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No. 18.

REPORT

OF THE

GEOLOGICAL EXPLORATION OF THE FORTIETH PARALLEL

MADE

BY ORDER OF THE SECRETARY OF WAR ACCORDING TO ACTS OF
CONGRESS OF MARCH 2, 1867, AND MARCH 3, 1869,

UNDER THE DIRECTION OF

BRIG. AND BVT. MAJOR GENERAL A. A. HUMPHREYS,
CHIEF OF ENGINEERS,

BY

CLARENCE KING,
U. S. GEOLOGIST.

VOLUME I.

[illegible] BAD LANDS, AT [illegible]

UNITED STATES GEOLOGICAL EXPLORATION OF THE FORTIETH PARALLEL.
CLARENCE KING, GEOLOGIST-IN-CHARGE.

SYSTEMATIC GEOLOGY

BY

CLARENCE KING

U. S. GEOLOGIST.

SUBMITTED TO THE CHIEF OF ENGINEERS AND PUBLISHED BY ORDER OF THE SECRETARY OF WAR UNDER AUTHORITY OF CONGRESS.

ILLUSTRATED BY XXVIII PLATES AND XII ANALYTICAL GEOLOGICAL MAPS, AND ACCOMPANIED BY A GEOLOGICAL AND TOPOGRAPHICAL ATLAS.

WASHINGTON:
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All the illustrations of this volume were executed by Julius Bien, the chromo-lithographs after studies by Gilbert Munger, plates in black after photographs by T. H. O'Sullivan.

ANALYTICAL GEOLOGICAL MAPS.

Office of the United States Geological
Exploration of the Fortieth Parallel,
23 *Fifth Avenue, New York, March,* 1878.

General: I have the honor herewith to transmit Volume I. of the Report of this Exploration. Its subject is Systematic Geology of the Fortieth Parallel.

The field-facts here assembled were observed by Arnold Hague, S. F. Emmons, and myself. All inductions are my own. Determinations of invertebrate fossils were made by the late Prof. F. B. Meek, or by Messrs. Hall and Whitfield. Purely microscopical details in the chapters on Crystalline Rocks are derived from Volume VI. of this series, and are thus credited to Prof. Ferdinand Zirkel.

The method of this volume is historical. It is an attempt to read the geology of the Middle Cordilleras, and to present the leading outlines of one of the most impressive sections of the earth's surface-film.

For the freedom of action you have always granted me, for your generous bestowal of every needed facility, and above all for your wise and just guidance of the general plans of the work, I beg to offer my warmest thanks.

That which a student of geology most earnestly longs for, I have freely received at your hands, and whatever value this Report may possess, either as a permanent contribution to knowledge or as a stepping-stone worthy to be built into the great stairway of science, I feel that the honor belongs first to you.

For those who are to continue the arduous labor of American field-study, I can wish no happier fortune than to serve within the department which you command.

Very respectfully, your obedient servant,

CLARENCE KING,
Geologist-in-Charge.

To Brig. Gen. A. A. Humphreys,
Chief of Engineers, U. S. Army.

CHAPTER I.

AREA AND EXPLORATION OF FORTIETH PARALLEL.

The Exploration of the Fortieth Parallel promised, first, a study and description of all the natural resources of the mountain country near the Union and Central Pacific railroads; secondly, the completion of a continuous geological section across the widest expansion of the great Cordilleran Mountain System.

In 1867, when the Fortieth Parallel Corps took the field, there was no authentic map which displayed the continuous topography from California to the Great Plains. The labors of several military explorers—among whom were Frémont, Stansbury, and Simpson, of the Corps of Engineers, and Bonneville, Lander, Beckwith, and Gunnison—had lifted our knowledge of the Fortieth Parallel country out of the condition of myths, and had fixed with commendable accuracy the geographical positions of many of the most important natural objects. Major Williamson, also of the Engineer Corps, had lately made a reconnoissance through northwestern Nevada, adding a valuable map of the lowlands lying near the California boundary. With all this, there were still serious gaps in our topographical knowledge, not only as to orographical details, but concerning the position and area of considerable mountain masses.

