper.	Remarks.
Lamellibranchiata.			
Aviculopecten affinis Walcott	×	....	
eurekensis Walcott	×	....	
hagnei Walcott	×	....	
peroccidens Walcott	×	....	
piñonensis Walcott	×	....	
2 sp.?	×	....	
Streblopteria similis Walcott	×	....	
Crenipecten hallanus Walcott	×	....	
Pterinopecten hoosacensis Walcott	×	....	
spio Walcott	×	....	
Pterinea pintoensis Walcott	×	....	
Leptodesma (2 sp.?)	×	....	
Ptychopteria protoformis Walcott	×	....	
Pinna consimilis Walcott	×	....	
inexpectens Walcott	×	....	
Myalina congeneris Walcott	×	....	
nemesis Walcott	×	....	
nessus Walcott	×	....	
Modiola? nevadensis Walcott	×	....	
Modiomorpha ambigua Walcott	×	....	
? desiderata Walcott	×	....	
? pintoensis Walcott	×	....	
Nucula insularis Walcott	×	....	
levatiforme Walcott	×	....	
Solenomya curta Walcott	×	....	
Macrodon hamiltonæ Hall	×	....	Ham. of New York.
truncatus Walcott	×	....	
tenuistriatus Meek & Worthen	....	×	Geol. III, vol. v, p. 576, 1873.
Grammysia arcuata Conrad (sp.)	×	....	Ham. of New York.
hannibalensis Shumard (sp.)	×	....	
Edmondia? circularis Walcott	×	....	
medon Walcott	×	....	
Pleurophorus meeki Walcott	×	....	
Sphenotus æolus Hall	×	....	Waverly of Ohio.
retusus Walcott	×	....	
salteri Walcott	×	....	
simplex Walcott	×	....	
Spathella? næna Walcott	×	....	
Cypricardella striata Walcott	×	....	
connatus Walcott	×	....	
Cardiola? filicostata Walcott	×	....	
Schizodus cuneatus Meek	×	....	Coal measures of Ohio.
curtiforme Walcott	×	....	
deparcus Walcott	×	....	
pintoensis Walcott	×	....	
Gastcropoda.			
Platyceras occidens Walcott	×	....	
piso Walcott	×	....	
Platyostoma inornatum Walcott	×	....	
Euomphalus (S.) subrugosus M. & W.	×	....	
Loxonema bella Walcott	×	....	
Macrochellus, sp.?	×	....	
Pleurotomaria nevadensis Walcott	×	....	
nodomarginata McChesney.	×	....	
sp.?	×	....	
sp.?	....	×	

Systematic list of fossils of each geological horizon—Continued.

CARBONIFEROUS—Continued.

Genera and species.	Lower.	Upper.	Remarks.
Gasteropoda—Continued.			
Naticopsis. sp.?	×	....	Not unlike N. rana M. & W.
Bellerophon majuscula Walcott	×	....	
textilis Hall	×	....	
sp.?	×	....	Like B. ellipticus Mc.Chesvey.
sp.?	×	....	Like B. sublævis Hall.
Metoptoma peroccidens Walcott	×	....	
Ampullaria? powelli Walcott	×	....	
Pulmonifera.			
Zaptychius carbonaria Walcott	×	....	
Physa prisca Walcott	×	....	
Pteropoda.			
Conularia missouriensis Shum'd	×	....	
Hyolithes carbonaria Walcott	×	....	
Dentalium (like D. primarium) Hall	×	....	
Cephalopoda.			
Orthoceras eurekensis Walcott	×	....	
randolphensis Worthen	×	....	
(2 sp.?)	×	....	
Gomphoceras sp	×	....	
Nautilus (like N. digonis M. & W.)	....	×	
Crustacea.			
Leperditia sp.?	×	....	
Pœcilopoda.			
Griffithides portlocki M. & W. (sp.)	×	....	

APPENDIX B.

MICROSCOPICAL PETROGRAPHY

OF THE

ERUPTIVE ROCKS OF THE EUREKA DISTRICT, NEVADA.

BY

JOSEPH PAXSON IDDINGS.

APPENDIX B.

MICROSCOPICAL PETROGRAPHY OF THE ERUPTIVE ROCKS OF THE EUREKA DISTRICT, NEVADA.

BY JOSEPH PAXSON IDDINGS.

CHAPTER I.

GRANITE AND PORPHYRY.

The representatives of this division of eruptive rocks from the Eureka District are but few in number, and bear a very close resemblance to one another, being all quartz-orthoclase rocks. They are composed of the same minerals, having in addition to the quartz and orthoclase a triclinic feldspar with biotite and hornblende in varying quantities. They are granite, granite-porphyry and quartz-porphyry.

Granite.—Of the many varieties of crystalline rocks found within the small area of the Eureka District, granite plays but an insignificant rôle, and is represented by only four thin sections from the exposure south of Ruby Hill; of these, 1, 2, and 3 show a fine grained rock of uniform texture, with the characteristic granitic structure. None of the individuals of quartz and feldspar have crystallographic outlines, but are irregularly shaped by reason of the mutual penetration of adjacent grains. The essential components of the rock are quartz, feldspar, hornblende, and biotite. the accessory minerals being titanite, iron oxide, apatite, zircon, and allanite, besides secondary minerals resulting from the decomposition of the first, which are chlorite, calcite, quartz, epidote, and hydrated oxide of iron. The rock is, therefore, an amphibole granitite. The most abundant primary constituent, quartz, occurs in irregularly shaped grains which, together with its inclusion of portions of all the other primary minerals, shows it to have been the last to crystallize. It occasionally occurs in porphyritical grains. The only charactertistic inclusions are minute fluid cavities with very small moving bubbles. It shows the phenomena of irregular optical orientation resulting from mechanical deformation. The feldspar is for the most part altered, but the fresher sections show it to be both orthoclase and plagioclase in nearly equal proportions. They both have a fine zonal structure; the former is frequently in Carlsbad twins, the latter in multiple twins, after the albite and sometimes also after the pericline law. The decomposition commenced at the center, resulting in some cases in a cryptocrystalline aggregate like kaolin, with calcite; in others filling the crystal with shreds of colorless mica, and minute, pale yellow grains, traceable to larger aggregations of epidote. Feldspar and quartz form the main mass of the rock, through which is scattered mica and hornblende in varying amounts. The hornblende is in poorly defined crystals, except some of the smaller individuals, which are well developed in the prism zone. The prismatic faces are much larger than the clinopinacoid, and the cleavage parallel to the former is strongly marked. It is in simple crystals and twins, twinned parallel to $\infty P \grave{\infty}$. The color is dark green, with strong pleochroism, most noticeable in sections parallel to the clinopinacoid and base. The colors are: $\mathfrak{c}$ = dark green, $\mathfrak{b}$ = brownish green, $\mathfrak{a}$ = light brown, $\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$. The angle of extinction read from the vertical axis is mostly from 17° to 19°, but in two instances is 21° and 25°. It incloses magnetite, apatite, and biotite, having been formed after the latter in every case. It is quite fresh, though the mica is almost completely decomposed. The biotite, with which the hornblende is intimately associated, occurs in comparatively thick crystals of irregular outline, of a deep brown color, with nearly uniaxial interference figure, and has occasional inclusions of iron oxide, apatite, zircon, and rarely feldspar. It is especially interesting from its mode of decomposition, which takes place along the basal cleavage and results in a dark green pleochroic chlorite, which must be formed of an aggregation of minute scales parallel to the lamination of the mica, for basal sections remain dark when revolved between crossed nicols and show no interference figure and no pleochroism, while transverse sections exhibit a marked fibration parallel to the mica cleavage and are pleochroic; being green, parallel, and yellow at right angles to the line of fibration. This chlorite, in turn, alters into epidote and possibly quartz. The epidote, in irregular grains, is pleochroic between intense greenish yellow and pale yellow. That it does not result directly from the decomposition of the biotite is evident from the fact that it never occurs in it unassociated with chlorite, while the latter occurs constantly alone, and also because lenticular masses of epidote are seen to have disturbed the parallelism of the chlorite scales, proving its subsequent crystallization.

Titanite in narrow rhombic sections and less regular grains is sparingly present. The iron oxide appears to be magnetite for the most part. Colorless apatite is abundant both in short, stout prisms, and long, slender, jointed needles, penetrating everything in all directions. Apatite and sharply crystallized zircon appear to be the first minerals formed in the rock. In thin section 2 there are three comparatively large crystals of allanite, dark brown, with strong absorption; two are twinned. An irregular grain of allanite is found in 4. Thin section 3 is highly decomposed and stained with hydrous oxide of iron. Thin section 4 is of a porphyritic variety, having a fine grained, microgranitic groundmass of quartz and feldspar. Though the feldspar of this rock is still mostly fresh, and the hornblende entirely so, the biotite is completely altered to green chlorite, epidote, quartz, and calcite.

Granite-Porphyry.—The microscopical study of the granite-porphyry of this district, though somewhat limited, is of great interest as showing the modifications produced in the final crystallization of a granitic magma through the chilling caused by the inclosing rocks, and consequently the relation of the quartz porphyries to the coarse grained granite; and also as pointing out the correspondence in microscopical structure of the metamorphosed sandstone of the district to certain forms of micro-granite. The most important occurrence of this rock is in the granite-porphyry dike and its apophyses south of Wood Cone, near Fish Creek Wells, which is represented by thin sections 10, 11, 12, 16, 19, 20, 21, 22, 24, 25, 26, 27, 28, 29. It is found to be a wholly crystalline rock of most varying structure, from coarse grained granite and porphyritic granite to dense porphyry with an aphanitic groundmass. It is composed of quartz and feldspar, both orthoclase and plagioclase, with a small amount of biotite and hornblende; and since the character of these minerals is the same throughout the different thin sections, and only their relative abundance and structural combination vary, it seems best to give a general description of each of the minerals first, and afterwards the special features which characterize the different modifications of the rock.

The most noticeable component is quartz, occurring both in macroscopic phenocrysts and in microscopic grains. In the former instance it is usually well developed in the form of dihexahedral crystals, sometimes having short prism faces; but it also occurs in rounded and irregular grains of varying size, the largest being about as large as a pea. In the granitic portions of the rock the grains are wholly irregular in form. The quartz substance is colorless and perfectly fresh, and is filled with minute fluid inclusions, mostly with a single gas bubble, sometimes in motion. Frequently there are double bubbles, the inner of which is sometimes briskly moving; the fluids in this case are water and liquid carbon dioxide. There are also rounded bays of groundmass penetrating the crystals, and more rarely minute portions of groundmass in dihexahedral cavities. The habit of the quartz differs from that of the quartz in quartz-porphyry by the abundance of liquid carbon dioxide and the absence of any isotropic glass, but corresponds closely to it in other respects. The microscopic grains of quartz which form a large part of the groundmass, have a granitic habit, being in part irregularly outlined, in part conjointly crystallized with the feldspar, producing micropegmatitic structure, to be described later on.

The feldspar is mostly orthoclase, but a triclinic species also is always present, the large phenocrysts of the former are often well crystallized with the ordinary faces, $\infty P\grave{\infty}$, $0P$, ∞P, $2P\acute{\infty}$, the clinopinacoid being the most strongly developed, forming tabular Carlsbad twins. The cleavage parallel to the base is very perfect, that parallel to the clinopinacoid less so, and in numerous individuals a fine striping is noticed, which is remarkably regular, but occasionally deviates from right lines and loses its parallelism. It at first suggests the polysynthetic twinning of plagioclase, but on closer examination appears to be an interlamination of albite in orthoclase parallel to the orthopinacoid, as in perthite; in one section nearly in the plane of the clinopinacoid the striping crosses the basal cleavage parallel to the direction of the other pinacoid, and the angles of extinction for the main crystal and the included lamellæ are about 7° and 18°, respectively, on the same side of the basal cleavage; angles which correspond to orthoclase and albite in such a section. A zonal structure is common to many individuals, and may be observed in the fresher crystals, even in the hand specimens, without the aid of a lens. There are no characteristic inclusions, but particles of the associated minerals are frequently met with, especially near the margin of the crystal. The plagioclase is very similar in occurrence to the orthoclase, being characterized by the abundance of striations produced by multiple twinning, mostly in one direction, like that in albite, but also in a second direction nearly at right angles to the first, like that in pericline. Exactly how many species are present has not been determined optically, but it is certain that labradorite is one of them, as the highest symmetrical extinction angles reach about 30°. It is in general quite free from inclusions; nevertheless, in some of the plagioclase crystals from widely different parts of the dike there are minute, colorless, rectangular bodies always parallel to the twinned lamellæ, that at once remind one of the glass inclusions characteristic of andesitic plagioclase. Their nature, however, is doubtful, for though without influence on polarized light in most instances, they appear in others to affect it slightly, and besides are without a gas-bubble, from which it seems probable that they are not glass, but possibly feldspar. The substance of the feldspar is sometimes perfectly fresh and transparent, at others clouded by minute, irregularly shaped particles, that reflect incident light and appear white. The orthoclase when further altered is filled with brilliantly polarizing shreds of colorless potash-mica, arranged parallel to three directions in the crystal. Calcite is noticed in the partially decomposed plagioclase, the decomposition in general setting in from the outside of a crystal and traversing it in the most irregular manner.

The next essential mineral to be mentioned is biotite. It is universally present, but in varying quantities. In the thin sections from this body it is mostly altered. The fresh mineral is in poorly defined, six-sided crystals of a dark brown color, with strong absorption parallel to the basal cleavage, the basal sections yielding apparently uniaxial interference figures, with a negative character, but sometimes showing a small angle between the optic axes. It is quite free from inclusions, but occasionally carries small crystals of zircon and apatite, and more frequently titanic iron; in one instance (12) it is surrounded by grains of iron oxide, and in another (22) by hornblende. The alteration that has taken place in most of the sections appears to be a bleaching out of the brown color, leaving a yellow or light green, brilliantly polarizing mica, with faint pleochroism, which is generally filled with slender acicular crystals of a yellowish brown color arranged in lines intersecting at 60°, besides larger and stouter crystals very perfectly developed, which have a high index of refraction and seem to belong to the tetragonal system. From their close association with partially decomposed titanic iron, which is characterized by strongly marked, rhombohedral cleavage, it is most likely that these minute, secondary crystals are rutile or anatase. The decomposition starts from the surface of the crystal, sections of partially altered mica being found with portions of the mineral still fresh in the center. A further stage of alteration produces a green, fibrous chlorite, and in one instance (12) quartz and epidote. The colorless potash-mica, scattered through the groundmass in shreds and fan-like aggregations, which appears brilliantly colored between crossed nicols, and shows a small angle between the optic axes, is undoubtedly of secondary origin, arising from the decomposition of orthoclase, as already mentioned, or from that of the brown mica; for in every thin section where it occurs both the brown mica and feldspar are more or less altered, and in those where they are both perfectly fresh it is wanting.

The hornblende is by no means a constant ingredient, being absent from all the more porphyry-like varieties and present in only part of the granitic ones. It is of a dark brown color, sometimes green, with strong absorption and pleochroism, and is seldom in fully developed crystals, though some cross sections with the characteristic cleavage show the presence of the prism and both the pinacoidal faces. The crystals are short and stout, their outline broken by intruding grains of the surrounding groundmass, which are also abundantly included in the hornblende, together with apatite, iron oxide, and more rarely mica. It would seem to be one of the later crystallizations, contemporaneous with that of the groundmass.

There are a great number of accessory minerals, which are not all present, however, in any one thin section, and are more abundant in the granitic than in the porphyry-like forms of the rock. The most exceptional of these is augite, found in only one thin section (22). It is of pale green color, with high index of refraction and characteristically great extinction angle. Titanite or sphene in wedge-shaped crystals and irregular grains is common to the hornblende-bearing varieties, with which mineral it is usually in close association. The iron oxide appears to be for the most part titaniferous, many of the larger grains showing a most pronounced rhombohedral cleavage, the decomposition in several cases resulting in leucoxene and a chemical test giving the reaction for titanic acid. Apatite and zircon in sharply defined crystals are everywhere present in small quantities, and garnet is found in a thin section from a closely related dike. Allanite is present in those sections rich in hornblende and biotite; it is especially abundant in No. 11, where ten grains of it were noted.

The groundmass of this rock, in all of its modifications, is wholly crystalline, no isotropic glass being found anywhere in it. It is composed of quartz and orthoclase feldspar, very little plagioclase having been recognized. To these is sometimes added hornblende, biotite, and titanic iron, besides the colorless potash-mica of secondary origin. The quartz and feldspar are either in an aggregation of irregularly outlined grains of nearly uniform size, which is the ordinary structure of granite, or they form orderly arranged groups of triangular or rhombic figures, and others elongated and feather-like. This structure is noticeable in ordinary light from the fact that the quartz remains pellucid after the feldspar has become clouded by partial alteration. Between crossed nicols, however, the appearance is very distinct. In the coarser grained varieties, especially at the spot represented in Fig. 1, Pl. VI, the field is covered with blocks of similar geometric and cuneiform figures—parallelograms, trapezoids, and variously shaped triangles—the sides of all those forming any single group being respectively parallel, besides which are long and narrow parallel strips, two sets of which, meeting obliquely, produce a feather-like appearance. It is further seen that all the figures in any one group extinguish light in the same azimuth or have the same optical orientation, and that the inclosing block is a single individual with a different orientation, the one being quartz and the other feldspar. In this particular case the small figures are of quartz and throughout the field have the same extinction as a central grain, the inclosing blocks being of differently oriented feldspar. This tendency to crystallize around grains of quartz or feldspar is more noticeable in the finer grained varieties, where the nucleus is incrusted with a shell that in section appears as a frame-like border, having a radiating structure composed of variously oriented sectors, though the portions formed by the same mineral as the nucleus have their axes of elasticity parallel throughout. Of the phenocrysts, quartz seems to be the only one around which this special crystallization takes place.[1] A very fine example of this structure is found in thin section 28, where it is seen to have formed after the primary crystallization of the phenocrysts, but previous to the final consolidation of the microgranitic groundmass. This distinctive structure, which is characteristic of many European granite-porphyries, has been described by Rosenbusch and called by him "Granophyr."[2] It is the "structure pegmatoïde" of the French petrographers, and is becoming generally termed micropegmatitic.

Having described the characters of the minerals composing this granite-porphyry, it remains to notice their structural combination, whose variety is the striking feature of this occurrence. Thin section 10, from the large area north of Wood Cone, is of a porphyritic granite, with little groundmass of fine grained granitoid structure. The large phenocrysts have no crystallographic outline, but pass by increasing abundance of inclusions into the groundmass, which contains biotite, hornblende, titanite and titanic iron, apatite, zircon, and allanite. Thin section 11, from southwest of the Wood Cone, is a local modification of slight importance; it is a fine grained mass without phenocrysts, with granitoid structure and composed of the same minerals as the previous section, but with a greater percentage of biotite and hornblende. Thin section 12, from the bottom of a gulch on the east side of the dike and north of Spring Valley road, is of porphyritic, coarse grained granite. The larger phenocrysts of feldspar have more or less well defined outlines. The orthoclases

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[1] This constitutes the *quartz auréolé* of French petrographers.

[2] H. Rosenbusch. Die Steiger Schiefer, etc., pp. 347, 352, Strassburg, 1877. Mikroskopische Physiograpie, p. 31, Stuttgart, 1877. Mikroskopische Physiograpie, vol. II, p. 383, Stuttgart, 1886.

have a marginal zone of included quartz grains, the inner limit of the zone being sharply defined. In places the inclosed grains are so numerous that the feldspar crystals merge in the groundmass and their outline is confused. The biotite, surrounded by grains of iron oxide, is partly altered to green chlorite and epidote. The hornblende is scarce and the crystallization of the groundmass granitoid. The next three sections—16, 19, 20—should be considered together, since they are from the same portion of the west side of the dike north of the last named road. No. 16 is from a distance of 30 feet from the plane of contact with the limestone and is rich in sharply defined porphyritical crystals, the quartz being in perfect dihexahedrons. There is an abundance of biotite and titanic iron with titanite, but no hornblende. The groundmass has the coarse grained micropegmatitic structure illustrated in Fig. 1, Pl. VI. No. 19, from a distance of 10 feet, and No. 20, from the contact, are still more porphyry-like, having much more groundmass with finer grained micropegmatitic structure, of very homogeneous texture, the only phenocrysts being feldspar and quartz; biotite, hornblende, and the associated minerals are wanting. The feldspar is more altered than that of 16 and colorless potash-mica is more abundant. Thin sections 21 and 22 are from the bottom of a gulch on the south side of the same road. The first from a distance of 1 foot from the contact with limestone, shows a porphyritic granite, rich in large, well defined crystals of feldspar and quartz, with much biotite and hornblende. The groundmass forms but a small part of the whole and is granitoid, the grains averaging 0·1 ^{mm} in size. The second thin section is from immediate contact and differs from the first in having much more groundmass with the same microgranular structure, the grains being only one-third as large as those at a foot distance. The phenocrysts are smaller and more sharply outlined, the fresh orthoclase having a satin-like sheen in thin section. Hornblende is more abundant in minute crystals, and augite occurs sparingly.