A general geographical sketch map of the Cordilleras of the United States, the preliminary sheet of the Atlas accompanying this report, shows the area covered by this Exploration, and indicates the special division into blocks corresponding to the maps of the series. It will be seen by reference to this sheet that the Exploration has covered a belt of country one hundred miles wide from north to south, extended from the meridian of 104° west, in a direction a little south of west, as far as longitude 120° west, partly enclosing the 40th parallel, but near the eastern extremity of the work deviating a little to the north of the line. This departure from the parallel was necessary in order to embrace the most northerly curves of the Union Pacific Railroad without increasing the hundred-mile width of the belt. It was further desirable because the resultant direction of the belt of exploration approached more nearly a perpendicular to the general trend of the Cordilleran system. Alike for the purposes of illustrating the leading natural resources of the country contiguous to the railroad and for purely scientific research, the belt was made one hundred miles wide from north to south. Though simple in its leading outlines, the structure of the Cordillera is in detail a labyrinth of intricate changes. One well observed section traced across a single range or a complex chain, or even through the whole broad system, would in most cases simply mislead the student. A parallel section five miles either side of it might result in a totally different reading. It is believed that this work, covering as it does a broad belt-section, has avoided the danger of insufficient or ambiguous evidence, and that the geological conclusions offered in this volume are safe.

The State Geological Survey of California had carried its bold explorations throughout the Sierra Nevada and Coast ranges, bringing to light the most stupendous exhibition of geological effects on this continent. Professor Whitney, not to be cut off by the political boundaries of his State, had pushed private investigations over much of the Pacific slope. Warren, Hayden, and others had undertaken the questions offered by the Great Plains. Between California on the west and the eastern base of the Rocky Mountains was a broad gap of 16° longitude, in which our geological knowledge was merely fragmentary and amounted practically to nothing, since it was all comprised in the notes of a few valuable and interesting localities of fossils, without the slightest data for correlation of horizons or the most shadowy outlines for stratigraphy.

With the help of an ardent and untiring corps, I have endeavored to work out the continuous geology across this gap, making adequate connections with the territory surveyed by Whitney on the one hand, and with Hayden's field on the other. Having completed this, I am now able to offer a comprehensive view of the broadest expansion of the great American mountain system, and to present in some detail a section of sufficient magnitude to render approachable some of the extended problems of mountain dynamics.

It has rarely fallen to the lot of one set of observers to become intimate with so wide a range of horizons and products. Embracing within its area a pretty full exposure of the earth's crust from nearly the greatest known depths up through a section of 125,000 feet, taking in all the broader divisions of geological time—a section which has been subjected to a great sequence of mechanical violence, and can hardly fail to become classic for its display of the products of eruption—this Exploration has actually covered an epitome of geological history.

The purpose of this volume is to present, as briefly as possible, a systematic statement of the data collected and the inductions we have been able to make. In Volume II. will be found a continuous description of the geological facts observed, treated geographically, beginning at the eastern extremity of the explored area and progressing westward, range by range, valley by valley, to the California boundary-line. Whoever wishes to know the structure and details of given features should consult that volume. In these chapters the method of treatment adopted is, to begin at the bottom of the geological column and present all the important facts we have accumulated on each successive formation, always attempting to correlate the wide-spread data and construct a continuous piece of geological history. Elements of difference and points of identity with other fields cannot fail to compel the reader, as they have the writer, to institute a constant mental comparison with localities and modes of geological action outside the area. In the interest of compactness, however, such comparisons have been nearly always omitted here. Presenting thus the fullest range of horizons, the arrangement of the book is chronological, beginning with the deposits of Archæan time and proceeding without break through the Quaternary.

Three classes of considerations are put forth: 1. Descriptions of geological facts. 2. The direct correlation of facts into methodical grouping. 3. Theoretical speculations. As far as possible, these are kept so sharply separated in independent chapters or sections, that the student will never be in doubt as to where actual observation stops and induction begins. He will be able to accept the facts as offered in the spirit in which they are given, as honest, unbiased, and approximately accurate, however his own logic may lead him to differ from my generalizations or speculations.

Readers are recommended to bear in mind that this work is not a geological survey, but a rapid exploration of a very great area, in which literally nothing but a few isolated details was before known. Unmapped, unstudied, it was *terra incognita;* and if in our difficult and arduous campaign we have done no more than outline the broader features of the geology, we have at least accomplished that, and have laid the foundation for those future slow and detailed surveys which we hope are sure to follow our pioneering labors. It has been my own share of the work to see as much of the field as possible, and to discover from the facts gathered by myself and my collaborators, Messrs. Arnold Hague and S. F. Emmons, those unforced natural generalizations which come of bringing the field data into their just and logical apposition. The value, therefore, which it is hoped this volume may possess, lies mainly in its being a piece of connected history, in which the leading outlines are emphasized.

In blocking out the explored territory into divisions suitable for atlas maps, it was found that the country naturally divided itself into five equal areas, each section covering a region having some independent characteristics. This natural division, as it came to be studied, proved in the main so desirable that it was finally adopted, notwithstanding that the boundary-lines do in some cases cut the geology rather unfortunately.

The Atlas, besides the Cordillera Sketch Map already mentioned, consists of duplicate series of geological and topographical sheets, on a scale of four miles to one inch, which, joined together on the proper projection-lines, form the continuous belt of work. Each area is shown first on a geological map based upon a portrayal of the mountain topography in grade curves of 300 feet vertical interval, the various formations appearing in their appropriate colors. Accompanying this is a second map of the same region, the topography of which is lithographed in mountain shading with a side light. Added to these are two atlas sheets carrying two continuous geological sections, drawn from actual observation, from east to west across the whole field of work.

Before entering upon the chapters of detailed geology, I give here a succinct description of the more general characteristics of the five map-areas. The greatest looseness prevails in regard to the nomenclature of all the general divisions of the western mountains. For the very system itself there is as yet only a partial acceptance of that general name, Cordilleras, which Humboldt applied to the whole series of chains that border the Pacific front of the two Americas. In current literature, geology being no exception, there is an unfortunate tendency to apply the name Rocky Mountains to the system at large. So loose and meaningless a name is bad enough when restricted to its legitimate region, the eastern bordering chain of the system, but when spread westward over the Great Basin and the Sierra Nevada, it is simply abominable. It is greatly to be hoped that the example of a few competent geographers and geologists who stand by Humboldt's name will gradually come to be followed by all, and the term Rocky Mountains be confined to the east front of the Cordilleras.

In this report and in the title of Atlas Map I., "Rocky Mountains" means that marginal chain which constitutes the eastern limit of the Cordilleran system. It is made up of several dependent ranges, and its most important geographic function in the United States is, to divide the Mississippi Basin from the Pacific rivers.

Map I. embraces a section of the Rocky Mountains consisting of a portion of Colorado Range extending from latitude 40° 20′ for a hundred miles due north; the northern extremity of Park Range, also a meridional body, lying about 30 miles west of Colorado Range; and a third range, having a northwest trend, and branching westward from Colorado Range, near the southern boundary of the map. These three intimately related mountain masses are old Archæan ranges, representing the earliest period of orographical uplift of which there is any evidence in the Cordilleran ranges. They are all of topographical importance, from the great altitude of their summits and their relation to the drainage-system. Park Range, the westernmost member of the chain, forms in our latitudes the Atlantic and Pacific watershed.