Thin section 24, from a local modification of the porphyry near its contact with limestone on the north side of the road, requires special notice. The rather small phenocrysts of quartz and feldspar have the same characteristics as those from other portions of the same body, but the groundmass is very different. It is bluish gray in thin section, spotted with minute black specks; under the microscope it is seen to be composed of irregular grains of quartz and feldspar having a granitic structure. The black specks are found to be angular microcrystalline patches, crowded with black particles, and bearing shreds of colorless mica, and appear to be remnants of a base less highly crystallized than the groundmass. Thin section 25 is from a breccia of porphyry and dark colored quartzite, the phenocrysts are angular fragments, the quartz is rich in fluid inclusions, and the opaque, black portions produce a very prominent flow-structure. Both sections are free from biotite or hornblende. Thin sections 26 and 27 are interesting because they come from the middle and side of a branch dike not 30 feet wide. The former has a dense groundmass, bearing large quartz dihexahedrons fairly flooded with fluid inclusions of water and liquid carbon dioxide; the groundmass is a comparatively coarse grained aggregation of quartz and feldspar, the latter more highly developed but entirely decomposed, there is a little completely altered biotite, much colorless mica and some epidote; the second thin section, from the side of the dike, is a dense gray mass, poor in quartz phenocrysts, but rich in small crystals of feldspar and biotite, the latter partially altered to chlorite; the groundmass is finer grained and shows in places an incipient micropegmatitic structure, which is noticeable around the quartz crystals and also in pseudospherulites; there is a little titanite, but no hornblende.

Thin section 28, from a narrow dike farther up the Spring Valley road, has been already alluded to as presenting a most beautiful example of micropegmatitic structure. It is a very fine grained rock, having a few small quartz dihexahedrons containing fluid inclusions of both kinds and portions of groundmass, besides a few crystals of feldspar, but no biotite or hornblende. Around the quartz and smallest feldspars are frames of feather or fernlike aggregates of intercrystallized feldspar and quartz, producing the effect of a flowered pattern on the microgranitic groundmass of quartz, feldspar and colorless mica. Thin section 29 from a small dike west of Castle Mountain is somewhat similar; the extremely fine grained groundmass bears numerous quartz crystals, with bays of groundmass, some inclusions of colorless glass and a few of water with moving bubbles, also crystals of feldspar completely altered to a cryptocrystalline aggregate, probably kaolin, besides calcite and hydrous oxide of iron; and a little decomposed biotite. The groundmass is microgranitic with an incipient, micropegmatitic structure developed around the quartzes. Garnet occurs in well formed rhombic dodecahedrons, having long slender needles radiating from their centers, which exert no influence on polarized light and are of an indeterminable nature.

Another variety of granite-porphyry is found near the summit of the Fish Creek Mountains, thin section 30. It is a fine grained rock, rich in biotite and hornblende. The sections show it to be composed of long rectangular feldspar crystals, six-sided mica plates and rather stout hornblende crystals cemented together by quartz and feldspar, with well developed micropegmatitic structure. Except in this last respect the rock closely resembles the fine grained micaceous modification of the large granite-porphyry dike near Wood Cone, No. 11. The feldspar is much altered, chiefly at the center of each individual, the product being partly potash-mica, partly calcite. Of the fresher crystals many are triclinic. An estimate of the relative abundance of the two feldspars, however, is impossible under the circumstances. Quartz does not occur in large phenocrysts, but forms the greater part of the groundmass, where, with a little feldspar, it assumes the peculiar structure already alluded to. It carries a small number of minute fluid inclusions with moving bubbles. The biotite, in quite sharply outlined six-sided crystals, is reddish brown in its fresher portions and shows a slight angle between the optic axes, but it is mostly altered to a light yellow chlorite, through which are scattered grains of a yellow, highly refracting mineral, resulting from the alteration of ilmenite and corresponding to leucoxene, besides very small, sharply defined, colorless crystals, apparently epidote. The crystals of hornblende are very well developed, showing the prismatic and both pinacoidal faces, together with the base and pyramid. The individuals are comparatively large and broad, with the characteristic cleavage. The color is light brown, frequently green along the margin. The pleochroism is strong from brown to yellow, $\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$. The highest extinction angle measures 19°. Along the cleavage crack red oxide of iron is sometimes deposited, and, though for the most part fresh, a few are completely altered to an irregular aggregate of fibrous chlorite and hydrous oxide of iron, through which run colorless needles with an extinction angle of 17°, which are probably actinolite. The accessory minerals are magnetite, with some ilmenite partly altered to leucoxene, a very little titanite, and a large amount of apatite, both in short crystals and also in extremely long, slender, colorless, hexagonal prisms, occasionally broken and bent, but generally perfectly straight, although one measures $0{\cdot}44^{mm}$ long by $0{\cdot}0075^{mm}$ wide, or is sixty times as long as it is broad, which indicates that the mass commenced to crystallize after all motion in it had ceased.

Quartz-Porphyry.—Unfortunately the only body of quartz-porphyry found in the district is completely decomposed. It occurs in the vicinity of the Bullwhacker mine and is represented by thin sections 31, 32, and 33, which have essentially the same structure, though the first is full of pyrite and the second and third are discolored by hydrous oxide of iron. It is closely related to granite-porphyry, having apparently a microgranitic groundmass; but a thin film of isotropic glass is detected between the grains along the thinnest edge of section 31, and colorless glass is found included in the macroscopic quartz grains, whose quartz-porphyry habit is further evinced by intrusions of groundmass, small amount of fluid inclusions, some of which have salt cubes, and by the absence of liquid carbon dioxide. The quartz shows a well developed rhombohedral cleavage, especially in section 32, and is the only primary mineral except apatite and zircon remaining unaltered. A small amount of feldspar is indicated by patches of a colorless, aggregately polarizing substance, probably kaolin. The mica occurs in comparatively large crystals, much elongated in the direction of the vertical axis, which have been altered to a mass of confused laminæ of colorless potash-mica, calcite and red oxide of iron. The groundmass also is crowded with shreds of potash-mica, but it seems probable that in both of its occurrences it is of secondary origin. Sections that have the outline of hornblende crystals are filled with calcite and ferrite, and quite large deposits of calcite with very distinct rhombohedral cleavage have filled cavities in the rock. Iron is present as magnetite and the hydrous oxides and as ilmenite and pyrite, the latter in comparatively large crystals, including portions of the groundmass. Apatite and zircon occur in very small quantities.

Appendix—Metamorphosed Sandstone—A micaceous fine grained rock occurs in several localities in the vicinity of Modoc Peak, which is traceable to thin beds of sandstone, which, however, are never so full of mica, and though the true nature of its occurrence is somewhat in doubt it is safe to consider it a highly altered forms of the same quartzose deposit, since a series of thin sections from the bedded sandstone and the very micaceous rock grades imperceptibly from one extreme to the other, the coarsest grained variety having the mineral composition and structure of a microgranite. Of the thin sections prepared, three, 437, 440, 450, are from dense cryptocrystalline sandstone of a yellowish pink color, bearing a few quite perfect crystals of muscovite and quartz. Under the microscope the rock is seen to be formed of minute quartz grains, shreds of potash-mica and patches of a colorless cryptocrystalline substance, through all of which is scattered much calcite and ferrite, and occasionally long, slender, beautifully terminated crystals of zircon. The quartz grains range from 0·1 to 0·05^{mm} in diameter, and have the granitoid form, in no instance suggesting waterworn fragments. They contain extremely minute fluid inclusions, which literally swarm in the microscopic quartz dihexahedrons of section 440. The form in which the calcite is found suggests its alteration from feldspar, or its deposition by infiltration in the place of decomposed feldspar, which is undoubtedly the case in one or two quite large sections. Thin section 451 is very similar to those just mentioned, and with 452 came from a body closely connected with the bed of sandstone represented by 450. The groundmass of 451 is the same in every respect as those just described, but there are numerous macroscopical individuals of mica and feldspar, the latter still showing in some cases the striping of twinned plagioclase, though mostly altered to a cryptocrystalline mass like that occurring in the groundmass, which may probably have the same origin. The poorly defined mica is completely replaced by calcite and ferrite. Sharply crystallized zircon and apatite are present in stout prisms with very uneven outline. The three remaining thin sections, 452, 466, and 463, exhibit the highest development reached, and might be considered micaceous microgranite. The groundmass is composed of granitoid quartz and partially altered feldspar in grains about 0·1^{mm} in diameter together with shreds of potash-mica and calcite. In this lie porphyritically imbedded well developed feldspar crystals and mica and occasionally quartz. The feldspar is much altered, but shows that it is partly Carlsbad twins, and is partly striped plagioclase. The mica is somewhat altered and is of brownish yellow color, with strong absorption. A large individual of quartz in 466 has a multitude of minute fluid inclusions arranged in planes parallel to the prism or rhombohedral faces. Ferrite, apatite and zircon also occur. The whole is a thoroughly granite-like rock, without signs of foliation.

It is interesting to note in this connection how an apparent granitoid form of quartz grains may sometimes arise from an entirely different cause. The phenomenon is exhibited in a quartz conglomerate of small grain, thin section 501, where it is observed in polarized light that between the coarser waterworn fragments of colored, cryptocrystalline quartzite lies a mass of colorless quartz in angular, closely fitting grains, the salient angles of one corresponding to reentrant angles of those surrounding it. Upon close examination in ordinary light each angular crystal is seen to inclose a large round grain of quartz, frequently full of fluid inclusions and containing microlites and trichites, the narrow border being perfectly pure quartz. This is illustrated in Fig. 3, Pl. IV. From this it is evident that the rock is an ordinary quartz conglomerate of rounded pebbles cemented together by silica that has crystallized around the fragments of quartz crystals, taking the same crystallographic orientation as the nucleus and thus extending the individual until obstructed by the surrounding bodies.

The same observations were first made and published by Törnebohm[1] in 1876 and subsequently were observed by H. Clifton Sorby[2] and published by him in an address before the Geological Society of London, February 20, 1880. The same phenomenon was described by A. A. Young in the American Journal of Science for July, 1881; and still later, in 1883, R. D. Irving published in the same journal for June a paper on the similar enlargement of quartz grains in the St. Peters and Potsdam sandstones and in certain Archean quartzites in Wisconsin, and in 1884 Irving and Van Hise published a bulletin "on secondary enlargements of mineral fragments in certain rocks,"[3] in which, in addition to quartz, the enlargement of feldspars by the same process of accretionary crystallization is described.

The same thing has been observed by T. G. Bonney and Mr. J. A. Phillips in England.[4]

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[1] A. E Törnebohm, "Ein Beitrag zur Frage der Quarzitbildung." Geol. Fören Stockh, 1876, vol. III, p. 35. Reviewed in Neues Jahrbuch für Min., etc., 1877, p. 210.

[2] Quart. Journ. Geol. Soc., London, 1880, vol. XXXVI, p. 62.

[3] Bull. 8 of the U. S. Geol. Survey, 1884.

[4] Quart. Journ. Geol. Soc., London, vol. XXXIX, p. 19.

CHAPTER II.

VOLCANIC ROCKS.

For so small an area the variety of volcanic rocks is great, yet there is a marked similarity between the individual crystals of the same mineral species wherever they occur, with some few exceptions, which links the various kinds of rocks together and suggests the possibility of a common source. Nevertheless, the difference between them in composition, structure, and physical appearance is sufficient to establish their individuality. They have been divided into three groups—andesite, rhyolite, and basalt—and have been considered in the order of their relative importance in the field.

ANDESITE.

Pyroxene-andesite (augite-andesite).—(*a.*)[1] The rock forming Richmond Mountain is a dense porphyritic lava, for the most part with a reddish purple homogeneous groundmass, rich in macroscopic crystals of flesh-colored feldspar, the largest 4 or 5^{mm} long, without distinct cleavage, and having a microtine habit; long black prisms of hornblende, with very perfect prismatic cleavage and less noticeable pyroxene crystals. The dense purple variety is in most every case parted or jointed in nearly horizontal planes. A dark bluish black variety, with a resinous oily luster, occurs in compact masses without fissile structure, and appears to pass insensibly into the purple rock. At Trail Hill, the most northern spur of Richmond Mountain, the same rock traced continuously from the main portion is vesicular and is rich in tridymite. A few hundred yards to the south a compact fissile exposure shows a more crystalline development and is exceptional.

Under the microscope thin sections from various parts of the body have essentially the same character—a gray, also yellowish to reddish gray, groundmass, composed of colorless or yellowish brown glass, very rich in feldspar microlites, augite prisms, and magnetite grains, with marked flow structure; abundant phenocrysts of zonally built plagioclase feldspar, with and without polysynthetic twinning, the

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[1] Since the first determination of these rocks was made, a separation and optical and chemical analysis of the pyroxenic constituent of the Richmond Mountain andesite have been made and published in the "Notes on the volcanic rocks of the Great Basin," by Arnold Hague and J. P. Iddings (Am. Journ. Sci., Vol. XXVII, June, 1884, p. 458). This showed that the greater portion of the pyroxene belongs to the orthorhombic species and has the composition of hypersthene. It is therefore more correct to place them under the head of pyroxene-andesites, though they were first termed "augite" andesites, those from Richmond Mountain belonging to the hornblende-bearing variety,

largest of which are so crowded with inclusions of foreign matter, with only a narrow border of pure feldspar, as to appear decomposed in the hand specimen. The smaller individuals of feldspar are quite free from like inclusions. Besides these are well-developed crystals of pale yellowish green, strongly pleochroic pyroxene; dark brown hornblende with the characteristic black border in not so sharply outlined forms; and, as accessory minerals, magnetite and apatite, with very rarely quartz, mica, zircon, and tridymite.

The phenocrysts of feldspar, including all that do not take part in the groundmass, are plagioclase. The largest individuals, reaching 4^{mm} in length, are in crystals nearly equally developed in the direction of the three axes, and show in the sections, besides crystal faces, rounded outlines. They are not abundant in the rock sections and can not be so carefully studied optically as the smaller feldspars, but from those that are met with it appears that they are not more basic than labradorite, and because of the great amount of glass included in them their separation and chemical analysis would be both difficult and uncertain. The smaller macroscopic individuals have well-defined crystal forms. Their sections are four, five, six, and eight sided and correspond to those cut from crystals with $0P$, $\infty P\breve{\infty}$, $\infty{}'P$, $\infty P'$, $2{}'P\breve{\infty}$, $2P'\breve{\infty}$ faces. They are for the most part prisms, lengthened in the direction of the brachydiagonal, though some appear tabular in the plane of the brachypinacoid. Irregularly outlined fragments are seldom met with. A very marked, sharply defined zonal structure is common to most all the larger crystals, but is wanting in the more minute ones of the groundmass. The cleavage parallel to the base and brachypinacoid is not very generally present nor very perfect, the feldspar having the irregular fracture and glassy appearance of sanidine, a resemblance still more striking because of the nearly total absence in half the individuals of polysynthetic twinning, though in almost every instance an apparently simple individual or Carlsbad twin is found to contain one or more thin lamellæ of feldspar twinned according to the albite law or to that of pericline. The medium sized individuals seen in the thin sections, which correspond to the smallest feldspars noticed in the hand specimens, from $0{\cdot}5^{mm}$ to $1{\cdot}0^{mm}$ in length, show the characteristic polysynthetic twinning of plagioclase and give angles of extinction symmetrical to the composition plane as follows: 15°-15°, 30°-31°, 33°-33°, 33°-34°, 36°-39°, which, from the table of extinction-angles published by MM. Fouqué et Michel-Lévy,[1] correspond to those of anorthite or a feldspar more basic than labradorite. The smaller individuals are twinned after the Carlsbad law, with very few exceptions, and are characterized by having but few lamellæ, of short length, lying in two directions at nearly right angles, twinned the one after albite parallel to the brachypinacoid, the other after pericline parallel to the basal cleavage when present. In many instances the lamellæ are entirely wanting, as just noticed. A careful study of all the sections that showed cleavage, or were

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[1] Fouqué et Michel-Lévy. Minéralogie Micrographique, p. 228. Paris, 1879.

nearly rectangular in outline, or extinguished symmetrically with respect to the trace of the brachypinacoid, gave from more than fifty measurements the following results in sections where the basal cleavage varied not more than 5° from being at right angles to the trace of the brachypinacoid; and in sections without cleavage, almost rectangular, the angle of extinction varied from 30° to 43°, in most cases being about 40°. In sections with symmetrical extinction it was 25°, 34°, 36°, 38°, 40°—that is, in the zone perpendicular to the brachypinacoid the angles of extinction measured from the trace of the latter plane reached 43° and were mostly greater than 31°, showing a part of the feldspar to be anorthite.

The frequent occurrence in this andesite of nearly rectangular sections of twinned crystals yielding both very high and widely varying angles of extinction led to an investigation of the position of the axes of elasticity in the two halves of sections cut from Carlsbad twins of plagioclase in a zone at right angles to the brachypinacoid ($\infty P\breve{\infty}$). From the nature of a Carlsbad twin it is evident that the plane of the optic axes in the two parts, being oblique with respect to the vertical crystallographic axis in plagioclase feldspars, would be symmetrically disposed only with respect to the vertical axis, considered as its axis of revolution; hence the extinction angles for the two parts of the twin, that is, the angles on a cutting plane included between the trace of its intersection with the brachypinacoid or composition plane and the traces of its intersection with the planes of the optic axes, respectively, would be symmetrical only for sections in the zone parallel to the vertical axis, that is in the zone $\infty P\bar{\infty}$, $\infty P\breve{\infty}$; consequently in the zone at right angles to the brachypinacoid there will be only one position where the extinction angles are symmetrical, and that is in the section parallel to the vertical axis, while in a plane perpendicular to it the extinction angles will be complementary, or equal when measured in the same direction: that is, the axes of elasticity in the two parts will be respectively parallel, but in all other sections of this zone they will be unequal. These relations, together with the degree of variation in the extinction angles throughout the zone may be graphically represented by the following diagram (Fig. 8), derived from the curves of extinction angles of feldspars in the zone at right angles to the brachypinacoid published by MM. Fouqué et Lévy.[1] The case of labradorite will serve as an illustration. Fig. 7 represents the projection of a Carlsbad twin of that species on the plane of the brachypinacoid; let (*a*) be the half in the normal crystallogaphic position, and (*b*) that in the twinned position, then it is evident that in considering a series of sections perpendicular to the plane of the brachypinacoid, if we pass from the position of a normal to the edge 0P, $\infty P\breve{\infty}$ of the first half (*a*) in the direction of the obtuse angle of that half, we at the same time pass from a position 52° from the normal to the edge 0P, $\infty P\breve{\infty}$ of the second half (*b*) in the direction of the acute angle of that half. In Fig. 8 the heavy line is the curve of the extinction angles for sections of the first half

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[1] Minéralogie Micrographique, etc.

(*a*); commencing at the normal, X, with a value of about 30°, the direction to the left corresponds to that which passes over the obtuse angle of that half (*a*); the light line is the curve for the second half (*b*), its corresponding normal, X′, being 52° 18′ to the right of the former, and starting at this point with the same value, 30°, but with opposite sign; its passage to the left corresponds to that over its acute angle. From the resulting figure it is readily seen that in the plane 26° 9′ to the right of the normal, X, which is the section parallel to the vertical axis, the angles of extinction in the two halves are equal and opposite, that is, symmetrical with respect to the brachypinacoid; and that in the plane 63° 51′ to the left of the same normal, X, which is the section at right angles to the vertical axis, the extinction angles are equal, but have the same sign, which agrees with the conclusions previously arrived at. The greatest difference in the size of the angles in any one section appears to be about 20°. That these variations occur in a great number of nearly rectangular sections is understood upon comparing with the diagrams the following table of angles made by the basal cleavage and the trace of the brachypinacoid in sections in the zone in question. The figures

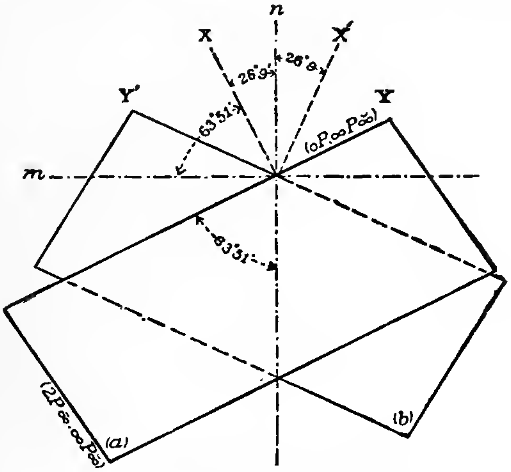


FIG. 7.—Carlsbad twin of labradorite.

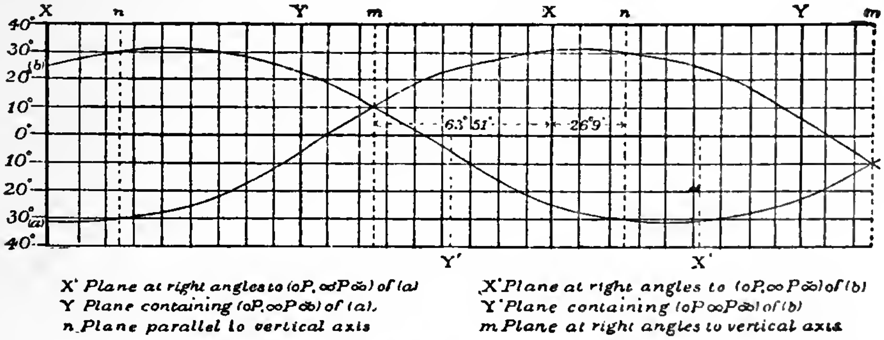


FIG. 8.—Diagram of extinction angles.