The three ranges are based upon plateau country, from 5,000 to 7,000 feet above sea-level. Passing west from the Missouri valley, the system of Great Plains rises from an altitude on the east of about 1,000 feet above sea-level, with remarkable gradualness, in one sweep up to the east base of Colorado Range, where against the foot-hills the elevation of the plains varies from 5,500 to 7,000 feet. Down the slope of this vast inclined plane the western tributaries of the Missouri and Mississippi flow, in rather shallow valleys, edged often by abrupt bluffs. Near the mountains these valleys of erosion are sometimes 500 or 600 feet deep; but followed down their course they are seen to grow shallower and shallower, till the flanks of the depression roll away from the stream-bottoms in gentle undulations.

The Plains geology, like the topography, is broad and simple, being composed of nearly level beds of Tertiary and Cretaceous age, tilted with the slight slope of the surface.

Tree vegetation is confined to the immediate stream-banks, and even there, over the middle belt of plains, is almost wanting. Shrubs are equally rare with trees, the whole vast surface being covered with a growth of upland grasses.

Seen from the east, Colorado Range presents a rugged front, deeply carved with cañons, which deliver their streams through gateways in the foot-hills. The lower slopes are of dull, rusty colors, dotted with an occasional sparse growth of trees. Farther up, in the middle altitudes, a forest, composed of coniferous trees and aspens, flourishes in the cool, moist strata of upper air, and above rise the naked, snowy crags, broken and eroded into impressive peaks. The profile of the range shows a high, slightly serrated ridge entering the area of Map I. from the south, and terminating in Hague's Peak, 13,832 feet high. Passing northward, the outline declines by long, sweeping curves to the region of the Union Pacific Railroad. North of that point there is only scattered forest, and the range to the northern limit of the map is little more than a block of undulating highland, with a few noticeable peaks.

Medicine Bow Range has even a more diversified profile, owing to prominent peaks, of which the highest is Clark's Peak, 13,167 feet. The next most important, Medicine Peak, reaches 12,231 feet, and Elk Mountain, near the northern termination, 11,511 feet. Between these three high summits are deep "saddles" covered with coniferous forest.

Park Range, like Colorado Range, enters the map in a meridional direction, defined as a high, nearly level-topped ridge, presenting a sharp mural face to the east. Its highest peak, Mount Zirkel, is 12,126 feet.

In the angle included between Colorado and Medicine Bow ranges is a fine, level area, which under the name of Laramie Plains sweeps northward many miles beyond our northern boundary. Its general altitude is 7,000 feet. It is drained by Laramie River.

In the depression between Medicine Bow and Park ranges is the oval basin of North Park, another gently undulating plain. The waters of the North Platte, which drain northwestward through the Park, continue 100 miles farther in the same direction, occupying the bottom of a broad valley which partakes somewhat of the character of the grass plains, and yet shows the influence of the more desert conditions of the country to the west.

In general, this Rocky Mountain region is one of heavy ranges, well forest-covered in the elevated regions, and dominated by fine peaks which bear perpetual snow. Around and between the ranges are gently undulating or wholly level plains clad with upland grasses. The region embraces heights from 5,000 to 13,832 feet above sea-level. As a whole, it is a highland from which the great plains decline to the east, bearing on their surface the Mississippi rivers, and sloping gently off westward into the Green River Basin, the declivity in that direction carrying the tributaries of the Pacific River Colorado. There is no desert over the whole highland, but toward the west the vegetation begins to be mingled with the characteristic *Artemisia* of the arid basin of the Colorado. Over this area is a sky of liquid but cold blue, singularly vaporless for many weeks of the year. Clouds, when they come, gather around the mountain summits or drift over the plain at low elevations, sailing against the hill-slopes to break up and dissolve in the dry air. In the aspect of the country the most conspicuous features are, the pale tone of the plains—light golden green in summer, russet in autumn, and white in winter; the deep blue green of the forest-covered heights always in view, looming over a plain; and, perhaps most characteristic of all, the cool but dazzling brilliance of the sunlight.