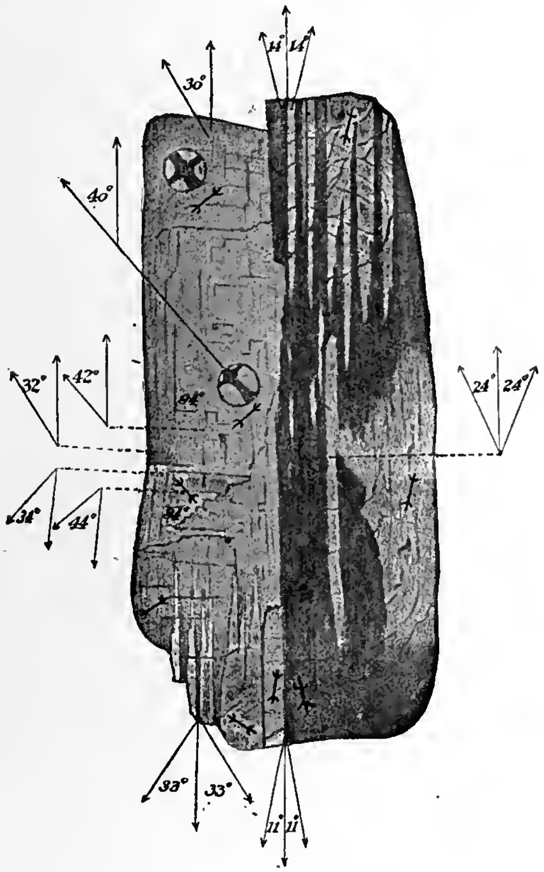
in the second column denote the degrees to be added to or subtracted from 90° to give the required angle for labradorite in sections taken every 5° from the normal to the edge $0P$, $\infty P \breve{\infty}$.

Table showing the angle between $0P$ *cleavage and the trace of* $\infty P \breve{\infty}$ ***in** **planes in the zone perpendicular to*** $\infty P \breve{\infty}$ ***for labradorite.***

Inclination of plane to that perpendicular to the edge $0P$, $\infty P \breve{\infty}$.	Angle to be added to or subtracted from 90°.	Angle between $0P$ cleavage and the trace of $\infty P \breve{\infty}$.	
		Obtuse angle.	Acute angle.
0°	3° 20′	93° 20′	86° 40′
5	3 20		
10	3 23		
15	3 26 40″		
20	3 32 20		
25	3 40		
30	3 50		
35	4 2 48		
40	4 20 6		
45	4 42 21	94 42 21″	85 17 39″
50	5 13 20		
55	5 46 40		
60	6 36 40		
65	7 46 40		
70	9 36 40		
75	12 36 40		
80	18 28 42		
85	33 37		
87	48 27		
88	69 22		
90	90	180	0

From this it will be seen that the variation in the angles made by the cleavage is only 1° 20′ for 45° of rotation each side of the normal, or for a whole quadrant, but for 70° on both sides the variation is only about 6°. Applying this to Figures 7 and 8 it will be readily seen what combinations may occur. Thus in a section in this zone 45° to the left of X the cleavage angle will be 94° 42′ in the half (*a*) and about 120° in the half (*b*), and whilst the extinction angle in the first half (*a*) is 20° that in the second half (*b*) is 0°. If in conjunction with this Carlsbad twinning we have the polysynthetic twinning of albite, as generally happens, we shall find sections in the zone under discussion one side of which will show striations having symmetrical extinction angles differing from the symmetrical extinction angles of the striations in the other side by as much as 20° in some cases, a phenomenon which might lead to the erroneous conclusion that two species of plagioclase feldspar had formed together along the plane of the brachypinacoid. It is possible that instances of such an occurrence, which have been mentioned by other observers, may be sections of Carlsbad twins of a single species.

In the thin sections of this pyroxene-andesite occur many examples of twinned feldspars, in nearly rectangular sections, that exhibit optical phenomena similar to those just described for labradorite, but which differ greatly in degree, the extinction angles being very much larger than those of labradorite for this zone as given by MM. Fouqué et Lévy, and which must upon this ground be referred to anorthite. An especially fine example of such a feldspar, in which are combined the three sorts of twinning most common to plagioclase—albite, pericline, and Carlsbad—is seen in thin section 79. It has been made the subject of a series of careful measurements, which are indicated on the accompanying diagram (Fig. 9). It consists of two nearly equal halves, twinned after the Carlsbad law, one having well-marked cleavage, which is absent from the other. Each shows striations due to albite twinning, which give symmetrical extinction angles that are not the same for the two halves. Near the middle of the first mentioned half is a portion twinned after the law of pericline, as the cleavage and extinction angles and position of the axes of elasticity show. The section appears to be in the zone perpendicular to ∞P$\breve{\infty}$ and nearly parallel to the base of the second half. There is also a marked zonal structure and variation of extinction of about 10° from the center outward, being greatest at the center. In the left-hand half the symmetrical extinction angles in the marginal zone reach 30° and 33°, while the extinction in the central portion is 40° and 44°. In the second half the symmetrical extinction angles are 11° and 14° in the marginal zone and 24° at the center. This variation is due to a change in the position of the axes of elasticity, which is shown by the fact that near the margin of the unstriated end of the first half the hyperbolas of the interference figure meet in the center of the field, but near the center of the same portion they come together on the edge of the field.



indicates the direction of the trace of the plane of the optic axes.

⊗ *indicates the position of the interference figure.*

FIG. 9—Carlsbad twin of plagioclase.

The phenomenon of zonal variation in the angle of extinction of feldspars indicates that the chemical composition of the crystals varies from the center outwards. And as the extinction angle, so far as observed in the feldspars of the andesite of this district, is usually greater at the center of the crystal than toward the margin, generally passing through a series of distinctly marked zones, which in rare instances have been found to differ by 20°, yet passing frequently by imperceptible gradations from one extreme to the other, it seems likely that during the growth of such feldspars changes have occurred in the chemical composition of the successive shells of enlargement, tending toward greater acidity, which, though often sharply defined or interrupted, have sometimes taken place in the most gradual manner possible, a process only conceivable by admitting the correctness of Tschermak's theory. The particular section of twinned feldspar described and illustrated in Fig. 3 has been treated with hot hydrochloric acid. The central portion of both halves was decomposed and clouded and the zonal structure more strongly emphasized. The marginal zones appeared to resist the attack of the acid completely. This proves that the central portion of the first half, with extinction angles as high as 40° and 44°, is anorthite or bytownite, and that the central portion of the second half is of the same species, but was cut in a position in which the extinction was only 24°. The outer zones are probably labradorite. The difference of their behavior toward hydrochloric acid is more striking than their optical difference.

The occurrence of anorthite in the volcanic rocks of western America has not been previously noticed, partly because no very thorough investigation of the nature of the plagioclase feldspar in them has been undertaken and also from the fact that all simple crystals showing no striæ between crossed nicols, were classed with orthotomic feldspar. Thus the simple crystals and Carlsbad twins of sanidine mentioned in Prof. Zirkel's report on the rocks of the 40th Parallel Survey,[1] as occurring in such abundance in the "angite-andesite" at Basalt Creek, Washoe, and near Clarks Station and Wadsworth, near the Truckee River, give in the zone perpendicular to the brachypinacoid angles of extinction ranging from 0° in a few instances to 40°, thus 33°, 34°, 35°, 36°, 38°, 39°, 40°, most of the reading being over 30°, corresponding to those of anorthite. One section cut at right angles to an optic axis showed the plane of the optic axes at an inclination of 43° to the trace of the brachypinacoid. Similar anorthite is found in the closely related andesites in the Cortez Range, head of Annies Creek, and on Emigrant Road, Palisade Canyon, and also from the Traverse Mountain, Utah. It occurs in the "augite trachyte,"[1] from the neighboring Wahweah Range, in the "trachytes"[1] from Emigrant Road and the south bank of Palisade Canyon, Cortez Range, and in the rock from Jacobs Promontory, Shoshone Range, erroneously determined as rhyolite,[1] which is almost identical with the andesite from Richmond Mountain. It will thus be seen that anorthite has a very wide geographical distri-

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[1] F. Zirkel: Micro. Petro., U. S. Expl. 40th Par., vol. VI, Washington, 1876.

bution in the West, though the rocks containing it can be shown to be of the same character throughout.

The largest individuals are characterized by a great abundance of glass inclusions, which extend from the center outward, always leaving a border of feldspar free from inclusions. They are very irregular in outline and form a net-work so thick in many instances as to equal in amount the feldspar which forms the meshes. The glass is colorless and filled with opaque grains and transparent globulites, besides colorless microlites, whose high index of refraction and similarity to other more determinable ones in the groundmass suggest their pyroxenic nature. There also occur inclusions of the groundmass developed to the same degree as that surrounding the feldspar crystal. The smaller individuals are freer from inclusions, but contain a greater variety, the glass ones having sharp outlines, either round or nearly rectangular, with a comparatively large gas-bubble and fewer microlitic secretions; liquid inclusions are less frequent, with a briskly moving bubble, besides needles and stouter prisms of apatite, magnetite grains and rarely augite. The feldspar substance is entirely fresh, without the slightest trace of decomposition; in some instances it is intersected by cracks, in which hydrous oxide of iron has been deposited, and which have led to the devitrification of part of the included glass, converting it into a yellow cryptocrystalline aggregate. One single individual contained calcite deposited along lines of fracture. There is also present among the phenocrysts feldspars with quite perfect cleavage, splinters of which parallel to the base give an angle of extinction of 0° and are probably oligoclase, their separation from anorthite by optical methods is not possible in the thin section.

The microscopic lath-shaped feldspar crystals of the groundmass, averaging $0{\cdot}03^{mm}$ in length by $0{\cdot}003^{mm}$ in breadth are slender prisms elongated in the direction of the brachydiagonal, irregularly terminating in two or more needles of different lengths and are in every case twinned with two or three lamellæ. The angle of extinction measured from the direction of their length varies from 0° to 26° and corresponds to labradorite or a less basic feldspar. Small square sections, not very abundant, prove by their diagonal extinction to belong to plagioclase.

The second most essential component is pyroxene, which occurs in macroscopic crystals averaging 1^{mm} in length, a few reaching 2^{mm} from which they diminish in size to $\cdot03^{mm}$, having sharply defined outlines, well developed faces in the prism zone, of which the pinacoidal are much the larger, and occasionally showing the pyramid P and rarely the base 0P. The larger number of individuals, however, are not crystallographically outlined, but appear as imperfectly developed crystals in more or less rounded forms. It is without the black border that surrounds the hornblende, but has a narrow granular margin of pale yellow transparent grains, without doubt augite of final crystallization, formed at the time of solidification of the groundmass about the primary larger individuals and to a lesser degree around the black bordered hornblendes and magnetite grains, but in no instance about the feldspars. Its presence is not universal, some pyroxenes being entirely free from it. In a very few instances an uncompleted black border has been added to the primary augite, in every case projecting beyond the crystal outline of the remainder of the surface, Fig. 3, Pl. III, and being inclosed in the narrow margin just described. This black border appears to be an aggregation of magnetite grains. A zonal structure is occasionally noticed. The prismatic cleavage parallel to ∞P is quite perfect in some crystals, but in others it is nearly lost in irregular fractures. The crystals are mostly simple individuals; a few are twinned parallel to the orthopinacoid and show three or four alternating bands between crossed nicols.

At the time when these rock sections were studied it was considered probable that all the pyroxene individuals observed in any one rock belonged to the same species, and that those sections with the axes of elasticity parallel to their cleavage or to the trace of the faces in the prism zone were sections cut in the zone at right angles to the clinopinacoid of augite, when they were accompanied by other sections with inclined position for these axes. Hence all the pyroxene in this case was thought to be augite. But the observations of Cross[1] on the hypersthene-andesites of Colorado and other localities, and our own observations on the andesites of the volcanoes of northern California, Oregon, and Washington Territory,[2] and on the volcanic rocks of the Great Basin,[3] and the studies of many other observers, in different parts of the world have demonstrated the joint occurrence of an orthorhombic and a monoclinic pyroxene in a great variety of rocks. Moreover, the pyroxene of this particular andesite from Richmond Mountain has been separated from the rock by means of the cadmiumborotungstate solution, as already described in the paper on the volcanic rocks of the Great Basin just mentioned. The pyroxene was found to consist of green augite and brown hypersthene; the latter was isolated with a small admixture of the augite and analyzed. From the composition of the whole, analysis I, a theoretical composition for the hypersthene and augite was calculated, resulting as follows:

	I. Mixture.	II. Hypersthene.	III. Augite.
SiO_2	51·16	51·39	49·02
Al_2O_3	3·50	3·26	5·64
TiO_2	·73	·73	·73
FeO	15·46	16·45	6·45
MnO	·56	·56	·56
MgO	19·22	19·75	14·37
CaO	8·84	7·31	22·60
Ign	·42	·42	·42
	99·89	99·87	99·79

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[1] Am. Jour. Sci., 1883, vol. XXV, pp. 139–144.

[2] Am. Jour. Sci., Sept., 1883, vol. XXVI.

[3] Am. Jour. Sci., June, 1884, vol. XXVII.

The percentage of FeO being greater than 14 per cent the orthorhombic pyroxene may be classed as hypersthene. The optical character was determined in the isolated crystals and corresponded to hypersthene.

A review of the thin sections of the andesite from Richmond Mountain shows that the two pyroxenes resemble one another closely in thin section, but the hypersthene is pleochroic to a greater or less extent, the augite not at all so. The pleochroism of the hypersthene is, of course, stronger in the thicker sections, but varies among the individuals in a single section and in some instances differs zonally in a single crystal, being stronger in the central portion of some individuals and in the marginal portions of others. It is green parallel to the $\mathfrak{c}$ axis and light brown parallel to $\mathfrak{a}$ and $\mathfrak{b}$ with $\mathfrak{a}>\mathfrak{b}$. In some cases they are nearly colorless. The augites are very light yellowish green to colorless. Cleavage parallel to the prism and more rarely to the pinacoids is observed in cross sections cut perpendicular to the positive bisectrix; but in many longitudinal sections there is no trace of cleavage.

The slight border of augite grains surrounding many of the pyroxenes is almost exclusively confined to the porphyritic augite crystals. This is most noticeable where both varieties of pyroxene have grown together in parallel crystallographic orientation, the hypersthene being the older secretion in most every case; the granular augite border extends around the augite crystal, but ceases at the hypersthene. The orthorhombic pyroxene is more readily altered than the augite, a fibration parallel to the $\dot{c}$ axis sets in from the surface and along the cracks, resulting in a light green, highly refracting mineral with an inclined extinction angle which reaches 15°, and is evidently a fibrous hornblende (actinolite). The crystals are sometimes coated with brown oxide of iron (limonite), which also coats the pyroxene microlites and porphyritical hornblendes. Though generally free from inclusions some individuals bear numerous magnetite grains, and irregularly shaped, colorless glass inclusions with a gas bubble, besides apatite needles and, rarely, imperfectly formed brown hornblende.

The pyroxene microlites of the groundmass, varying from 0·04 or 0·05$^{\mathrm{mm}}$ in length to microscopically minute proportions, are long slender prisms parallel to the vertical axis, terminated by a pyramid. They are of a pale greenish color and contain numerous magnetite grains, which are in no case associated with the feldspar microlites. Their augitic nature is shown by their crystalline form, color, and high index of refraction, taken in connection with their angle of extinction, which varies from 0° to more than 35°, being indeed directly traceable, through occasional larger individuals, to those of unquestionable augitic nature. A part, however, may be hypersthene. The parallel, fibrous decomposition product is in one instance, No. 90, colored red by oxide of iron, producing small prisms of a reddish yellow color, precisely similar to those mentioned by Prof. Zirkel as of an indeterminable nature in the "trachyte" from the south bank of Palisade Cañyon, Cortez Range, previously referred to, which are there also traceable to augite. This microscopic augite of final crystallization appears more readily altered than the macroscopic primary crystals, and when discolored by iron oxide forms dark red, narrow borders around the still fresh larger augites and black bordered hornblendes, suggesting the characteristic black border of the latter mineral, from which, however, it is easily distinguished. Aggregations of augite crystals around a foreign nucleus are occasionally met with.

The hornblende of this rock is quite abundant in crystals, which are not very well developed, except in the prism zone, where, besides the ordinary faces, ∞P and $\infty P \grave{\infty}$, there is occasionally the orthopinacoid, $\infty P \dot{\infty}$. The terminal faces are not recognizable in the thin sections studied, but, judging from the macroscopic crystals in the hand specimens, they appear to be those usually developed. The majority of individuals seen under the microscope are irregularly outlined. The largest reach 4 to 5^{mm} in length, but the greater number average less than 1^{mm}. They do not take part in the composition of the groundmass. The cleavage is very perfect, parallel to the prism, forming a very sharp network of parallel lines, thus differing from the pyroxene, in which the less perfect cleavage is combined with irregular cracks. There is in some instances a second cleavage, parallel to the clinopinacoid, never well developed. Some of the individuals are twinned in the usual manner parallel to the orthopinacoid. The hornblende is dark reddish brown in color, with a strong absorption. In the dark and more resinous varieties of the andesite (Nos. 77, 78, 79) the color is reddish brown, being dark brown parallel to the axis of least elasticity ($\mathfrak{c}$), nearly the same shade of brown parallel to the axis of mean elasticity ($\mathfrak{b}$), and light yellowish brown parallel to the axis of greatest elasticity ($\mathfrak{a}$); that is, $\mathfrak{c}$ = dark brown, $\mathfrak{b}$ = dark brown, $\mathfrak{a}$ = yellowish brown, and $\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$, possibly $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. In the lighter colored, purple and fissile varieties of the andesite (Nos. 85, 86) the pleochroism is greater, but the absorption less, the brown color having a greenish tinge and the pleochroism being as follows: Parallel to $\mathfrak{c}$ browish green, parallel to $\mathfrak{b}$ reddish brown, parallel to $\mathfrak{a}$ yellow, and $\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$. In the specimen from Trail Hill (No. 90) the color parallel to $\mathfrak{c}$ is brownish red, parallel to $\mathfrak{b}$ brown, parallel to $\mathfrak{a}$ light brown, $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$.

The hornblende individuals are surrounded by an opaque black border that bounds the whole outline of each section, the fractured or eroded portions in the same manner as the crystal faces; its width varies somewhat, and is not constant for any one individual. It is quite sharply defined, both on the outside and inside, though occasionally it is seen shading into the hornblende substance as minute opaque dust. It appears to be magnetite, having the same luster in incident light and the same products of decomposition, hydrous oxide of iron. Spots of similar magnetite dust occur inclosed in the hornblende, besides the inclusions of coarser grains and crystals of magnetite, sometimes arranged in lines parallel to the clinopinacoidal cleavage. The fact that the black border does not occur between the hornblende and feldspar or augite when they are in contact, but always between hornblende and the groundmass, together with the fact that it surrounds the fractured portions and lines the intruding bays of groundmass in crystals, with more or less rounded angles, and that the outline of the border is generally that of the crystal, while that of the hornblende substance within is mostly irregular, suggests its being the result of a change in the condition of the molten magma when hornblende ceased to crystallize out and previously formed hornblende crystals may have been partially melted, or replaced by magnetite. This has in some instances proceeded so far as to form pseudomorphs of magnetite after hornblende (thin sections 90, 91, 87, 88), as noticed by other observers. Some of the pseudomorphs (thin section 91) show minute grains of augite uniformly mingled with the magnetite,[1] suggesting more strongly that there has been a melting of the hornblende, followed by recrystallization, under conditions which led to the production of augite in place of the hornblende. This corresponds to the results obtained in the artificial reproduction of hornblende, in which augite has always been formed instead of hornblende. The hornblende is very free from inclusions, for besides magnetite, only a small amount of colorless apatite is found, and in one or two cases feldspar and augite. It is absolutely fresh in all the sections made from Richmond Mountain; as remarked before, it is not a constituent of the groundmass.

Magnetite is less abundant than the minerals just described, and of much less importance in the composition of the rock, yet at the same time it is a constant ingredient. It occurs in crystals and irregularly shaped grains, the largest about 0·2^{mm} in size, from which they range to almost indistinguishable grains in the groundmass; it is very evenly disseminated, but not very abundant.

Apatite is another constant factor, though of little importance; it occurs in comparatively large, stout crystals, 0·2^{mm} long by 0·05^{mm} broad, giving sharp hexagonal cross sections and showing in longitudinal sections the pyramidal termination, P. It is colorless, but in some instances is crowded with opaque microlites arranged parallel to the vertical axis of the crystal. These give it a brown or gray dusted appearance and exhibit an absorption parallel to the longest axis. One cross section shows these microlites arranged parallel to the longest axis and in planes parallel to the prism faces (section 79). The apatites also contain a few inclusions of glass with gas bubbles, which are in negative crystal cavities. The apatite is found closely associated with the phenocrysts and seldom alone in the groundmass.