Map II., a section of the Green River Basin, represents a very different set of conditions. A chain of east-and-west mountain elevations, made up of Uinta Range and its easterly dependencies, is traced across the general basin of Colorado River, dividing it into two distinct provinces. The region north of the Uinta represents an upper series of depressions, taking the name Green River Basin from the main river, whose various tributaries carry off the complicated drainage. South of the Uinta system lies the great plateau basin of the Colorado, one of the most extraordinary geographical features of the globe.

The area shown upon Map II. is a section across the southern portion of the Green River Basin, including the Uinta system, which bounds the Basin on the south, and the western highlands, in which Wahsatch Range forms the western boundary of the depression.

The general configuration of the Green River area is that of a rude triangle, having the Uinta system as the base, the Wahsatch as the western side, and the great Wind River Range, with the westward members of the Rocky Mountain chain, as its eastern boundary. From north to south the level extent is about 150 miles, with an equal distance along the southern margin of the basin. Viewed as a whole, it is a broad area of desert plains, slightly varied by local ridges and the mural escarpments of horizontal Tertiary tables. These lesser details are not of sufficient dimensions to change the prevailing character of the rolling plain. Along the middle is the north-and-south line of the greatest depression occupied by the winding bottom of Green River. The rise from the river to the extreme limits of the basin east and west is only about 1,000 feet. The lowest altitudes are 5,500 feet. The character of these plains differs widely from the grassy upland levels of the Rocky Mountain system. It is essentially a desert, bearing upon its surface even less vegetation than the Great Basin. The prevailing desert colors are yellowish-gray, red, and ashen hues, derived from the disintegrated material of the soft, fresh-water Tertiary strata whose comparatively level beds are the groundwork of the country.

Among the most interesting topographical and geological features of the desert levels are the so-called Bad Lands, which are essentially escarpments of the edges of Tertiary tables, varying from 200 to 600 or 700 feet in height, and carved by meteoric agencies into fantastic and architectural forms. They occur both east and west of Green River, in the basins of Bridger and Washakie, and are developed on a remarkable scale. Those of Washakie are found on the southern face of a long escarpment varying from 200 to 400 feet in height. The soft level marls and sands of the Eocene are sculptured into innumerable turrets, isolated towers, and citadel-like masses, which, when seen at a little distance, present the aspect of a great walled city, with outlying bastions and buttresses, and lines of level buildings along the crest of the wall. The Bad Lands are characterized by an almost entire absence of vegetation. A few *Artemisias* and other stunted desert shrubs grow at rare intervals upon the plains and upon the tops of the mesas, but the sculptured fronts are quite devoid of any plant life. The very soft gray, clay faces of the abrupt walls show the level edges of strata, which add to the architectural effect the appearance of a gigantic masonry.

Toward the east and the west, where the basin rises in the region of its bounding mountain masses, the Tertiary plains rise by a series of gently graded steps or soft inclined planes; so that, in approaching one of the mountain ranges from the deserts, the green, forest-covered uplands are seen rising in a sharply defined ridge above the level surfaces of the Tertiary table-lands.