As accessory minerals biotite ranks first in importance, being of special interest on account of its scarcity in this pyroxene-andesite of Richmond Mountain and in the similar pyroxene-andesite of Cliff Hills, as compared with its great abundance in the hornblende-mica-andesite and andesitic pearlite of the district. It is found in only two thin sections from Richmond Mountain (Nos. 79, 78), and in each of these there is only a single individual of rounded form with intruding bays of groundmass. The mineral is brown, with strong absorption, and is filled with minute grains of magnetite deposited

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[1] The same observation has been made by Dr. K. Oebbeke: Beiträge zur Petrographie der Philippinen und der Palau-Insel. Neues Jahrbuch für Min., etc., 1881. B. B. I, p. 474.

along the lines of cleavage. An exceptional occurrence of mica is found in the andesite exposed southeast of Trail Hill (No. 91). It does not form macroscopic crystals, but occurs in small, irregular patches, closely associated with the macroscopic augite, and also in more or less regular plates, quite uniformly disseminated through the groundmass. It is brown and has a strong absorption, showing a large angle between the optic axis, and appears in so fresh a rock to be undoubtedly of primary origin. A similar occurrence is noted in the exceptional "augite-andesite" from Palisade Canyon, Cortez Range, described by Prof. Zirkel.[1] The two rocks, however, appear quite different both in the hand specimen and under the microscope. The latter is coarsely crystalline and contains plagioclase, quartz, hypersthene, and brown mica, while the former has a microcrystalline groundmass with porphyritical crystals.

Quartz phenocrysts are very rare. Two rounded grains of very pure quartz without inclusions are found in thin section 87. An irregular grain containing some fluid inclusions, with briskly moving bubbles, in thin section 86, exhibits a varying optical orientation, plainly arising from unequal tension throughout the individual. It is found in the groundmass of the holocrystalline varieties (91–97), as the last mineral to crystallize, forming a cement for the other constituents. It can be determined optically as a positive uniaxial mineral. It contains numerous glass and gas inclusions. Its outline is very irregular, as the quartz individual extends among the neighboring feldspar grains for some little distance, producing an irregular patch of quartz substance, which becomes alternately dark and light throughout its whole extent, as the thin section is rotated between crossed nicols—a micropoikilitic structure.

Tridymite is very abundant in the vesicular forms of this andesite, thin sections 90, 87, 88. It occurs as microscopic aggregates of hexagonal plates about 0·02$^{\mathrm{mm}}$ in diameter, filling small amygdaloidal cavities and incrusting the walls of larger ones with easily recognizable macroscopic crystals. Tridymite has been found by Prof. Zirkel in the precisely similar rock from the south bank of Palisade Canyon, Cortez Range,[2] and in the rock from the same locality,[3] before noticed in connection with the occurrence of anorthite.

The groundmass of these andesites has the "felt-like" structure noticed by Prof. Zirkel as characteristic of "augite-andesite." It consists of a colorless glass base crowded with microlites of feldspar and augite, with minuter crystals of magnetite associated with the augite, besides more or less dark colored globulites of an indeterminable nature, the whole generally showing a marked flow-structure. The proportion of glass base to microlites varies in different localities on Richmond Mountain. It is most abundant in the dark resinous variety (Nos. 77, 78, 79), where it is nearly equal to the microlites in amount. The gray color in these thin sections appears to be due to minute magnetite grains, together with augite

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[1] F. Zirkel. Micro. Petro., U. S. Expl. 40th Par., vol. vi, p. 227, No. 527.

[2] Op. cit. specimen No. 311.

[3] Op. cit. specimen No. 310.

microlites, the reddish tint of the other varieties (Nos. 85, 86, 87, 88, 90, 91) arising from the presence of a higher oxide of iron incrusting the magnetite. In the first mentioned variety the number of augite microlites exceeds that of the feldspar. In the lighter colored fissile forms (Nos. 85, 86) the feldspar is in excess and the glass base is not so abundant. In the vesicular andesite the composition of the groundmass is not homogeneous throughout, for besides the amygdules of tridymite are light colored spots where the augite, magnetite and globulites are almost wholly wanting (No. 88). Glass base is altogether absent from the mica-bearing groundmass of thin section 91, which is microcrystalline, with grains and lath-shaped microlites of feldspar cemented together with quartz. An exceptional red variety is found in which the colorless glass base is so thickly crowded with red oxide of iron as only to be detected in the thinnest possible section (No. 92).

(*b.*) The pyroxene-andesite of Cliff Hills is identical with that of Richmond Mountain; it shows the same modifications in the field as the latter, corresponding to which are the same microscopic characters. Thin section 102 is from a resinous blue-black variety similar to Nos. 77, 78, 79 of Richmond; section 107 is from a reddish purple form, and corresponds to No. 90 from Trail Hill. Thin section 108 is like No. 92, and the remaining two sections, 104 and 109, are slightly modified varieties. Under the microscope the typical andesite has a gray groundmass of glass with microlites of feldspar and augite and an abundance of magnetite. It bears phenocrysts of feldspar, augite, hypersthene, and black bordered hornblende.

The feldspar is triclinic without any admixture of recognizable orthoclase, the individuals are all striated by multiple twinning. Their outline is mostly rectangular, some with the angles truncated or rounded, indicating their form to have been prisms in the direction of the brachydiagonal, having the faces $0P$, $\infty P\breve{\infty}$, $\infty P'$, $\infty{}'P$, $2P\bar{\infty}$. The largest phenocrysts are developed more equally in the direction of the three axes; the feldspar microlites in the groundmass are wholly lath-shaped. The angles of extinction of the porphyritical crystals reach 35°, 40°, and 44° in the zone at right angles to the brachypinacoid, which correspond to anorthite, as does also the high light they exhibit between crossed nicols in very thin sections. Optically it can not be determined whether other species of triclinic feldspar are at the same time present among the larger phenocrysts, unless the great divergence of extinction angles in the zonally built individuals, which reaches in one instance 32° (102), be taken as evidence of difference in chemical composition between the different zones. The zonal structure is beautifully developed in some individuals, especially so in the crystal just referred to, and also in another in the same thin section, Fig. 6, Pl. III. Where the inner zone has a sharp crystallographic outline, while the outer one is rounded at the corners, the angle of extinction for the former being 38° and for the latter only 18°, narrow strips of twinned feldspar pass through the different zones, without taking part in the zonal structure, and having the same angle of extinction throughout.

The individuals show both the polysynthetic twinning of albite and of pericline, besides the simple Carlsbad twinning, which is often shown by the outline of the sections, but the striæ are in many cases few in number, and are sometimes altogether wanting.

The larger feldspar crystals are especially rich in inclusions, which are massed in the center or arranged in concentric zones, or are scattered irregularly through the crystal. A good example of the zonal arrangement is seen in thin section 107. The zone of inclusions in every case consists of minute particles of glass carrying globulites and possibly gas bubbles, so densely crowded as to exceed in amount the inclosing feldspar substance; when occurring scattered their form is seen to be in some cases very irregular; in others rectangular, with the edges parallel to the outlines of the feldspar crystal. In thin section 102, there are brown and gray globulitic glass inclusions bearing angite microlites, besides which are isolated colorless glass inclusions with gas bubbles, and an occasional microlite. There are also inclosures of the groundmass and of the associated microlites. The smaller crystals are much freer from inclusions. The lath-shaped feldspar microlites forming the groundmass are unevenly terminated and twinned in two or three stripes; the angle of extinction is in general low, sometimes reaching the limit of labradorite, to which species they seem to belong in part, though it is probable that a less basic species is also present.

Pyroxene is abundant both as macroscopic crystals and as microlites in the groundmass, its crystals are prisms, frequently very long and slender, with the prism zone well developed; the pinacoidal faces are much larger than the prismatic; the cleavage is poor, and there are many irregular fractures. The twinning is that ordinarily met with. The pleochroism of the hypersthene is strong, but varies greatly among the individuals in one and the same rock section, in some cases being scarcely perceptible. The absorption and pleochroism are green parallel to $\mathfrak{c}$, light reddish brown parallel to $\mathfrak{a}$. In sections at right angles to the vertical axis the colors are, yellow parallel to $\mathfrak{a}$ and grayish purple parallel to $\mathfrak{b}$, that is $\mathfrak{c}$=green, $\mathfrak{a}$=light reddish brown to yellow, $\mathfrak{b}$=grayish purple. Sections apparently in the same crystallographic position vary greatly in their degree of coloring. They are poor in inclusions, of which the most characteristic are magnetite grains, apatite needles and glass. There is around most of the augite crystals a narrow border of augite grains of final crystallization, which also surrounds the black border of hornblende and magnetite as previously described; some individuals are entirely free from it, and a very few have a partial black border like hornblende, Fig. 2, Pl. III. It is especially noticeable in thin section 104, where of two pyroxene crystals almost in contact one, an augite, has a complete border of magnetite, partially altered to red oxide, while the other, a hypersthene, has no border whatever. The decomposition of the pyroxene results in the same yellow fibrous mineral mentioned under the Richmond Mountain andesite. The granular augite border and the smaller augite crystals and microlites in the groundmass of thin section 107 are similarly decomposed and colored with red oxide of iron, as in the corresponding variety of andesite from Trail Hill. The same is true of thin section 108, the excess of red oxide rendering the slide nearly opaque. The augite microlites in the groundmass are very abundant and are traceable directly to the larger crystals; they are in stout prisms or irregular grains and in most every case have one or more magnetite grains attached. The pyroxene in these rocks, like that in the andesite of Richmond Mountain consists of pleochroic hypersthene and nonpleochroic augite, with the same characteristic differences throughout.

The hornblende is much less abundant than the pyroxene and occurs only in larger phenocrysts, with poorly defined outline, being frequently rounded and also irregular, as though corroded. The cross sections are six and occasionally eight sided, and show the prism and pinacoids. They are surrounded by a heavy black border, the substance of which sometimes penetrates nearly to the center of the crystal. A zonal arrangement of the minute magnetite particles is seen in some individuals, thin section 107. The hornblende is brown, with strong pleochroism: $\mathfrak{c}=$ dark reddish brown, $\mathfrak{b}=$ brown, $\mathfrak{a}=$ light brown, $\mathfrak{c}>\mathfrak{b}>\mathfrak{a}$. Inclusions are few, except grains of magnetite, beside which there are a few prisms of apatite having a sharp hexagonal cross section.

Biotite phenocrysts are present in small amount, always with rounded outlines and crowded with magnetite grains. Magnetite and apatite occur as in the Richmond Mountain andesite. Quartz, though quite noticeable in macroscopic grains in the hand specimens as an accessory mineral, is not found in the thin sections studied, except one small particle, 0·25^{mm} in diameter, which carries both glass and fluid inclusions (107).

The groundmass is composed of feldspar and augite microlites, with much minute magnetite associated with the augite, crowded together in a colorless glass base, the whole showing a distinct flow-structure. The proportion of augite and feldspar is about equal, but the size of the microlites is not so uniform as in the Richmond Mountain andesite, and numerous crystals, from 0·05 to 0·1^{mm} long, are scattered through the mass, giving it a much less homogeneous texture. The fundamental structure, however, is felt-like, which completes the correspondence between the two pyroxene-andesites of the district, which are indeed but 15 miles apart. They represent, however, a rock of very wide occurrence in the West, judging by the collection of the Exploration of the Fortieth Parallel, which, with a constant microscopic habit of groundmass and of phenocrysts, varies only in macroscopic habit; that is, in compactness, structure, and color, and in the relative size or abundance of the phenocrysts, and in the absence or presence of hornblende and biotite, an excess of which is generally accompanied by a modification of the groundmass, resulting in difficulty determinable forms intermediate between pyroxene-andesite, hornblende-andesite, and hornblende-mica-andesite. From the foregoing description it is evident that the rocks forming Richmond Mountain and Cliff Hills are pyroxene-andesites, with a very considerable percentage of hornblende as an essential ingredient and biotite as an accessory one. They might in fact be termed hornblende-pyroxene-andesites.

A very striking correspondence between the different varieties in each of the two pyroxene-andesite occurrences in the district will be seen on comparing together thin sections 102, 104 with 77, 78, 79; 107 with 90, and 108 with 92. The other sections from Richmond Mountain have corresponding varieties at Cliff Hills, which, however, were not made into thin sections. Several thin sections remain, which need a brief mention. No. 109 is from a modification of the Cliff Hills rock, which in some respects resembles the basalt of Magpie Hill and that on the south slope of Alhambra Ridge, but which is found under the microscope to be a much finer grained pyroxene-andesite, rich in magnetite, with phenocrysts of the same feldspar and pyroxene, but without hornblende or mica, and bearing some small red altered crystals of olivine, whose presence might throw considerable doubt over the determination were there not frequent patches, not inclusions, of coarser grained groundmass free from magnetite, identical with the groundmass of the neighboring andesite. Thin section 110 is a variety from a limited exposure in the tuff northwest of Devils Gate, which is poor in large phenocrysts.

Hornblende-[Mica]-Andesite.—The hornblende-[mica]-andesite of the district, though closely related to the pyroxene-andesite in many respects, has sufficient strongly marked points of contrast to constitute a separate rock. The areas of exposure of the two in the field are nowhere in contact, and no transition of one into the other is detected under the microscope, except in the andesitic pearlites to be described later. The hornblende-[mica]-andesite has a light purple and reddish purple groundmass rich in macroscopic crystals of feldspar, hornblende, and biotite, of which the feldspar predominates; it is further characterized by the total absence of pyroxene. Several modifications which occur in separate and limited exposures will be noticed in their proper connection. Under the microscope the rock (thin sections 38, 41, 35, 37, 42, 42*a*, 39) is seen to consist of a microcrystalline feldspathic groundmass, in some cases entirely free from glass base. It is rich in macroscopic phenocrysts of feldspar, black bordered hornblende, and reddish brown biotite. The accessory minerals are apatite and very little magnetite, and zircon; quartz is an accessory mineral in some occurrences, especially in that east of Pinto Road (39).

The feldspar is wholly triclinic, being for the most part striated, and the unstriated sections giving angles of extinction belonging only to plagioclase. The porphyritical crystals are beautifully developed, yielding sharply outlined sections, one or two millimeters in length, of the usual form. They show remarkably fine zonal structure, well illustrated in Fig. 1, Pl. v. In this feldspar, besides the successive stages when the crystal had rectilinear outlines, there were three periods when its form must have been quite rounded as if partially fused. The cleavage in these feldspars is very imperfect, and is for the most part wanting, the crystals being irregularly cracked like sanidine. The polysynthetic twinning after albite and pericline is very unevenly developed. The latter, never repeated to any great extent, is present in many individuals, the lamellæ seldom traversing the entire width of the crystal; those produced by the former twinning vary greatly both in breadth and length in the same individual, as well as in different ones, the feldspars in general being characterized by a paucity of striations. This is well shown in Figs. 3 and 4, Pl. V, and Fig. 2, Pl. VI, the two figures on Pl. V, also illustrating the characteristic difference between the largest of the phenocrysts (Fig. 3, Pl. V), and the medium sized ones (Fig. 4, Pl. V), both being magnified to the same extent, 35 diameters. The largest have quite irregular outlines and an abundance of striæ, while the medium sized feldspars are very sharply crystallized and are poorly striated. Besides the multiple twinning, nearly every individual is twinned in halves, either after albite or in a manner corresponding to that of Carlsbad in orthoclase; and frequently several individuals have formed in parallel orientation with the brachypinacoid as the plane of contact (Fig. 2, Pl. VI). The angle of extinction averages about the same in each of the thin sections studied. By far the larger number of readings give angles ranging from 15° to 31°, some being lower and a very few being higher; for example, in thin section 35 the observed angles in the zone perpendicular to the brachypinacoid are 7°, 15°, 20°, 20°, 21°, 21°, 28°, 30°, 31°, 32°, 35°, 35°, 40°. In the other thin sections the higher angles are even scarcer and belong to very perfectly rectangular sections with few striations. Anorthite is probably present only in small amounts, the greater number of the porphyritical feldspars being labradorite. The lath-shaped microlites of feldspar in the groundmass are fibrous and twinned, and have angles of extinction varying only a few degrees from zero and are for the most part oligoclase; the species of the ill defined patches or grains of feldspar in the groundmass is optically indeterminable. The large crystals of feldspar contain numerous small colorless glass inclusions, each with a single gas bubble; what sometimes appear like particles of dust are found under a high power to be aggregates of these sharply defined inclusions $0 \cdot 02^{mm}$ in diameter; they are occasionally arranged in systematic order, but more commonly are scattered irregularly through the crystal; some are attached to needles of apatite. There are also inclosed a few microlites of apatite, some of which in turn contain glass inclusions, and rarely small crystals of zircon. The substance of the feldspar in the thin sections studied is absolutely fresh.

The hornblende is found only in macroscopic crystals affording the characteristic six sided cross sections and having in every case a black border, except in the green variety of hornblende-[mica]-andesite at the east base of Hoosac Mountain (42, 42*a*). The substance of the hornblende is entirely decomposed, not a single unaltered fragment having been found in any of the thin sections. The resulting product is a finely fibrous, yellowish green mineral, faintly pleochroic and with a rather high index of refraction, whose angle of extinction is over 20° in some sections, and which must therefore be a fibrous amphibole. Its fibers start from transverse fissures and run parallel to the vertical axis of the crystal for a short distance, thus forming a net work, the meshes of which are filled with a colorless substance without noticeable action on polarized light, whose granular texture and botryoidal form suggest amorphous quartz. Scattered through these minerals are numerous opaque and transparent globulites of indeterminable nature, together with ferrite and red oxide of iron directly traceable to the black border, from which it projects into the crystal in thin branching plates (35). A more intimate mixture of the two principal decomposition products has taken place in thin section 41, most of which has fallen out in grinding. In thin sections 42, 42*a*, the hornblende sections are without black borders and the alteration has advanced farther, resulting in a yellowish green, fibrous chlorite, with extinction parallel to the fibers, which has spread through the groundmass of the rock, imparting to it a green color.

Biotite is less abundant than the hornblende, though in much larger crystals. It occurs in six-sided crystals with very marked pleochroism and strong absorption, being deep red when the section is parallel to the base, and in oblique sections in ordinary light orange, yellow, and green (35). The interference figure shows a small optical angle, which varies somewhat in different thin sections, the plane of the optic axes being perpendicular to that of symmetry in the crystal. Twinning parallel to ∞P (110), where the composition plane is the base 0P, is frequent. It is recognized by bands with different angles of extinction in sections slightly inclined to the base, and by the different positions of the interference figures in such sections, and also by difference in the pleochroism in some sections nearly perpendicular to the base. There are numerous black microlites arranged in lines perpendicular to the six faces of the mica crystal, besides irregularly scattered prisms of apatite, and more rarely zircon. In thin section 39 there are portions of the groundmass, each containing one or more apatite crystals. The biotite has remained perfectly fresh in most of the thin sections, though the hornblende, has been entirely decomposed. In section 37 the biotite, though bleached out and stained yellow by iron oxide, still retains its optical properties.

Quartz appears as a very inconstant accessory ingredient, being wholly wanting in the form of primary phenocrysts in the typical crystalline hornblende-[mica]-andesite 41, 35, but occurring in abundance in the glassier variety from east of the Pinto Road (39), where it is in rounded grains and fragments, the largest 3^{mm} in diameter. They carry numerous dihexahedral glass inclusions with gas bubbles, around which in polarized light the quartz shows the phenomena produced by strain. Other small grains and fragments are found sparingly in thin sections 42*a* and 38. Microscopic quartz grains form a constituent of the groundmass in the crystalline forms of the rock and are determinable as such in thin section 41; they are more numerous in thin section 35. They also occur in small aggregates around the sides of cavities resembling chalcedony. The abundance and intimate association of this modification of quartz with the groundmass of the rock, and the abundance of macroscopic quartz in the rock near Pinto Road makes it an intermediate variety between andesite and dacite.

Magnetite in macroscopic grains and in microscopic crystals is very evenly disseminated through the groundmass, but is not nearly so abundant as in the pyroxene andesite. It is everywhere coated with red oxide and in thin section 37 it has been converted into the yellow hydrous oxide.

Apatite is especially well developed in stout hexagonal prisms with a pyramidal termination and occasionally the base, a beautiful example being found in thin section 37, Fig. 4, Pl. III. They are dusted gray in the center and show the customary pleochroism. Cross sections show inclusions parallel to the sides of the prism. There are also glass inclusions in negative crystals, Fig. 1, Pl. III. Apatite is associated with hornblende and biotite and also occurs isolated in the groundmass; it is specially noticeable in thin section 37. It has a fine red color in thin sections 35, 39. Zircon is a constant ingredient, though in very small quantities. It is in microscopic crystals of a yellow color easily recognizable by their sharp outline, high index of refraction, and consequent brilliant display of interference colors between crossed nicols. They are rather more frequent in thin sections 35, 42.