Within the limits of Map II., the only one of the great bounding mountain ranges that encompass the Green River Basin is Uinta Range, which forms the southern barrier to the basin. It is an immense single mountain block, about 150 miles long, having an average elevation of 10,000 to 11,000 feet, and rising at its culminating point, Emmons's Peak, to 13,694 feet. It is defined, both on the north and on the south, by Tertiary table-lands, which abut unconformably against its steeply inclined strata. As a range it is unlike any other in America, being in fact a great, lofty plateau of nearly horizontal strata, which at the north and south edges are sharply broken and thrown into highly inclined positions. The physical and geological section, therefore, is of a great, flat anticlinal, having a plateau summit thirty or forty miles wide. The whole upper region, above 8,000 feet, is covered by a superb forest growth, chiefly made up of *Pinus flexilis*, *P. ponderosa*, *Abies Menziesii*, *A. Engelmanni*, *A. Douglasi*, *A. grandis*, and *A. amabilis*, together with *Juniperus Virginiana* on the lower levels. The upper plateau region is deeply carved, by the erosion of the glacial period, into a net-work of immense amphitheatres, opening downward into a series of great ice-worn cañons. The resultant topography is that of an intricate series of narrow ridges and a great procession of angular peaks, all carved out of horizontal beds. It is a type of mountain architecture only paralleled by the uplands of the Caucasus. Instead of the sharp, granitic needles, or contorted strata of most mountain-tops, the Uinta peaks show, all along their flanks and on the mural faces, the level, heavy bedding of the great quartzitic and sandstone formation of the range. If the Bad Lands of the plains are architectural, the high peaks of the Uinta are in a different way quite as markedly imitative of masonry. Considerable banks of perpetual snow are found upon the shadowed slopes through the whole heights, and the view from one of the upper summits is varied by open, green Alpine pastures, varied by innumerable lakes of transparent water which occupy the erosion-hollows of the old glacier-beds. Here and there the amphitheatre walls and the lake surfaces of the high mountain basins are brilliantly glacier-polished. There is rarely in one region a more marked physical contrast than may be observed between the stretches of clay desert and Bad Land,—in which all the topographical features are subdued by the low vertical scale, where vegetation is wanting, and the whole tone of the landscape is ashen,—and the vast, rolling, wave-like ridges of the Uinta foot-hills sweeping up with their deep green covering of coniferous woods, surmounted by the lofty pyramidal summits whose dark-red strata are traced in level lines across all the surfaces that are lifted above the plane of vegetation.

Passing westward, and rising to the highlands which bound the Green River Basin in that direction, a gradual change is noticed in the vegetation. The desert plants give way to grass, and the level Tertiary strata to inclined ridges of older rocks that crop sharply through them. The highland culminates in the wall of Wahsatch Range, which forms a sharp division between the Tertiary plateau regions and the deep depression of the Great Basin to the west. The high region embraced by the Wahsatch and the plateaus around Weber River is deeply cut by cañons of the drainage of Bear and Weber rivers, whose waters flow westward through gaps in the Wahsatch and are finally delivered into Great Salt Lake.

The area of Map III. embraces the Wahsatch and a considerable part of the highland immediately east of it, which, taken together, form a great elevated bounding-mass overlooking the low plains of Salt Lake. Wahsatch Range, forming the west margin of the highland, is a marked topographical feature, and for geological interest is certainly second to no single mountain block in the world. The range itself is really a great mountain wall, the result of a profound break in the earth's crust; the western half of the range has been carried down beneath the level of the present plains, leaving a lofty face presented to the west. This mural escarpment has been carved down by numerous deep cañons, leaving the summit of the wall in the form of a series of sharp, towering peaks. It is really the edge of the plateau system to the east, although its higher summits are lifted several thousand feet above the level of the horizontal Tertiary strata which sweep up toward it from the east. Erosion has also dug out a series of cañons parallel to the front of the range, along its eastern side, defining it somewhat from the Tertiary table-land. The heights of the range are sparsely wooded, considerable coniferous groves gather on the cooler mountain shoulders of the highest group south of Salt Lake, and a few inconsiderable bodies of forest are seen along the summits, as far as the northern extremity of the map. From the valley of Salt Lake, the highest peaks rise between 8,000 and 9,000 feet. The average elevation of the entire wall is not less than 4,000 feet above its base.

Far more than Uinta Range, the Wahsatch partakes of the desert character of the low country to the west. Along the west base of the range lie the plains of Salt Lake and the valley of the Jordan, whose level does not vary far from 4,200 feet above the sea. These lowlands stretch westward for nearly a hundred miles, forming a great connected series of deserts, all the lowest portion of which is occupied by Great Salt Lake.