The groundmass of the typical hornblende-[mica]-andesite of this district (35, 41) is microcrystalline without glass. It is composed of microlites of plagioclase, largely oligoclase, in an aggregate of feldspar and quartz grains of irregular outline, that are nearly free from microlites at the center, especially in thin section 41. Besides these minerals are minute crystals of magnetite and in thin section 35 opaque microlites, which are seen to be made up of opaque and transparent yellow grains and correspond to the shreds of brown mica that occur in thin section 41. This is more abundant in the fine grained andesitic breccia (38), where it also occurs in well defined hexagonal plates. A flow structure is evident in the arrangement of the lath-shaped feldspar microlites. The groundmass in thin sections 42, 42*a*, 39 presents a less advanced stage of crystallization, the lath-shaped microlites being accompanied by smaller and fewer faintly polarizing feldspar grains in a relatively small amount of colorless glass. Through this in the green variety from the east base of Hoosac Mountain (42, 42*a*) is disseminated yellowish green fibrous chlorite, resulting from the decomposition of the hornblende.

Thin sections 45, 46, and 48 are from highly decomposed rock, whose original character has wholly disappeared, but which still retains, besides some partially altered mica, apatite and zircon in a perfectly fresh condition.

An interesting example of altered hornblende-mica-andesite and at the same time of local accessions of porphyritical quartz is the occurrence west of Glen Dale Valley, south of Hoosac Mountain (49, 50). The feldspar of the rock is completely replaced by calcite, quartz and colorless potash-mica, which are also the residual products of the decomposition of the groundmass. Hornblende with dark border is very abundant in thin section 49. It is altered to yellowish green, coarsely fibrous chlorite, which polarizes strongly and extinguishes parallel to the fibers, and contains small, yellow, highly refracting grains, possibly epidote. The mica has become colorless, but retains its negative, apparently uniaxial character, and is rich in the most beautifully developed microscopic crystals, that are in part tetragonal pyramids of a colorless mineral with high index of refraction, apparently anatase, in part slender prisms of epidote (?) and thin plates of hematite, besides smaller grains in lines perpendicular to the sides of the mica plate and apatite prisms with glass inclusions (49). Quartz is sparingly present in rounded macroscopic grains in the variety rich in hornblende, but is very abundant in the purple variety (50), poor in hornblende, which in the field appears as a local modification of the former. The quartz occurs both in rounded fragments and in dihexahedral crystals and contains glass inclusions.

Andesitic Pearlite and Dacite.—The third and most interesting form of andesite found in the district unites under its numerous and varied forms characters both of the pyroxene-andesite and hornblende-mica-andesite, and presents, as an extreme variety, dacite. Its connection is most intimate with the hornblende-mica-andesite, which indeed is found passing into it in an outcrop back of the windmill pump east of Secret Canyon road (74), and also east of Hoosac Mountain (73, 75*a*, 75*b*, 76). It is again found in association with hornblende-mica-andesite in Sierra Canyon and in the gulch south of Carbon Ridge. Its resemblance to pyroxene-andesite will be seen to be confined to a variety with microlitic, felt-like groundmass, and to the presence of pyroxene, which is lacking in the hornblende-mica-andesite just described. In the two principal localities where it has come to the surface, at Dry Lake and in the vicinity of Sierra Canyon and South Hill, it presents so great a variety of form that the extremes of the series would scarcely be suspected of belonging to the same geological body, but this is evidently the case in the occurrence south of Dry Lake. The following table of comparison is arranged to show the parallelism in the forms from which thin sections have been made. The series commences with the most crystalline variety and that most closely allied to the hornblende-mica-andesite, and finishes with the most glassy, porous, and quartzose form, or dacite

Dry Lake.	Sierra Canyon.	South of Carbon Ridge.	East of Hoosac Mountain.
....	52		
53	61		
54	62 63	71	73
55	....	....	74 75 *a* 75 *b*
56	64		
57			
....	66		
58			
....	68	....	76
....	69		
59			
....	70		
60			

The rock in question is a pearlite with a variously modified glassy groundmass and abundant phenocrysts of feldspar, hornblende, hypersthene, augite, biotite and quartz. The character of these minerals is constant throughout and similar in most respects to those found in the more crystalline andesites. They may be here described then for the whole series. The feldspar is triclinic, eight-tenths of the individuals being striated and the remainder giving angles of extinction for twins in the zone at right angles to the composition plane too great for orthoclase. In only a very few individuals was the nature of the feldspar in doubt and its orthotomic nature possible, but even here the evidence was entirely negative. It is probable that orthoclase is present to a very limited extent—one macroscopic crystal, a carlsbad twin in hand specimen 51, a hornblende-mica-andesite from Sierra Canyon like 52, having a brilliant unstriated basal cleavage, proved optically to be sanidine. The crystal form of the plagioclase is like that already described, but a greater number are in angular fragments. The zonal structure is marked and the polysynthetic twinning irregular; in many instances the striæ are scarcely perceptible, and in a few cases they are altogether wanting. The angles of extinction range from a few degrees to between 25° and 31°. The feldspars are therefore labradorite in part, though a large proportion are probably andesine. In several thin sections they correspond to anorthite, which will be more fully noticed under the description of the different varieties. The inclusions of glass and of the groundmass are the same as those in the feldspar of the pyroxene-andesite and hornblende-mica-andesite.

The hornblende is without a dark border of any kind. It is in all other respects like that found in the pyroxene-andesite and the fresher hornblende-mica-andesite of Sierra Canyon (52). It occurs in well developed crystals of a greenish brown color with very strong pleochroism. There are no characteristic inclusions, it being for the most part quite free from them. It appears to have withstood decomposition better than the hypersthene, as it shows no signs of alteration even in juxtaposition to almost completely altered hypersthene, Fig. 5, Pl. III. The hypersthene is strongly pleochroic, green and light reddish brown, similar in all points to that of the pyroxene-andesite. Its decomposition, which is the same as that already described, has advanced farther than in the pyroxene-andesites and is illustrated in Figs. 5 and 9, Pl. III. Augite is found only in two thin sections from this locality, Nos. 56 and 57.

Biotite is macroscopically the most prominent mineral in the quartzose members of this series. It is in hexagonal plates of a dark brown color with strong absorption, and is optically negative with a very small angle between the optic axes. It is twinned as in the hornblende-mica-andesite. Quartz is not so abundant in the thin sections as in the hand specimens and is always in rounded grains or angular fragments with a few glass inclusions. Magnetite, apatite, and zircon are common to all the varieties of this pearlite. The apatite is like that found in the other andesites; a fine example showing the terminations and a basal cleavage is represented in Fig. 8, Pl. III.

The zircon crystals are not more numerous in this than in many other rocks where there are found to be three or four crystals to a rock section, but their occurrence here in unaltered feldspars or isotropic glass renders them more than usually favorable for study, and so a number have been drawn to show their crystal faces, which were recognized by careful study in all possible lights and were drawn with the aid of a camera. Owing to the high index of refraction of zircon the marginal faces can not be as accurately determined as those near the center of the figures, and the terminal planes of Figs. 15 and 20 being extremely minute could not be made out for the same reason. It should also be remarked that the drawings are not mathematical projections, because with the high magnifying power employed, in one instance 900 diameters, only a small part of a crystal is in focus at any one time, and a certain amount of distortion necessarily follows. The figures represent, however, the sharpness of the crystallization and will indicate the forms taken by the crystals. Besides the short, stout crystals, from $0{\cdot}05$ to $0{\cdot}1^{mm}$ long, more usually met with, there are sometimes long, slender prisms reaching a length of $0{\cdot}37^{mm}$ and terminated at one or both ends, Figs. 15 and 16, Pl. III. The form of Fig. 15 appears to be the two prisms, ∞P, $\infty P\infty$, the double pyramid or zirconoid $3P3$, and the pyramids P and $P\infty$; that of Fig. 16 ∞P, $\infty P\infty$, and $3P3$; and Fig. 17 ∞P, $\infty P\infty$, $3P3$, with P or $P\infty$. Fig. 18 represents a very simple form, combining a prism with a pyramid of the opposite order. Fig. 19 seems to present both prisms ∞P, $\infty P\infty$, the double pyramid $3P3$, and the two pyramids P and $P\infty$; and Fig. 20 ∞P, $\infty P\infty$, $3P3$, and two pyramids P and $P\infty$. The occurrence of similar microscopic zircons has been observed by the writer in most all kinds of rocks, except the very basic, but more especially in the mica-bearing varieties, with which mineral it is frequently in close association.

In noticing the different varieties of this andesitic pearlite the description will be confined to the series found in the vicinity of Dry Lake and the correspondence or points of difference in the similar forms from the other localities will be mentioned in their proper connection. At the top of the table stands the quartz-bearing hornblende-mica-andesite (52) found in Sierra Canyon, forming the connecting link that unites by its microscopic structure the hornblende-mica-andesites and andesitic pearlites. The groundmass of this rock is completely crystalline, exactly as in the typical hornblende-mica-andesite of the district (35). In the thin section besides the plagioclase there are two or three unstriated sections which may possibly belong to sanidine. The fresh hornblende is without dark border, a few individuals having a slight aggregation of magnetite grains around them, which is also noticeable around the biotite. There is no pyroxene present, but some well developed quartz crystals. The nearest approach to crystalline andesite in the Dry Lake series is thin section 53, whose gray groundmass is microspherulitic. The spherulites are composed of radiating colorless needles, besides which are multitudes of transparent globulites and trichites, straight and curved, some black and opaque, others red and referable to mica, and some formed of a string of transparent grains which are also found in short, stout, interpenetrating microlites, which appear to belong to augite. The whole shows a marked flow structure and bears phenocrysts of labradorite, biotite and hornblende crowded with magnetite grains and no longer fresh; besides completely altered pyroxene [hypersthene]; zircon occurs in good crystals. There is no macroscopic quartz, but small aggregations of colorless plates appear to be tridymite. Thin section 61 is more highly crystalline and illustrates the first stages of the formation of the feldspathic grains in the groundmass of the hornblende-mica-andesite; they are seen forming around the phenocrysts as centers, which are the same as those in 53 with the addition of macroscopic quartz.

A modification common to four separate localities is represented by thin section 54, and approaches closely to the pyroxene-andesite of the district; the silver gray groundmass has a satin-like sheen in transmitted light, produced by fibrous feldspar microlites in nearly parallel arrangement in a colorless glass base, having a marked flow structure, with a felt-like appearance in the thicker parts of the section; there are also grains of magnetite and a little hypersthene. The larger phenocrysts are well developed and the inclusions are very fine. Feldspar is in excess of the other constituents, and hornblende and hypersthene occur in about equal proportions, biotite being scarce. The corresponding varieties (62, 63, 71, 73) are almost identical. In 62 the feldspar microlites are more delicate, biotite is wanting and quartz occurs in macroscopic grains; 63 is richer in glass and poorer in large crystals and has a little brown mica in the groundmass.

In 71 the glassy groundmass is richer in augite microlites, and also contains some of hornblende and biotite. It very closely resembles the pyroxene-andesite of Richmond Mountain; 73 is remarkable for the abundance of biotite in hexagonal plates in the groundmass. This variety of the pearlite is further characterized by the presence of feldspars with very high angles of extinction, several of which reach 40° and 45°, indicating anorthite, which is the feldspar so abundant in the pyroxene-andesite. The next variety is a still more glassy rock, 55; it is a colorless glass with a pearlitic fracture, with scattered microlites, which are beautifully developed, some, in long prisms with pyramidal termination and transverse jointing, appear to be apatite; others, shorter and stouter, are more doubtful, but resemble those in 53, which are probably augite. There are also curved and tapering microlites and strings of grains apparently of the same mineral. Larger microscopic crystals scattered through the groundmass are hypersthene, hornblende and biotite. There is but little magnetite. Of the macroscopic crystals, feldspar is very abundant as labradorite, with possibly a little anorthite; biotite is also abundant, and hornblende and hypersthene are scarce. There is one rounded grain of quartz with good rhombohedral cleavage. Thin section 75 is like 55; 75*a* is taken from the same specimen and shows a slight modification caused by streams of opaque particles and hair-like trichites, which lie scattered or aggregated in the most delicate dendritic forms. A small part is black in incident light and may be magnetite, but the greater part is bright red and is hematite. Thin section 74 is similar.

The remaining varieties differ from the preceding in having the glass base filled with opaque and more or less transparent, ill defined microlites and flocculent matter, imparting to it a black, red, yellow or white color. Thin section 56 is from a brecciated pearlite rich in angular fragments and crystals of labradorite, hypersthene, augite, hornblende, and magnetite, with no mica. The groundmass is glass, probably of itself colorless, but so crowded with microlites and more or less opaque grains as to appear in the section dark brown, yellow, and bluish. In some places it is brown and globulitic, in others it is filled with flocculent matter, which is brown in transmitted light and white in incident; in other places it is colorless, with few microlites. The transition from one kind to another is generally sudden and the flow structure is well marked, being especially beautiful in thin section 57, which is similar to 56, as is also 64, though of a lighter color. Mica and quartz are both wanting in these last three thin sections. The varieties represented by thin sections 58 and 66 are very similar to the last, much more so than their appearance in the hand specimen would indicate. Their secretions are the same—labradorite, hypersthene, and hornblende, with a little augite and no mica or quartz. They are not brecciated, however, and the groundmass is lighter colored, the opacite being red and white in incident light and the flow structure very striking. There is a fine example of partially altered hypersthene shown in Fig. 9, Pl. III.

Variety 59 has a more pumice-like groundmass, the glass having numerous gas bubbles. It is much lighter colored, with more white and less yellow opacite, and is in part cryptocrystalline. The phenocrysts are labradorite, eight-tenths of the feldspars showing striæ and the rest probably belonging to plagioclase. There is a very little partially altered hypersthene, considerable hornblende, and much biotite. The quartz, so abundant in the hand specimen in large rounded grains, is scarce in the thin section. The two varieties from Sierra Canyon (68, 69) are denser than that just described. The glass groundmass of 68 is without gas bubbles and is crowded with yellowish translucent particles, which reflect incident light and appear white. It is in places spherulitic and abounds in angular fragments of plagioclase, nine-tenths of the feldspars being striated. There is, besides, quartz, with fine glass inclusions, a very little pyroxene, more hornblende, and much biotite. Thin section 69 is identical with the last under the microscope. Thin section 76, from east of Hoosac Mountain, is similar to the foregoing, but has a cryptocrystalline groundmass and is somewhat decomposed. Some portions of the groundmass of 70 are crystalline and bear feldspar microlites, but the whole is the same as 68 and 69. Thin section 60 is more porous, but has the characteristics of the last four sections. Its feldspar is all plagioclase and gives angles of extinction corresponding to labradorite. This last quartz-bearing group (59, 60, 68, 69, 70) appears to be true dacite, and as such is very interesting.

It may be well to note at this point some of the characteristic features distinguishing these closely allied rocks as they are found in this district. The groundmass of the hornblende-mica-andesite is in general microcrystalline, without glass, having, besides lath-shaped feldspar microlites, which are probably oligoclase, interpenetrating grains of quartz and feldspar. It is freer from magnetite and contains no pyroxene. The groundmass of the pyroxene-andesite, on the other hand, is very glassy, with a felt-like structure produced by feldspar and augite microlites, the feldspar being labradorite, with an abundance of magnetite. The phenocrysts of the former rock are labradorite, dark bordered hornblende in every case decomposed, considerable biotite, and sometimes quartz, but no pyroxene or the remains of any. The phenocrysts of the pyroxene-andesites are anorthite, hypersthene, augite, dark bordered hornblende, with very little biotite and only an occasional quartz. The andesitic pearlites hold an intermediate position between the two, some of the varieties being quite like the hornblende-mica-andesite, while others approach closely to pyroxene-andesite, yet all have features differing from both. The groundmass is a glass more or less full of microlites, and in the greater number of cases is crowded with indeterminable globulites and particles. Besides the feldspar phenocrysts, which are for the most part labradorite and possibly a very little orthoclase, with some anorthite, there are hornblende crystals without dark border, hypersthene, a little augite, biotite, and quartz. The dacites are a modification in which the macroscopic quartz has greatly increased, together with the biotite, while pyroxene has nearly disappeared. They are also the most pumice-like.

CHAPTER III.

RHYOLITE.

There are three distinct varieties of rhyolite in the Eureka District, more noticeably distinct in the hand specimen than in thin section, since their essential constituents are the same throughout. The difference arises from a change in the relative proportion of the phenocrysts and in the nature of the groundmass. That from about Pinto Peak which covers the greatest area has a light colored groundmass, for the most part white, also gray and purplish gray, partly vitreous and partly crystalline in appearance, with numerous porphyritical crystals of quartz and feldspar and a few scattered bits of mica. A second variety, from Rescue Canyon, has a reddish purple, vitreous groundmass, crowded with large crystals of quartz and brilliantly reflecting sanidine; and the third, from south of Carbon Ridge, has a dense, reddish purple groundmass, often finely banded, having few phenocrysts except those of copper-colored mica. Upon a superficial examination of these rocks in the field it would seem natural to separate the three varieties into the classes suggested by Von Richthofen in 1867.[1] That from Rescue Canyon has all the appearance "at a distance" of granite, and might be said to be "granite-like," while that from Pinto Peak is certainly "porphyry-like," and the variety from south of Carbon Ridge, being quite poor in macroscopic crystals and having a beautifully banded structure, answers to the description of rhyolite proper; but under the microscope the granite-like variety is found to have an almost wholly glass groundmass, and to correspond, therefore, more or less closely to quartz-porphyry. The groundmass of the porphyry-like kind, on the contrary, is found to be microcrystalline in most cases, or microgranitic, and the third to vary from a quite glassy to an entirely crystalline rock. Hence no systematic classification has been undertaken, the varieties receiving local designations sufficient for the purposes of the present report.[2]

Pinto Peak Rhyolite.—Under the microscope thin sections from a great number of specimens of this variety present an extremely monotonous appearance; a fine grained, more or less wholly crystalline groundmass rich in large crystals and fragments of

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[1] Von Richthofen. Natural System of Volcanic Rocks, San Francisco, 1867, p. 16.

[2] Since this was written a study of the rhyolites of the Great Basin led to more definite conclusions regarding von Richthofen's classification of rhyolites, which were expressed in a paper on the volcanic rocks of the Great Basin by Arnold Hague and J. P. Iddings. Am. Jour. Sci., vol. XXVII, 1884, p. 461.

quartz and feldspar, with occasionally a little biotite. The microscopical habit of these porphyritical crystals is so constant in all the thin sections of this group as to permit of a single detailed description, the different modifications of the groundmass only requiring special notice. The feldspar present is sanidine, with which plagioclase is associated to a greater or less extent. The latter is in some cases entirely wanting, but in others is almost as abundant as the sanidine. Sometimes both occur in very small quantities in the thin sections and hardly ever outnumber the quartz. Sanidine occurs in well developed crystals and also in angular fragments. Sections of the former are mostly rectangular, with the corners rounded; others show more than four sides and indicate that their crystal form is made up of $0P$, $\infty P \grave{\infty}$, ∞P, $2P\acute{\infty}$ Zonal structure is rarely observed. Many of the individuals are in Carlsbad twins. The cleavage is frequently very perfect, though often entirely wanting, but there are always concoidal fractures, and the resemblance to quartz is often very striking, requiring an optical test to distinguish between them. It is characterized by a much lower double refraction, which in these extremely thin sections causes it to remain generally dark or but faintly lighted between crossed nicols. Quite a number of sections happen to be nearly at right angles to the optical bisectrix and exhibit very small angles between the optic axes, the interference figure being almost a cross and showing the bisectrix negative. There are several of these in thin section 112. A fortunate section parallel to the clinopinacoid occurs in thin section 142 and is at right angles to the optical normal, which is found to be positive, the interference figure being hyperbolas that unite in the center of the field. The inclination of the plane of the optic axes is about + 7° to the basal cleavage, and the angles of the sides of the feldspar section correspond to those cut from $0P$, ∞P, and $2P\acute{\infty}$. Besides the basal cleavage, which in this section is very perfect, is a second less regular cleavage parallel to the trace of the orthopinacoid. The plane of the optic axes in these sanidines is sometimes in the plane of symmetry, sometimes at right angles to it. The substance of the sanidine is very pure and free from inclusions of foreign matter. Numerous minute gas cavities, however, occur irregularly scattered, some of which have their sides wet with fluid, but the gas has always the greater volume. A notable exception to this freedom from inclusions occurs in thin section 141, Fig. 2, Pl. v, where two sharply outlined crystals of sanidine grown together with different orientation about a fragment of plagioclase are filled with quartz in orderly arranged forms, with constant crystallographic orientation throughout certain portions of the feldspar crystals, which is shown by the extinction of light and the parallel position of numerous small dihexahedral glass inclusions with gas bubbles, found only in the quartz, whilst irregularly shaped gas cavities occur in the feldspar substance. This is a most interesting fact from its relation to the subject of fluid and glass inclusions in volcanic rocks, for it would appear from this instance that quartz and feldspar crystallizing out at the same time and under the same conditions have inclosed, the one glass with gas, the other gas without glass, which gas appears in the larger cavities to be associated with water, suggesting that its condition at the time of its inclosure was that of highly expanded steam. This crystal is further interesting as a sporadic development of micropegmatitic structure.

The plagioclase is in crystals very similar to those of sanidine, but is not nearly so abundant, being almost entirely wanting in all of the thin sections from the rhyolite dikes (Nos. 138, 140, 141, 142, 144, 143, 146, 153, 155, 148, 150, 134, 137). The twinned lamellæ vary considerably in length, breadth and frequency, and in most all the individuals are twinned both after the law of albite and that of pericline, besides which the composite crystals are also twinned in a manner corresponding to the Carlsbad twins of orthoclase, which can be seen from the outline of the section and inequality of the sets of angles of extinction in the two halves, Fig. 7, Pl. III. The investigation of the extinction angles was not very satisfactory, owing to the scarcity of favorable sections; the majority of readings were low, the highest being 17°, leading to the conclusion that the triclinic feldspar is, for the most part, oligoclase. It is also of very pure substance, with few gas cavities and more rarely small glass inclusions; it is without zonal structure and has poorly marked cleavage. The feldspar is extremely fresh in the thin sections from the region of Pinto Peak and in those from most of the dikes, but is partially replaced by calcite and kaolin in thin section 146. In 138 it is entirely altered to calcite and kaolin, the latter appearing in the thin section as a colorless aggregate of fibrous, faintly polarizing particles.

The most abundant and constant of all the ingredients is quartz, the phenocrysts of which are well developed dihexahedrons and angular fragments, less frequently rounded grains. It is irregularly cracked and of very pure substance, free from inclusions, except an occasional "bay" of groundmass and a few colorless glass inclusions with single gas bubble, around which, in some cases, is seen in polarized light the phenomena of strain or unequal tension, the effects of which are still further shown by small cracks that pass through the center of the dihexahedral glass inclusions and extend a short distance into the quartz crystal, constituting three planes corresponding to three of the planes of symmetry parallel to the vertical axis. These appear in longitudinal section as a straight line or an inclined fracture, and in cross-section as a six-rayed star. A fine illustration is found in thin section 111, Figs. 1 and 2, Pl. IV, where a cross-section and longitudinal section occur within 1^{mm} of one another. In the cross-section of quartz is a minute fluid inclusion with moving bubble, a very rare occurrence, though quite numerous fluid inclusions are found in the fine dihexahedrons of quartz in thin section 127. Quartz in irregular grains forms a large part of the groundmass. Small phenocrysts of biotite are found sparingly in some of the thin sections, but are wholly wanting in others. The biotite is for the most part free from magnetite grains or other inclusions when fresh. It is altered in some cases to a colorless, brilliantly polarizing mica, crowded with yellow, opaque grains. This group of rhyolites is very poor in accessory minerals, there being only two, which are of exceptional occurrence. Zircon in fragments and minute crystals is occasionally met with in association with biotite. Garnet in well developed dodecahedrons, and also in irregular grains of a light red color in thin section, occurs in Nos. 111, 112, 122, and 123.

The most striking feature of this variety of rhyolite is its groundmass, which presents the microgranitic structure, not frequently met with. The remarkable thinness of the sections prepared from this rock offers a highly satisfactory field for study and leaves no reasonable doubt of the entire absence of glass in the composition of the groundmass of most of the thin sections. Besides the granular crystalline development there are those that are partly cryptocrystalline and others that are spherulitic and glassy. A microcrystalline structure is common to thin sections 111, 112, 113, 114, 115, 116, 120, 119, 123, 140, 141, 153, 127, 134, 137. The groundmass of 112 may be taken as representing that of all the first nine sections. It is composed of microscopic interpenetrating grains of quartz and feldspar, through which are scattered larger grains, averaging 0·06^{mm} in diameter, for the most part quartz, with gas cavities like those in the phenocrysts of feldspar. A small portion is determinable as orthoclase and striped plagioclase. The quartz is often in aggregates of half a dozen or more grains and is accompanied by irregular fragments of light red garnet. There is also a little biotite in microscopic crystals, more abundant in thin section 116. Through it all are innumerable dust-like particles, dark in transmitted light, but reflecting incident rays and giving a whitish-gray color to the section. They are probably minute gas cavities. In addition to this are patches of yellow, ill defined grains, corresponding to Vogelsang's ferrite, which is only in small quantities and alone indicates the flow structure, best seen in the thin section without the aid of a lens. The groundmass in this section (112) is porous and is filled with small, irregularly shaped cavities. In the others it is more or less dense and varies somewhat in the size of the grains.

Still more interesting are the changes of structure in the groundmass of the rhyolite from the dikes. Thin sections 140, 141, 127, 134, and 137 represent the most crystalline variety, being coarser grained than that just described. They are without any sign of flow structure and carry larger grains, which are micropegmatitic in thin section 140. The grains are composed of a colorless grain or crystal of quartz with hexagonal outline, inclosing semi-opaque particles, which are white in incident light, and are sometimes arranged radially. The same structure appears as a narrow border around the quartz phenocrysts. The grains in the groundmass of thin section 141 are also mottled in polarized light, but in 127, where the similarly clouded grains attain a diameter of 0·05^{mm}, one in the thinnest edge of the section shows a beautifully developed micropegmatitic structure, which near the center of the grain is in triangular figures only 0·002^{mm} in size, and near the edge is in long, narrow strips. The groundmass of 138 and 146 consists of somewhat larger grains of quartz in a cryptocrystalline matrix, which is identical with the substance occupying the sections of decomposed feldspars, already described as kaolin. Here, also, it is possibly the alteration product of feldspar in the groundmass and not a devitrified glass. The abundance of calcite is undoubtedly due to infiltration from the surrounding limestone. Thin sections 142, 143, and 125 present less coarsely crystallized varieties, the first two being similarly decomposed.

A lower stage of crystallization, in which the groundmass is largely or entirely glass, is found in thin sections 118, 155, 122, 117, 126, and 130, some of which are partly crystalline. The glass is spherulitic. There are also narrow bands of fibers, the fibers lying at right angles to the direction of the bands, which make the flow-structure very pronounced, Fig. 1, Pl. VIII. Thin section 155 is interesting as containing round and oval spherules of colorless glass, with a few concentric inclusions, reminding one strongly of leucite crystals. They polarize faintly in radiating rays. An entirely glassy modification, which occurs in a small chimney about ten feet wide, is shown in thin sections 144, 145, and is a pale green glass rich in feldspar microlites, some of which are striated. They are partly rectangular, with the four corners prolonged like a "skate's egg." The corners of others are fringed, but the majority appear like bundles of colorless fibers, the larger of which are compact in the middle and extinguish light as a single individual, Fig. 14, Pl. III. One can thus trace the connection from the single microscopic fiber to the dense, sharply crystallized feldspar, that is large enough to be seen without the use of a lens. In the thin section, from the buff-colored, porcelain-like portion of the same flow (145), the microlites are more numerous and are accompanied by clouds of yellow spots with aggregate polarization.

Thin sections 129 and 132 are from rhyolitic pearlites, poor in microlites, with some gas cavities and globulites of an indeterminable nature. The pearlitic structure, consisting of spherical fractures which inclose one another like the imbricated scales of an onion, is very well marked in thin section 129. The rhyolite at the head of Yahoo Canyon (157) is similar to the cryptocrystalline forms of this variety and is poor in phenocrysts. That from the saddle northeast of Combs Mountain (158) corresponds to the more coarsely microcrystalline kind and is very poor in macroscopic crystals, which are quartz, feldspar, and biotite, the only inclusions noticed being glass.

A completely decomposed rhyolite, thin section 148, is worth mentioning. In the hand specimen it is seen to be kaolin, with numerous quartz crystals. In thin section it is colorless, the groundmass having no action whatever on polarized light and being filled with minute grains which are white in incident light, also larger yellow and red grains of iron oxide, resulting apparently from the decomposition of magnetite, besides other small transparent yellow globulites with high double refraction, whose nature is indeterminable. The macroscopic quartz crystals have colorless glass inclusions, which are for the most part spherical, a few having the form of negative crystals. There are no fluid inclusions and some of the quartzes show distinct rhombohedral cleavage.

Rescue Canyon Rhyolite.—The second variety of rhyolite found in the district, thin sections 162, 165, has many points of resemblance in microscopical habit to that just described. It is, however, richer in phenocrysts, which under the microscope are found to be angular grains and fragments of quartz, which are very free from inclusions except a few glass dihexahedrons, the dark color of the quartz not being traceable to noticeable inclusions. There is also faintly polarizing sanidine, sometimes indistinguishable from quartz except by optical tests. In this, also, there are no inclusions to account for the slight opalescence seen in the crystals on surfaces at right angles to the base. Besides sanidine there is a comparatively large amount of striated plagioclase, some with angles of extinction corresponding to labradorite. In addition to these abundant and larger phenocrysts and a small amount of biotite, in which this variety of rhyolite resembles that first described, there is a small percentage of pyroxene in fragments and crystals, partly altered; one or two fragments of brown hornblende without dark border, and some larger magnetite grains. There is also an irregular grain of garnet and one of allanite. The groundmass is partly crystalline, partly glassy and axiolitic, with much ferrite in fine particles which mark its fluidal structure and give it a red color.

Banded Rhyolite.—The third variety differs from both the others and is in some instances of rather doubtful nature, owing to the abundance of plagioclase and scarcity of macroscopic quartz. The four thin sections prepared, 174, 173, 169, 168, have numerous points of resemblance and, though differing somewhat, may be classed as the same rock and described as rhyolites. Thin section 168 is of a wholly crystalline rock, in which the phenocrysts are quartz (with a few glass inclusions and less frequently gas cavities) and feldspar, the greater part of which is sanidine, which is with difficulty distinguished from quartz except by optical tests. Several sections of sanidine, with quadratic form and right-angled cleavage, remain dark when revolved between crossed nicols, and give interference figures like crosses that are optically negative. They have numerous irregularly shaped gas cavities, which are especially abundant near the margin of the crystal. Some of the cavities have a thin coating of fluid around their walls, and a few contain more liquid than gas. In these the bubble is movable. There is also plagioclase and a little biotite, the latter filled with magnetite and red oxide of iron. The groundmass is composed of quartz grains, unstriated feldspar, and microscopic spherulites, with many curved microlites which consist of strings of transparent grains with a rather high index of refraction. Besides these there is a little mica and magnetite. Thin section 169 is similar in the character of its groundmass, which, however, is less coarsely crystalline and has a more marked flow structure, produced by variations in microstructure and in the minute particles of coloring matter. It is poor in phenocrysts.

The two remaining thin sections (173, 174) are of somewhat doubtful character. The groundmass is but partially crystalline, with yellow and colorless glass. It is rich in grains of iron oxide, both black and red, and has a markedly banded structure, as shown in Fig. 2, Pl. VIII. It is poor in phenocrysts, the greater number being plagioclase, with marked zonal structure. They carry more glass inclusions than are found in the plagioclase of the other rhyolites of the district. Biotite filled with red oxide of iron is next in abundance, besides which there is a little apatite in comparatively large crystals, and one crystal of augite. There are numerous groups of colorless grains of irregular shape, which appear to be tridymite. There is, indeed, a close resemblance in some of its microscopical characters to certain forms of andesite, while at the same time it seems closely allied to some forms of rhyolite.

Rhyolitic Pumice.—Before describing the pumices it will be interesting to notice the rhyolite of Purple Hill because of its easily traced connection with the adjoining pumice and pearlite into which it is seen to pass. Thin section 176 is from rhyolite on the summit of the hill; No. 177 is from the same at the northeast base of the hill where it passes into pumice. No. 180 is from denser pumice, almost pearlite, and 178 is from the dark compact pearlite. The first is light gray in thin section and has a glassy groundmass filled with faintly polarizing particles and larger feldspar microlites, together with numerous amygdules of tridymite. The phenocrysts are quartz and feldspar, of which sanidine predominates over the plagioclase. There is a little impure biotite and a fragment of pyroxene and some magnetite. In the next thin section (177) the phenocrysts are much scarcer and the groundmass is a colorless glass filled with gas cavities, some of which are spherical, but the majority are elongated, spindle shaped, and drawn out to long tubes, that are much twisted and bent. There are numerous six-sided microscopic mica plates and a smaller number of feldspar and hornblende microlites. Much, if not all, of the opaque grains that are scattered in patches through the groundmass is foreign to the rock and has filled cavities during the grinding of the thin section. A more advanced stage is seen in thin section 180; the phenocrysts are the same in character, but are more abundant, with a noticeable amount of pleochroic hypersthene. The glassy groundmass is rich in spherical gas bubbles and microlites of feldspar, hornblende, and biotite, with a small percentage of trichites, which reach a greater development in the more perfect pearlite, thin section 178. The colorless glass of this rock bears a multitude of the most beautiful microlites, consisting of colorless rectangular crystals of feldspar, brown hexagonal plates of biotite, dark green prisms of hornblende, and curved trichites which appear opaque under a low magnifying power, but are found to consist of a transparent fiber with serrated edges or to be a string of disconnected globulites. They are grouped about an opaque grain from which they radiate in all directions, frequently resembling the down of a thistle and suggesting in some instances a bunch of ravelings. There are, besides, other indeterminable, smaller microlites and a few gas bubbles.

Closely related to the rhyolite of Purple Hill, both in their field occurrence and mineral composition, and in the latter respect allied to the purple rhyolite of Rescue Canyon, are the tuffs and pumice found in the vicinity of the town of Eureka, on the west of Richmond Mountain, and also on the south slope of the same mountain. These are specially interesting because of numerous alteration products which have resulted from outflows of basalt that have broken through them. Thin sections from a series of specimens representing different stages of alteration naturally exhibit the same character of phenocrysts, which have not been affected by the remelting and may therefore be considered in one general description, the modifications of the pumice having been confined to the glass base. Thin sections 185, 188, 189, 193, 191, 192, 196, are from the quarry and hill slope east of the town. The phenocrysts consist of angular fragments, seldom of perfect crystals of quartz and feldspar with a small amount of hypersthene, hornblende, and biotite, together with magnetite, apatite, zircon, and garnet as occasional accessory minerals. The quartz is of very pure substance carrying only glass inclusions, one of which, in thin section 192, is brown, a neighboring inclusion being colorless. There are two instances in the same thin section of quartz and feldspar grown together with micropegmatitic structure. Of the feldspar, sanidine is the predominating species, many of the unstriated sections being optically determinable as such. Triclinic feldspar is always present in greater or less amount. A zonal structure is frequent and some individuals bear inclusions of glass in the form of the most beautifully defined negative crystals; the feldspar is everywhere perfectly fresh. The strongly pleochroic hypersthene is in places crowded with apatite and glass inclusions. It is precisely similar to that in the pyroxene andesite and andesitic pearlites; while the dark green hornblende without black border and the biotite correspond exactly to the same minerals in the pearlite. The accessory minerals have also similar characters to those found in the pearlites. Small fragments of allanite are abundant in Nos. 189, 191, 192.

Thin sections 185 and 188 are from unaltered portions of the pumice breccia; 185 is from the quarry back of the engine house and 188 from a spot 6 feet distant from the plane of contact with the basalt a little to the north. They are essentially the same rock, 188 being the better section. It consists of a fine grained mixture of colorless pumice fragments full of elongated fluid inclusions with variously sized gas bubbles, sometimes looking like welded glass threads, together with a proportionately smaller amount of crystallized minerals, in a matrix of yellow glass that appears to be made up of minute glass particles held together by glass, in which are much fewer gas cavities, and which is partly cryptocrystalline. There are also occasional fragments of glass of other kinds, some brown and others microfelsitic and in part cryptocrystalline, the outline of the brecciated fragments being sharp and well defined. Thin section 189, taken from a spot 18 inches distant from the line of contact, shows the effects of partial remelting, the character and composition of the breccia being the same as in the last thin section. The greatest change is noticed in the colorless porous fragments, where the size of the fluid and gas cavities has been greatly reduced, the whole seeming to be contracted and crumpled together; there begin to appear also in the place of the cavities minute black grains and microlites in small numbers. The definition of the pumice fragments is no longer marked, and they commence to merge in the surrounding matrix.

In thin sections 193, 191, and 192, from immediate contact with the basalt, where the fusion has been complete, the resulting body is a compact glass almost free from gas or fluid inclusions, which have been driven out by the heat, since the mass was under little or no pressure. The glass in some instances, as in section 192, has retained its former brecciated character, preserving the outline of its component fragments, but has so contracted as to present many more phenocrysts to the same area of thin section and has become of very dark, blue-black color. This color seems to be due to innumerable black hair-like trichites, opaque grains, and a smaller number of transparent microlites, both short and stout and long and curved. There are in this thin section portions of the neighboring basalt having an exceptionally dark brown glass base. In 193 and 191 the evidence of a former brecciation has almost entirely vanished; the glass of the different fragments in some places has been very uniformly mingled, especially in 193, though occasional fragments have offered greater resistance to fusion. The lighter color of 193 is due to the reflection of light from mist-like clouds of gas bubbles of the minutest dimensions, which appear at first to be opaque particles, but are found under a power of 850 diameters to be transparent globules, with a heavy dark border. They are especially abundant around two small cavities in thin section 191 and probably cause the yellowish white lining of the larger cavities in the hand specimen, which is peculiar to several occurrences. Thin section 196 is from another form of alteration of the same pumice; it is rather more crystalline and is filled with opaque particles that are red and yellow in incident light and give the rock its color; it is also very porous.

The same effects have been produced in the pumice by the numerous outbreaks of basalt along the south slope of Richmond Mountain, and the thin sections from this locality present in many instances the same characters as those just described. They will therefore need but a brief mention and will serve rather as evidence of the identity of the two bodies of pumice and of the uniformity of the alteration arising from the same cause. Thin sections 199, 200, 204, 205, 206, 207, 208, and 209 are from rocks on the small spur south of the summit of the mountain, and occurring under different conditions they vary somewhat in character. Thin section 199 is of a fine grained altered pumice not in immediate contact with basalt, and resembles thin section 196. There is much opaque coloring matter in the base and an abundance of phenocrysts consisting of much quartz and nearly equal quantities of sanidine and triclinic feldspar; in one Carlsbad twin one half exhibits an interference cross that is optically negative, while the other half gives a bar parallel to the clinopinacoid, in which case the section must be perpendicular to the negative bisectrix of the first half, having an angle between the optic axes of about 0°, and at the same time at nearly right angles to one of the optic axes in the other half having a large optical angle and the plane of the axes parallel to that of symmetry. Still another Carlsbad twin shows the plane of the optic axes normal to that of symmetry. There is rather more hypersthene than is common to these pumices. It is partially decomposed and displays a very striking pleochroism, owing to the thickness of the section.

Thin section 200 is the most interesting of all the alteration products, on account of its undoubted relations to the basalt and its higher degree of metamorphism; it is traceable directly to the same deposit of pumice as 199, and lies in apparently undisturbed layers directly over basalt, which did not in this instance reach the surface, but thoroughly altered the overlying pumice, breaking through it lower down the slope. In thin section it is a whitish gray, fine grained breccia of about the same grain as 199. Under the microscope the porphyritical crystals are seen to be angular fragments of quartz, sanidine, and plagioclase of the same size and abundance as those in the last named section; pyroxene, however, is wanting and only a little biotite is present, besides a single grain of garnet. The groundmass has retained its brecciated character, though the pumice fragments have lost their original form and appear to merge into one another; but the degree of crystallization is far more advanced, hardly any portion of it being without influence on polarized light. As a natural result of its brecciated character the structure is most varied, which is the more pronounced between crossed nicols. It is partly spherulitic and axiolitic and partly cryptocrystalline and in places it is microcrystalline in irregular grains.

Thin sections 204 and 205 are from a small outbreak of rhyolite on the south side of the spur about 100 yards from the locality of 199, which, though not traced in the field to unaltered pumice, exhibits under the microscope so close a resemblance in many respects to the last described form as to leave little, if any, doubt that this small flow of porcelain-like rhyolite is a highly altered pumice breccia that has escaped from its place of confinement, probably having been heated under pressure to a greater degree than the breccia met with in situ on the surface. In thin section it is whitish gray, 204 having a glassy groundmass strongly resembling that of 199, which is filled with faintly polarizing particles, and shows as great a diversity of structure, which indicates its once brecciated condition. It is in places spherulitic, cryptocrystalline, and microcrystalline. There is a marked flow structure and a smaller amount of fragmentary crystals, consisting of quartz and feldspar, with very little biotite and one fragment of greenish brown hornblende. Thin section 205 has a groundmass of more uniform structure, composed of microscopic grains of varying size, which pass into cryptocrystalline portions. The flow structure is most noticeable in the thin section without the aid of a lens. The phenocrysts are quartz and feldspar in fragments. A cross-section of zircon, $0{\cdot}1^{mm}$ broad, shows only one set of prism faces and a good cleavage parallel to the other, which is seldom met with in microscopic zircon crystals (Fig. 10, Pl. III.) This thin section is similar to those from the Pinto Peak rhyolite.

Thin sections 206, 207, and 208 from contact with basalt on the slope and at the base of the same spur show exactly the same kind of alteration as 193, 191, and 192, which have been already described. The glass, however, is brown and red, without the black trichites, and there is only a trace of the bisilicates and of biotite. No. 209 is a beautiful section of a reddish brown breccia formed of fragments of brown glass almost free from microlites cemented together by a dark red ferrite-bearing glass, rich in microscopic shreds of biotite, which is very abundant, together with green hornblende in small fragments. Pyroxene is scarce, there is comparatively little quartz, and there are about equal amounts of sanidine and plagioclase, besides which are magnetite garnet and zircon.

Of the remaining instances of altered pumice one from contact with basalt on the end of the east spur of Hornitos Cone, 210, is of purplish brown glass, containing portions with very different structures, being itself an intimate mixture of brown and gray glass with numerous grains of magnetite and a great abundance of brown hornblende in fragments, and with more perfect crystals of strongly pleochroic hypersthene with a narrow dark border; besides biotite, quartz, and feldspar, of which plagioclase is in excess. The relative amount of the bisilicates and mica is much greater than in any of the pumices previously described, and with an excess of triclinic feldspar approaches nearer to the composition of an andesite. The altered breccia from the summit of the cone presents in thin section 211 a reddish gray matrix, bearing yellow, orange, and red fragments, which are found to vary greatly in microstructure. There are comparatively few and small phenocrysts, principally of quartz and feldspar, with still less biotite. The groundmass is a glass, in places microfelsitic, also spherulitic, and passing from cryptocrystalline into microcrystalline. Among the fragments are several that appear to belong to basalt.

Similar to the last is the coarse breccia from the east side of Black Canyon, three sections of which exhibit the changes wrought by the adjacent basalt. In general they are poor in phenocrysts, plagioclase being the most abundant, together with a little biotite and pyroxene, and besides the variously modified glassy portions are pieces of the same basalt. The glass of thin section 224 is filled with irregularly shaped fluid inclusions with stationary bubbles, besides patches of gray polarizing particles and numerous magnetite grains. In thin section 225 the fluid inclusions have diminished both in size and number and the contorted flow structure of the individual glass fragments has been reduced more nearly to straight lines and to a general parallelism throughout the whole mass, except in the case of the less fusible pieces. The fluid inclusions have wholly disappeared from the glass of thin section 226, which is both colorless and bright yellow, and is full of opaque red particles, without doubt red oxide of iron. It is rich in trichites and microlites of feldspar, some of which are colored yellow.

From the foregoing it appears that the richly quartzose, rhyolitic pumice in the vicinity of Richmond Mountain, containing, as it does, a large percentage of triclinic feldspar, which is, however, subordinate in amount to the monoclinic, and at the same time carrying a varying amount of biotite, pyroxene, and green hornblende, holds an intermediate position mineralogically between the dacite and the rhyolite of Rescue Canyon.

A thin section of pumice, 241, altered to a compact glass by the rhyolite of Pinto Peak, is interesting as containing only a little mica in addition to the quartz and feldspar, and therefore closely resembling in composition the surrounding rhyolite. In addition to these phenocrysts, which are few, is garnet. The glassy groundmass is nearly colorless, and contains only a small amount of black particles and starlike groups of trichites. Another altered pumice, 242, from the basin west of Secret Canyon road, is like the last in composition, the light brown glass being in places filled with rectangular microlites of feldspar.

Differing greatly from the foregoing pumices is a tuff of fine grain occurring over a small area on the east slope of Hornitos Cone, where it appears as a bedded deposit of dark gray volcanic sand, altered by an outflow of basalt to a blue black, basalt-looking mass. Thin section 223 shows it to consist of a purplish brown glass crowded with fragments of feldspar, hypersthene, and augite, with some black bordered hornblende and large grains of magnetite. The feldspar is wholly triclinic, the angle of extinction in several instances exceeding that of labradorite and corresponding to anorthite. It also contains a multitude of colorless glass inclusions and a few large ones of brown glass. The hypersthene has the pleochroism common to that of the neighboring andesite, and the greenish brown hornblende fragments are all surrounded by a black border. There is no doubt that this tuff belongs to pyroxene-andesite, though it is the only occurrence of the kind met with in the district. The brown glass is in places globulitic, with more or less feldspar microlites and black grains and trichites in very beautiful aggregations.

CHAPTER IV.

BASALT.

The basalt that has been erupted in the vicinity of Richmond Mountain and to the east, forming Basalt Peak, Strahlenberg, and Crater Cone, and also that found in the neighborhood of Pinto, though varying much in macroscopical habit, that is, in color, density, and compactness, and in its occurrence in large masses or thinly fissile plates, exhibits in thin sections under the microscope the greatest uniformity in structure and in the microscopical character of its component minerals. It has many points of similarity to pyroxene-andesite and the grounds for its determination as basalt will be considered when the nature of its elements has been described. In general it consists of a very homogeneous mixture of lath-shaped feldspar microlites and augite crystals and grains, the latter being in excess, with a smaller amount of hypersthene, besides which are minute crystals of magnetite in a more or less abundant glass base. The whole is of very even grain and macroscopic phenocrysts are almost never met with. Olivine, which is considered an essential constituent in most basalts, plays the part of a very inconstant accessory mineral in this variety. Since the microscopical habit of the different minerals in the basalts from the above mentioned localities is constant throughout the series of thin sections, a single detailed description of them will be sufficient.

The feldspar is triclinic, in lath-shaped crystals for the most part well developed; their size varies considerably within certain limits, the average length being between 0·1 and 0·05$^{\mathrm{mm}}$, a few reaching 0·25$^{\mathrm{mm}}$, and a much greater number being microscopically minute. They have a sharp outline along the base and brachypinacoid, but are less regularly terminated, partly squared off as if by a pinacoidal face; they are generally notched or pronged, appearing as if made up of several prisms of unequal length; frequently the halves of a twin are separated for a short distance at either end of the crystal by a film of globulitic glass. The smaller individuals show but two twinning stripes, but in the stouter crystals more are present. They are of different lengths, sometimes wedging out in the middle of a crystal. A second twinning at nearly 90° to the first is seldom seen, except in some of the stouter individuals. In all the thin sections where the feldspar microlites are of sufficient size, the angles of extinction reach those of anorthite for many individuals, which also show a very high light in extremely thin sections between crossed nicols, indicating that a portion of the feldspar belongs to that species. There are besides many more faintly polarizing crystals with low extinction angles, which may most likely belong to a less basic feldspar. The long narrow crystals are without zonal structure and are free from inclusions of any kind. In several thin sections of somewhat more coarsely crystalline structure the shorter, thicker crystals have both zonal structure and numerous globulitic glass inclusions.

The pyroxene constituent consists of both augite and hypersthene. The augite in thin section is almost colorless with a slight tinge of yellowish green. The hypersthene is colored light green and light reddish brown with the same pleochroism as that already noticed in the andesites, a phenomenon more common in the larger crystals, though not of constant occurrence in any one thin section and frequently confined to the inner portion of a crystal. The hypersthene is of older growth than the augite, which frequently incloses slender prisms of the former. The crystals of augite are not sharply outlined, except in a few of the larger individuals, but have an uneven, jagged outline and are in the form of irregularly terminated prisms and grains, with an octagonal cross-section, which is well defined in many cases, with the pinacoidal faces more highly developed than the prismatic. It has a good cleavage parallel to the latter, with an occasional less perfect jointing parallel to the former; there are also irregular transverse fractures across the long slender prisms. The larger crystals are sometimes twinned one or more times in the ordinary manner parallel to the orthopinacoid, and are often rich in glass inclusions with a gas bubble and sometimes a colorless microlite; apatite needles are not met with, but grains of magnetite are abundant. A curiously curved crystal of augite occurs in thin section 260, one half being bent without fracture through an angle of 40°. Augite is the most abundant mineral composing these basalts and is considerably in excess of the feldspar; the size of its grains is variable, the majority ranging from 0·01 to 0·05$^{\mathrm{mm}}$; many are smaller and a large number evenly scattered through the groundmass average 0·1$^{\mathrm{mm}}$ in diameter, while a small number of porphyritically developed crystals measure 0·75$^{\mathrm{mm}}$ in length and are frequently associated in groups of half a dozen or more. Augite is also found in aggregates of radiating prisms encircling macroscopic grains of quartz. It is in nearly every instance perfectly fresh, but in thin section 262 a fibration parallel to the vertical axis has taken place, accompanied by a red coloration around the margin of the crystal; the fibers polarize brilliantly between crossed nicols and extinguish light parallel to their length.

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The olivine, which appears to be only locally developed in this group of basalts and is found in only a few thin sections, is in porphyritical crystals and fragments, the largest not more than 0·7$^{\mathrm{mm}}$ long and some as small as 0·05$^{\mathrm{mm}}$. The sections are in symmetrical figures of four and six sides, and also in irregular shapes: the outline is not sharply defined, but notched. The substance of the olivine is colorless in thin section and very pure. There are in most cases two or more straight cracks parallel to the plane of the optic axes and the usual cleavage, besides numerous fractures in various directions; frequently curved, presenting the appearance common to pearlite structure, a beautiful example of which is to be seen in Fig. 11, Pl. III. Inclusions are very rare, the only kind noticed being of colorless glass with a fixed gas bubble. The olivine is more or less decomposed in every instance, the alteration proceeding in two different ways, which are not found in association in the same thin section. One is the characteristic alteration into serpentine, in which a green fibrous aggregate is formed, the fibers projecting normally from the fractures, in which is frequently deposited iron oxide. The resulting product has the appearance of a network with meshes of variously oriented fibers, which are at times so intimately mixed as to produce aggregate-polarization. In thin section 292 the color is green, with only a small amount of reddish yellow; but in thin section 286 its color is brownish green. The other kind of alteration may be seen in thin sections 282, 284, 269, and also in 295, 296, and takes place in a different manner. There commences from the surface and fractures as in the ordinary process a fibration, not in directions always normal to the surfaces of fracture, but in lines parallel throughout the entire crystal, and parallel also to some direction in the plane of the more perfect cleavage. The fibers have a light yellow color at first, which deepens into a reddish brown or blood red as the decomposition proceeds; they polarize light brilliantly and show a parallel extinction and sometimes a faint pleochroism. In some cases there appear reddish yellow scales and thin plates and a general lamination, and less frequently the lamination or fibration is altogether wanting, when the section yields a nearly uniaxial, negative interference figure, the plane of the optic axes in the other cases being found to be perpendicular to the direction of the fibers. The alteration in some individuals has started from the center, leaving the outer portion still fresh. It is represented by Figs. 11, 12, 13, Pl. III. The ordinary serpentine alteration product is sometimes colored the same orange or blood red, but is easily distinguished by its internal structure, which is that of irregularly aggregated fibers, not of uniformly parallel fibers. A distinction between the two has not been made by Prof. Zirkel, for in his Basaltgesteine he describes a reddish serpentinization of olivine from the basalt of Kotzhardt in the Eifel, and afterwards a form of decomposition of the olivine in the basalt from Steinheim near Hanau, that corresponds exactly to the second process, just described, and says in conclusion that it is still doubtful whether the "reddish yellow" originates immediately from the fresh mineral or first from the "green."[1] And again in his report on the microscopical petrography for the Exploration of the Fortieth Parallel he remarks that, in the excellent basalt from east of Spanish Spring Station, in the Virginia Range, "olivine occurs, its larger crystals altered along the borders and cracks, and its smaller ones filled with a brownish red, somewhat fibrous substance, which is, without doubt, of a serpentinous character."[2] The thin section of this rock has been examined and the

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[1] F. Zirkel. Basaltgesteine. Bonn, 1870, p. 65.

[2] F. Zirkel. Microscopical Petrography. Washington, 1876, p. 230.

red alteration found to belong to the second kind of decomposition, one section of dark red altered olivine yielding a negative interference cross with one dark ring.

Prof. Rosenbusch describes a similar occurrence in the melaphyre from Asweilen, among the crystalline ingredients of which, he says, "lie large grains having the appearance of specular iron. They have partly the form of olivine and show by well preserved remnants of this mineral that they are pseudomorphs after the same. In other cases, however, such an origin is not demonstrable; the blood red substance is then either very compact and faintly or not at all translucent (basal section) or else it shows a perceptible, monotonous cleavage, strong pleochroism, and a position of the axes of elasticity parallel and at right angles to the cleavage. One can scarcely consider this body as anything else than a blood red mica, for I know of no such pleochroism in specular iron."[1] In the melaphyre from Reidelbacher Hof near Wadrill and the olivine-diabase from Eckelhausen and Gonnesweilen on the left bank of the Rhine, the decomposition of the olivine has resulted in the same red micaceous mineral. It is very common in the basalts of the Fortieth Parallel collection, as noticed by Prof. Zirkel; but after a careful search through all the thin sections of basalt from that region, with one rather doubtful exception, it appears that the two different processes are never found to have taken place together in the same thin section. The resultant mineral from its optical properties is evidently not a confused aggregate, but a crystallographic individual, with parallel orientation of all its parts, for the extinction of light is the same throughout and the interference figure that of a doubly refracting crystal.

In order to arrive as nearly as possible at its actual nature, fragments of a similarly altered, porphyritic olivine in the basalt from Truckee Valley, Truckee Range,[2] were subjected to hot concentrated hydrochloric acid, and afterwards placed under the microscope, when they were seen to have lost their intense red color, which was due to red oxide of iron, and to remain light yellow. The tabular fragments gave for interference figures hyperbolas, which parted only a short distance, indicating a small angle between the optic axes and showing a negative bisectrix. One plate was marked by lines intersecting at 60°, leaving no reasonable doubt that the substance in this case is a nearly colorless, mica-like mineral, colored by red oxide of iron, which latter is occasionally seen in well crystallized hexagonal films in the cracks of less altered olivine. That this mineral is a foliated, crystallized form of serpentine seems probable from the fact that most of these basalts are so fresh, with the decomposition of the olivine frequently confined to the weathered surface, that a very radical change is not likely to have taken place, and that a simple hydration and oxidation of a very ferruginous olivine would supply all the chemical elements necessary to transform it into anhydrous unisilicate of magnesia and ferric oxide; besides which is the fact that the optical properties of the mineral in question correspond to those given

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[1] H. Rosenbusch. Mikroskopische Physiographie. Stuttgart, 1877, p. 400.

[2] Fortieth parallel collection, No. 22329.

by Miller for thermophllite, a foliated mineral naving the composition of serpentine, concerning which Prof. Dana remarks that it seems probable both that this is "truly crystallized serpentine" and that "the crystallization of this species is actually micaceous, like that of chlorite and talc."[1] The red, completely altered, macroscopic olivine is seen in the hand specimen to have a glistening, mica-like cleavage surface. There remained in the portion subjected to acid well developed, nearly opaque octahedrons, most likely picotite. The crystallization of the olivine appears to have preceded that of the other minerals by only a short period, stopping just as they began, for no inclusions of them are found in the olivine except around its border, where angite and more rarely feldspar are seen penetrating its surface, causing it to have an uneven and broken outline.

A less important, though ever present, component is magnetite, which is very abundant in well crystallized octahedrons of from 0·03 to 0·01 ^{mm} and less. It is very uniformly scattered through the rock, and in some cases, thin sections 285, 282, 283, is closely associated with augite, attaching itself to the surface of the crystals and being included in them, but it is seldom seen penetrating the substance of the feldspar crystals. It is everywhere fresh and there is no evidence under the microscope of the presence of titaniferous iron. As accessory minerals the only one to be mentioned is quartz, which is found in one or more macroscopic grains in nearly every hand specimen, but which is rarely met with in the thin sections. There is a fragment in thin section 261, which is 1·4^{mm} long, with an angular outline and conchoidal fracture. It is cut exactly at right angles to the optic axis, yielding a slightly distorted interference cross and proving to be a single individual grain. It contains a crystal of zircon, several hair-like trichites, and a few irregularly shaped fluid inclusions with very broad dark borders, carrying extremely active gas bubbles, which disappear at a very slight elevation of temperature, thus indicating the fluid to be liquid carbon dioxide. There is besides these inclusions a dihexahedral cavity filled with glass and a comparatively large crystalline grain which crowds the bubble of gas out of its usual spherical shape. The character of its inclusions, the unity of the whole quartz as a single individual, together with the surrounding shell of augite crystals, leaves no doubt of the primary nature of this quartz, which corresponds in a measure to that of quartz-porphyry. There are besides in some thin sections amygdules of a green or red, radially fibrous, delessite-like mineral, and in others microscopic aggregates of one of the zeolites, whose action on polarized light and apparent polysynthethic twinning suggest the characteristics of chabazite as given by MM. Fouqué and Michel-Lévy.

Glass is more or less abundant in all the basalts from the localities mentioned. It is for the most part colorless in thin section. In a few instances it is brown, and in the darker varieties it swarms with seemingly black globulites, which, however, are

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[1] J. D. Dana. A System of Mineralogy, 5th ed., p. 465.

found to be transparent with very dark borders. This glass base and the microstructure of the rock as a whole are the only variable factors in this otherwise monotonous group of rocks. The variations in these features will be separately mentioned in the following notes. Thin sections 253, 260, 261, 256, 257, 258, and 262 are from the flow of basalt east of the town of Eureka, at the western base of Richmond Mountain. No. 253 is vesicular, with relatively great irregularity in the size of the crystals, a small amount of glass base, and, what is generally noticeable, a marked flow structure. Nos. 260 and 261, which are closely related in the field, have a more even grain and comparatively little glass, with few globulites and acicular microlites. The first is vesicular, with some cavities filled with the delessite-like mineral and possibly the trace of olivine. The second is compact; the mottled appearance of its groundmass is not traceable to any modification of the crystalline structure and must lie in the isotropic base. Nos. 256 and 258, from compact and vesicular portions of the same flow some distance from the last two, are alike in structure, being of uneven grain with numerous larger augite crystals similar to No. 253. The glass is partly brown, which is also the case in thin section 257, which is exceptionally beautiful, having a coarser and more even texture with a larger amount of glass (Fig. 2, Pl. VII). Thin section 262 differs from all the rest in having little or no glass and, besides the lath-shaped feldspar microlites, possessing ill defined feldspar grains approaching a microcrystalline structure. The basalt on the summit of Richmond Mountain, thin sections 264, 265, 267, 268, has the same modifications of its structure. Nos. 264 and 265 are rich in colorless glass filled with the minutest globulites, which give it a brown color. The crystalline constituents are very small and almost wholly augite and magnetite. The crystals of 267 are larger and include more feldspar, which is also true of 268, where the mottled appearance of the rock is due to the unequal distribution of the augite grains. In these four thin sections augite is greatly in excess of the feldspar. A fine thin section with rich brown globulitic glass and minute augite crystals, closely resembling No. 264, is from a bowlder on the foothills to the north of the mountain (270). No. 269 is a red, finely porous variety from near the summit of Richmond Mountain. Its red color is the result of the partial decomposition of abundant olivine. The rock is more highly crystalline than the neighboring basalt. It is rich in feldspar and poor in slightly globulitic glass. Of the basalt exposures in the pumice at the south base of Richmond Mountain, the most westerly dike exhibits fine columnar structure. Its thin section, 271, shows it to be quite like No. 260, in being well crystallized, with little glass and considerable feldspar, and a very little olivine. That from immediate contact with pumice on the spur south of the summit, 273, is finely vesicular, poor in crystals, and full of ferrite, resembling those portions of basalt found included in several altered pumices. Thin section 274 is from one of the coarser grained, more highly crystallized varieties, which is poor in glass, but very rich in augite, and having a trace of olivine in the form of a small number of characteristically decomposed sections.

The basalt covering the large area east of Richmond Mountain is represented by three thin sections from Basalt Peak, 283, 282, and 284; one from the light colored vesicular variety from Strahlenberg, 285; one of compact rock from Basalt Cone, 286, and another, 288, from back of the Toll House on Newark Valley road. The first three are characterized by relatively large crystals, and a coarsely globulitic glass, which in 284 is nearly opaque, being of a dark, rich brown in the thinnest places. They all three contain olivine, which is completely decomposed in the ordinary manner in 283, but is only partially altered in 282 and 284 to the red, laminated substance, already described. The basalt of 285 is without olivine and is in a less perfectly crystallized state. The colorless glass is almost free from globulites; the feldspar microlites are small, and the augite is in much larger individuals with nearly all the magnetite attached. The structure of 286 is identical with that of 282, the glass is coarsely globulitic and there is a small amount of serpentinized olivine present. The globulitic base of 288 is crowded with feldspar microlites, with many microscopic porphyritical augite crystals, and numerous grains of perfectly fresh olivine. Of the two thin sections from the neighborhood of Pinto, 290 is in every respect like that from the summit of Richmond Mountain (264), and contains no olivine, while 292 is identical with the basalt of Crater Cone (286), and abounds in altered olivine.

The foregoing detail is necessary in order to emphasize the fact of the unity of the somewhat scattered outflows of this rock, as it shows the slight and nonessential character of the variations, the fluctuating percentage of the olivine, and that its presence or absence is without influence on the microstructure of the rock. The grounds, then, for separating this rock from the andesites and classifying it as a basalt may be summed up as follows: (*a*) The great difference in microstructure between the andesite of the district and this rock, which is not porphyritically developed and which is very glassy, with extremely small crystals of nearly uniform size, having no macroscopic phenocrysts, with rare exceptions; (*b*) that while the feldspar is in well developed lath-shaped crystals, the augite is mostly in less regularly outlined crystals, and in much greater abundance, occurring frequently in larger individuals, in addition to which there is a small percentage of hypersthene; (*c*) the presence of olivine, though in variable quantities. It is, however, not a normal basalt, and may be considered more properly an intermediate rock between basalt and pyroxene-andesite.

Another variety of basalt is found in the southeastern corner of the district, at Magpie Hill and on the southern slope of the Alhambra Ridge. Thin section 295 is from the former and shows it to be a very homogeneous mixture of feldspar, augite, olivine, and iron oxide, with no isotropic glass; but there are irregularly scattered patches of a light purple, cryptocrystalline substance, which may be the remains of a glassy matrix. The rock is thoroughly crystalline, and as such is very different from the first described variety. The body of the rock is made up of rather broad, interpenetrating, lath-shaped feldspar crystals, in which are many small augite prisms and grains of magnetite, together with an abundance of larger and better developed olivine crystals. There are a couple of grains of porphyritical quartz, and calcite is pretty generally disseminated through the whole mass. The feldspar is probably labradorite with some little anorthite. It is not well outlined, but is in prisms, elongated in the direction of the brachydiagonal, with multiple twinning after albite, a few rare individuals having a second twinning at about 90°. There are no characteristic inclusions, some crystals being free from any, others containing glass and small portions of the associated minerals, besides long, slender jointed apatite needles. The augite is not abundant and occurs in irregular grains and in short prisms with pyramidal termination. It is of a light green color without pleochroism, and is intimately associated with the magnetite. The olivine is in larger, quite characteristic crystals, the largest 1^{mm} long. It is almost completely decomposed to the blood-red micaceous mineral already described, and is in every respect similar to that found in the basalt from the vicinity of Richmond Mountain. The magnetite, which is very abundant, is in irregular grains and crystals, with some long, narrow forms, that suggest titaniferous iron.

The two quartz grains in 295 are very interesting. They are angular fragments about 4^{mm} long, with distinctly corroded outlines and several conchoidal fractures; they are surrounded by shells of radiating augite prisms and calcite. One of them is represented in Fig. 4, Pl. IV. The only inclusions are a few dihexahedral cavities containing at low temperatures liquid carbon dioxide. The bubbles, which have very narrow dark borders, are motionless at a moderately low temperature, but become greatly agitated at about 60° or 70°, and at a few degrees higher temperature disappear, reappearing on being cooled again. The quartz is evidently primary; that is, antedates the final consolidation of the rock; but the calcite, which surrounds it and penetrates numerous small cavities, and also occurs in irregular patches through the groundmass of the rock, is secondary. In the augite border surrounding the quartz grains occurs a strongly pleochroic mineral in short, stout, well developed crystals. It is biaxial and monoclinic, and two cross-sections show the characteristic form and cleavage of epidote, with the strong absorption parallel to the clino-diagonal, but the pleochroism is unusual for that mineral, being reddish purple parallel to the axis $\mathfrak{c}$, light yellow to colorless parallel to $\mathfrak{a}$, and strong yellow parallel to $\mathfrak{b}$. This is the pleochroism of piedmontite or manganese epidote, which is probably the mineral present. It is not found in any other part of the thin section.

The basalt from the south slope of the Alhambra Ridge, thin section 296, is similar to the last in microstructure, but is full of phenocrysts. The groundmass is formed of the same interpenetrating crystals of feldspar, in this instance labradorite, with much more augite, magnetite, and red altered olivine, and with no glass. The larger phenocrysts are not sharply outlined, the feldspars, by including more and more of the other minerals, pass gradually into the surrounding groundmass; they have numerous gas cavities, some containing a fluid, besides very few glass inclusions. The augite is in part so clouded with dust-like particles as to be almost opaque. Hypersthene occurs among the larger phenocrysts, having a very irregular form, and the same pleochroism that it exhibits in the andesite of this region. Associated with the phenocrysts is light reddish brown mica, which has a small angle between the optic axes; it is apparently of primary origin. There are, besides, large grains of iron oxide and considerable calcite.

PLATE III.

1. APATITE FROM HORNBLENDE-MICA-ANDESITE.

Thin section 37, magnified 240 diameters. Longitudinal section of an apatite crystal, shewing prismatic, pyramidal, and basal faces, and bearing glass with a gas bubble in a negative crystal cavity, as well as a multitude of needle-like inclusions arranged parallel to the principal axis of the crystal.

2. AUGITE FROM PYROXENE-ANDESITE OF CLIFF HILLS.

Thin section 102 *a*, magnified 55 diameters. Section showing a partial black border of magnitite, wholly external to the augite crystal.

3. AUGITE FROM PYROXENE-ANDESITE OF RICHMOND MOUNTAIN.

Thin section 77, magnified 55 diameters. Section showing a similar black border.

4. APATITE FROM HORNBLENDE-MICA-ANDESITE.

Thin section 37, magnified 240 diameters. Crystal of apatite with prismatic, pyramidal, and basal faces, showing a basal cleavage and needle-like inclusions parallel to the principal axis of the crystal.

5. HORNBLENDE AND PARTLY ALTERED HYPERSTHENE FROM ANDESITIC PEARLITE.

Thin section 58, magnified 75 diameters. Section of a fragment of hornblende and hypersthene in juxtaposition, with magnetite and glass inclusions. The hornblende has remained fresh while the hypersthene has been partly altered into fibrous actinolite.

6. FELDSPAR FROM PYROXENE-ANDESITE.

Thin section 102, magnified 25 diameters, in polarized light with crossed nicols. Section of a triclinic feldspar showing a marked zonal structure, the extinction angle at the center being 25° greater than that in the outer zone. There are very narrow strips twinned after albite that do not show zonal variation. At the center is an abundance of glassy inclusions that appear black between crossed nicols.

7. FELDSPAR FROM PINTO RHYOLITE.

Thin section 122, magnified 31 diameters, with crossed nicols. Section of a triclinic feldspar, showing by its outline that it is a Carlsbad twin, each half has also the multiple twinning of albite, and each a different set of extinction angles. It is cracked transversely.

8. APATITE FROM ANDESITIC PEARLITE.

Thin section, 75 *a*, magnified 230 diameters. Longitudinal section of apatite, showing both ends terminated by the base and pyramid and having well defined basal cleavage, with a small amount of needle-like inclusions.

9. HYPERSTHENE FROM ANDESITIC PEARLITE.

Thin section 58, magnified 40 diameters. Partly altered hypersthene with inclusions of magnetite, glass, and small apatite crystals. It shows the fibrous decomposition taking place from the extremities and fractures of the crystal and proceeding in a direction parallel to the principal axis of the crystal.

10. ZIRCON FROM RHYOLITE.

Thin section 205, magnified 100 diameters. Cross section of a zircon crystal, showing only one set of prism faces and a cleavage parallel to the other.

11. OLIVINE FROM BASALT OF BASALT PEAK.

Thin section 282, magnified 78 diameters. Section of olivine, showing spheroidal fractures and the irregular outline caused by the crystal losing itself in a multitude of inclusions of augite and feldspar. The red decomposition is seen taking place from the cracks, giving the effect of a fibration that is parallel throughout the whole crystal.

12, 13. OLIVINE FROM BASALT OF BASALT PEAK.

Thin section 282, magnified 75 diameters. Sections of olivine, showing the same cleavage and decomposition as Fig. 11, in one the alteration setting in from the outside, in the other beginning at the center.

14. FELDSPAR FROM RHYOLITE.

Thin section 145, magnified 550 diameters. Form of feldspar microlites, probably oligoclase, found crowded together in a glassy rhyolite. They show various stages, from rectangular compact crystals with sprouting corners to the finest fibers.

15. ZIRCON FROM ANDESITIC PEARLITE.

Thin section 54, magnified 175 diameters. Long, slender zircon crystal, 0·37$^{\mathrm{mm}}$ long, terminated at both ends, lying in groundmass; appears to have the form ∞P, ∞P∞, 3P3, with P and P∞.

16. ZIRCON FROM ANDESITIC PEARLITE.

Thin section 61, magnified 455 diameters. Long, slender crystal, 0·13$^{\mathrm{mm}}$ long, lying isolated near the edge of the rock section, terminated at one end and broken at the other, with the faces ∞P, ∞P∞, and 3P3.

17. ZIRCON IN ANDESITIC PEARLITE.

Thin section 75*b*, magnified 470 diameters. Stout crystal, 0·09$^{\mathrm{mm}}$ long, lying in glassy groundmass, with apparently ∞P, ∞P∞, 3P3, and P or P∞.

18. ZIRCON FROM RHYOLITE.

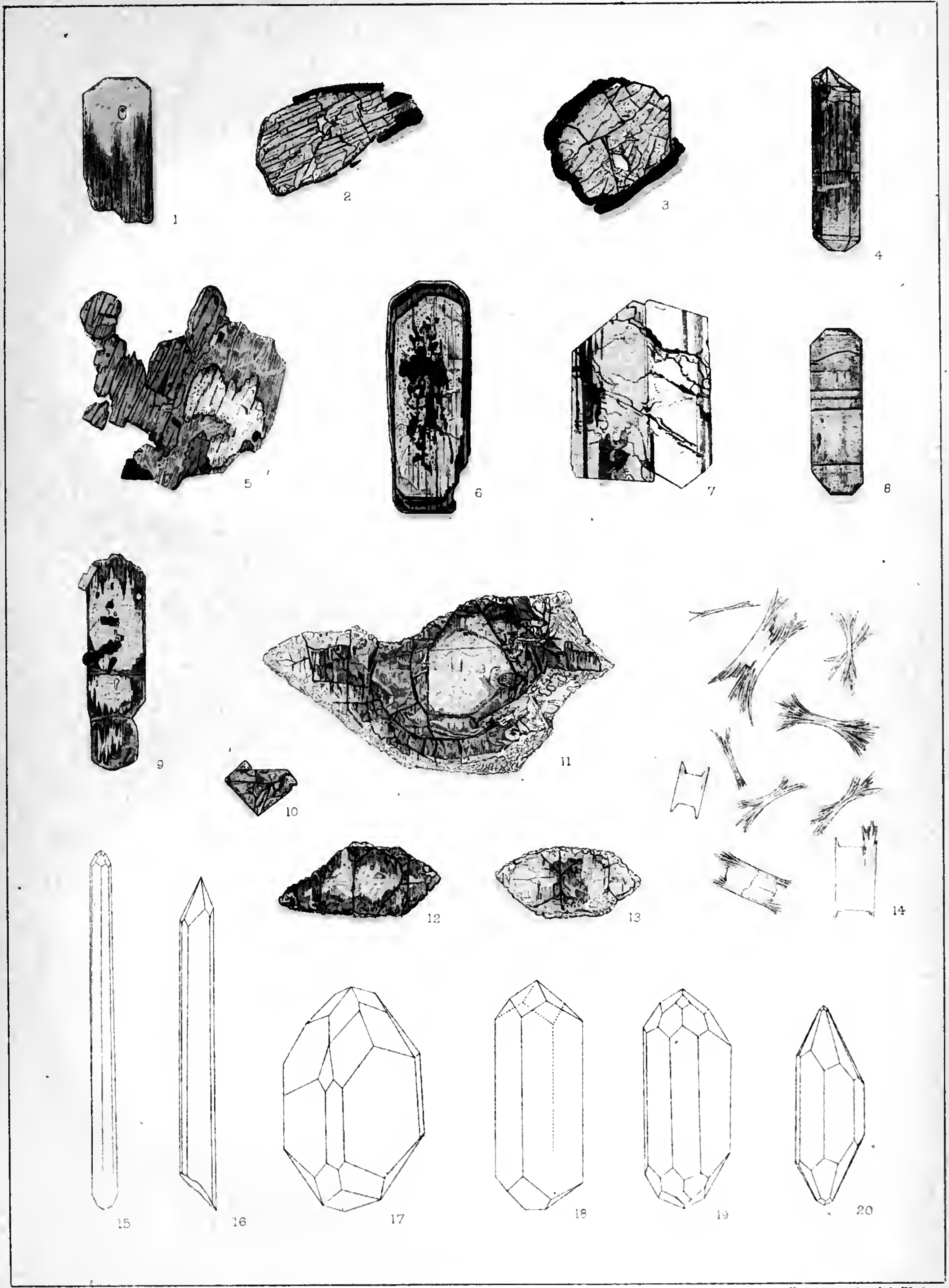
Thin section 168, magnified 540 diameters. Simple crystal of zircon, 0·08$^{\mathrm{mm}}$ long, inclosed in feldspar, formed of a single prism and the alternate pyramid.

19. ZIRCON FROM ANDESITIC PEARLITE.

Thin section 58, magnified 900 diameters. Crystal of zircon, 0·044$^{\mathrm{mm}}$ long, occurring in feldspar and appearing to have the faces ∞P, ∞P∞, 3P3, P, and P∞.

20. ZIRCON FROM ANDESITIC PEARLITE.

Thin section 73, magnified 570 diameters. Crystal of zircon, 0·06$^{\mathrm{mm}}$ long, in feldspar, having ∞P, ∞P∞, 3P3, and two pyramids.



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MICROSCOPIC PETROGRAPHY.

PLATE IV.

1. FRACTURES ABOUT GLASS INCLUSIONS IN QUARTZ OF RHYOLITE (CROSS SECTION).

Thin section 111, magnified 300 diameters. A cross section of a quartz crystal that bears glass with gas bubbles in dihexahedral cavities. About each inclusion the quartz is cracked for a short distance in three planes, corresponding to three of the planes of symmetry passing through its vertical axis. The cracks appear as six-rayed stars that are parallel to each other throughout the section. In this figure a number have been brought together from different parts of the same quartz section, in order to show the different appearances when the inclusions are cut through the middle or near one end, or when the section passes just above or below them. From the inclusion nearest the top of the figure it will be seen that the section is slightly inclined and not exactly at right angles to the principal axis of the quartz crystal. The illustration shows the upper end of this last-named inclusion and the lower end of the one just below it to the right.

2. FRACTURES ABOUT GLASS INCLUSIONS IN QUARTZ OF RHYOLITE (LONGITUDINAL SECTION).

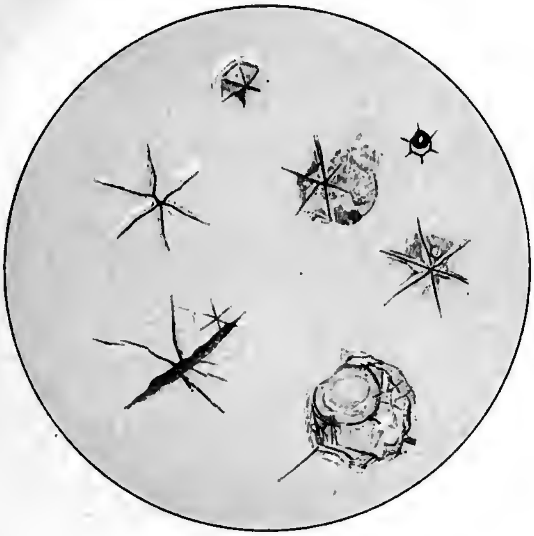
Thin section 111, magnified 300 diameters. A longitudinal section of a quartz crystal only 1 millimeter from that in Fig. 1, showing the same kind of glass inclusions with vertical fractures. These are drawn as they occur, without any change of position. Those lying at the surfaces of the quartz section have had the gas bubbles cut in grinding and filled with balsam.

3. QUARTZ-CONGLOMERATE.

Thin section 501, magnified 33 diameters. Section of fine grained conglomerate with siliceous cement, showing that the apparently granitoid quartz grains are rounded, water-worn grains, about which the silica of the cement has crystallized with the same crystallographic orientation as the nucleus, thus extending the individual until obstructed by the surrounding fragments.

4. QUARTZ FRAGMENT IN BASALT OF MAGPIE HILL.

Thin section 295, magnified 28 diameters. Section of crystalline basalt, showing an irregularly shaped fragment of primary quartz, surrounded by a shell of augite crystals and patches of calcite. The somewhat darker, broader grains in the augite shell are piedmontite. The rock is composed of feldspar, minute augite, and magnetite crystals, with larger crystals of red altered olivine.



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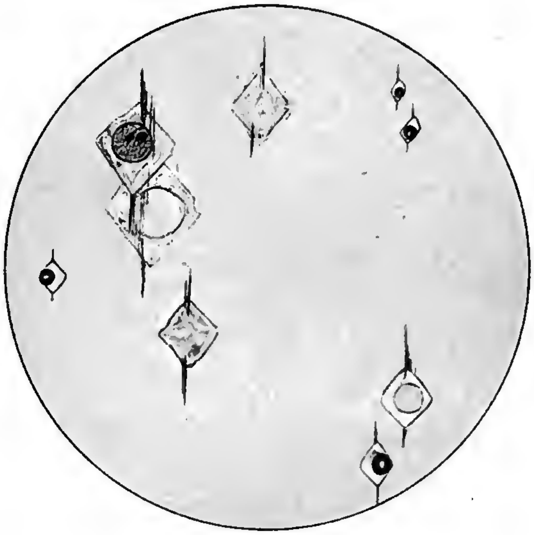

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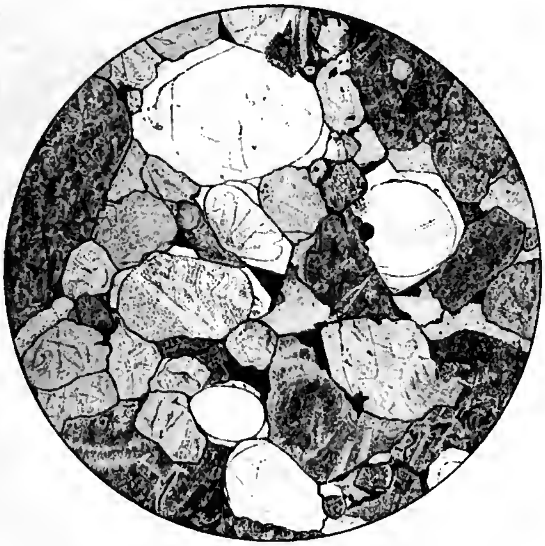

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MICROSCOPIC PETROGRAPHY.

PLATE V.

1. PLAGIOCLASE FELDSPAR IN HORNBLENDE-MICA-ANDESITE.

Thin section 42*a*, magnified 45 diameters. Between crossed nicols, exhibiting zonal structure and several rounded contours due to partial corrosion at different stages of its growth. Also a net work of irregular cracks.

2. A MICROPEGMATITIC PHENOCRYST IN RHYOLITE.

Thin section 141, magnified 19 diameters. Three sanidine crystals surrounding a plagioclase, most of which has fallen out, leaving a hole. The sanidine is filled with irregularly shaped shreds of quartz arranged as in pegmatite. Between crossed nicols. The quartz is dark, the feldspar light.

3. PLAGIOCLASE FELDSPAR FROM HORNBLENDE-MICA-ANDESITE.

Thin section 35, magnified 35 diameters. Between crossed nicols, exhibiting polysynthetic twinning, zonal structure, and microscopic inclusions of glass.

4. PLAGIOCLASE FELDSPAR ADJACENT TO FIG. 3.

In same thin section, magnified 35 diameters. Between crossed nicols, exhibiting polysynthetic twinning and microscopic inclusions of glass.

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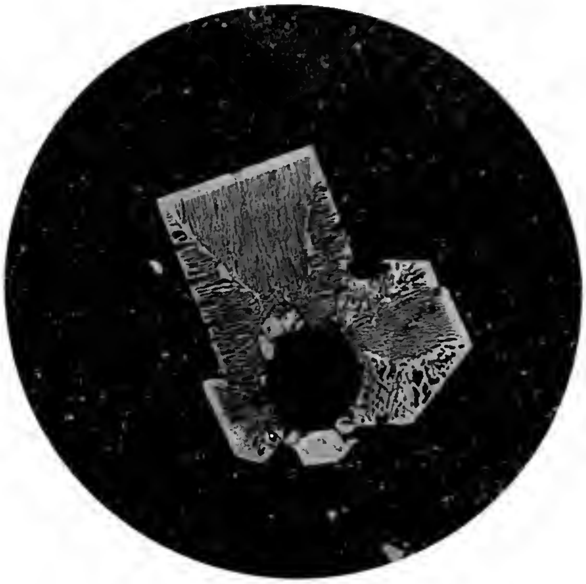

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PLATE VI.

1. MICROPEGMATITIC STRUCTURE IN GRANITE-PORPHYRY.

Thin section 16, magnified 100 diameters. Intergrowth of quartz and feldspar. The quartz is the lighter colored portion in the form of triangles and rhombs.

2. PLAGIOCLASE FELDSPAR IN HORNBLENDE-MICA-ANDESITE.

Thin section 35, magnified 32 diameters. Between crossed nicols, exhibiting the parallel growth of twinned individuals and zonal structure.

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PLATE VII.

1. PHENOCRYSTS OF BLACK BORDERED HORNBLENDE AND PLAGIOCLASE FELDSPAR IN HORNBLENDE-BEARING PYROXENE-ANDESITE.

Thin section 77, magnified 50 diameters. The glass inclusions in the feldspars and the feldspar microlites in the groundmass are shown.

2. BASALT.

Thin section 257, magnified 225 diameters. The lath-shaped plagioclase and magnetite grains are distinctly shown, but the angite is not well defined.

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PLATE VIII.

1. RHYOLITE; MICROSPHERULITIC WITH A MARKED FLOW STRUCTURE.

Thin section 130, magnified 66 diameters. The angular and irregular form of the phenocrysts of quartz and feldspar shows the fractured character.

2. RHYOLITE; GLASSY AND BANDED.

Thin section 174, magnified 14 diameters. Small phenocrysts of feldspar.

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