Along the south and west sides of the lake, the streams of the Wahsatch furnish a natural irrigation which has been turned to good account by the Mormon settlers, producing a margin of green farms and meadow lands that slope nearly or quite to the margin of Salt Lake; but to the southwest, west, and north, the plains come to the brink of the lake as arid, level deserts, covered more or less by saline efflorescences, and unbroken save by bare mountain ridges of nearly naked rock, which rise like islands out of the glistening alkali desert. Along the base of the Wahsatch, around the various islands of the lake, and equally about the island-like mountain masses that rise from the neighboring deserts, are traced a series of horizontal lake-terraces, the highest of which are about a thousand feet above the present level of the lake. This wonderful and conspicuous feature arrests the attention of all travellers, and is readily seen to mark the ancient level of an extinct lake. In fact, the whole basin of Utah is, as will hereafter be described, simply the dry bed of a very great early Quaternary lake, to which G. K. Gilbert has given the name of Lake Bonneville.

Salt Lake itself, having no outlet, and receiving the influx of Jordan, Weber, and Bear rivers, besides several unimportant Wahsatch streams, rises and falls with every climatic fluctuation, and the density of its saline solution varies constantly, being inversely proportionate to the volume of water.

The area of Map IV. comprises the plateau of central Nevada, and lies between the basin of Utah, or the Great Salt Lake desert, on the one side, and a strikingly similar desert lowland on the west. It is a region whose valley plains vary from 5,000 to 7,000 feet in altitude, and whose most prominent topographical feature is the great series of approximately parallel mountain ranges which are traced from north to south over the whole plateau. The most lofty and considerable of these ranges, near the middle of the plateau, is Humboldt Range, a bold, rugged mass of Archæan and Palæozoic rocks, rising to elevations above 12,000 feet, and lifting fully 6,000 feet above its base. The mountain ranges of the plateau are, for the most part, extremely barren. They are characterized by the unusual predominance of naked rocks and the almost complete absence of forest. The longitudinal valleys that separate these isolated mountain ranges are generally covered with a strong growth of desert shrubs, and here and there along the lines of drainage, or about some small lake, are refreshed by limited passages of green vegetation. The climate is essentially that of a desert, subject to very great extremes of temperature, in spite of which vegetation flourishes remarkably in the presence of artificial irrigation. The long, winding valley of the Humboldt, which descends from the middle of the Nevada plateau westward to the depressed basin of Nevada, offers facilities for the irrigation of a considerable amount of land, and here the grain and grass crops are seen to be remarkably luxuriant. Wherever, in the whole plateau, a mountain stream has sufficient force to flow out into the valleys, cultivation is repaid by an extraordinarily rapid and fine growth of farm products. Throughout the high mountains, near the summits, especially in the neighborhood of any regions of crystalline rocks, there are abundant springs and fine mountain brooklets; but before they reach the lowlands they are drunk up by the parched earth or all evaporated

The area of Map V. shows a section of the basin of Nevada, where it descends by gentle steps from the central Nevada plateau. Here, as in the Great Salt Lake desert, are immense stretches of level plains of sand and alkaline clays, carrying the saline lakes which gather in the lowest basins. Here, again, is the bottom of a large extinct lake of the Quaternary period, contemporaneous and equally extensive with Lake Bonneville. This great extinct sheet of water we have named Lake Lahontan, in honor of the explorer. Although the area of the residual saline lakes is entirely inferior to that of Great Salt Lake, the detached sheets of brackish water which are fed by Humboldt, Truckee, and Carson rivers are of very great picturesque and scientific interest. The basin of Nevada is ribbed by several barren mountain ranges, treeless and naked, displaying the brilliant and bizarre colors of countless outbursts of Tertiary volcanic rocks. The aspect of this desert differs greatly from that of Salt Lake in the elements of bright color. The dull, ashen deserts, margined with terraces covered with desert vegetation are interrupted by the tumultuous piles of red, yellow, white, pink, green, black, and gray rocks which form the irregularly disposed mountain masses.

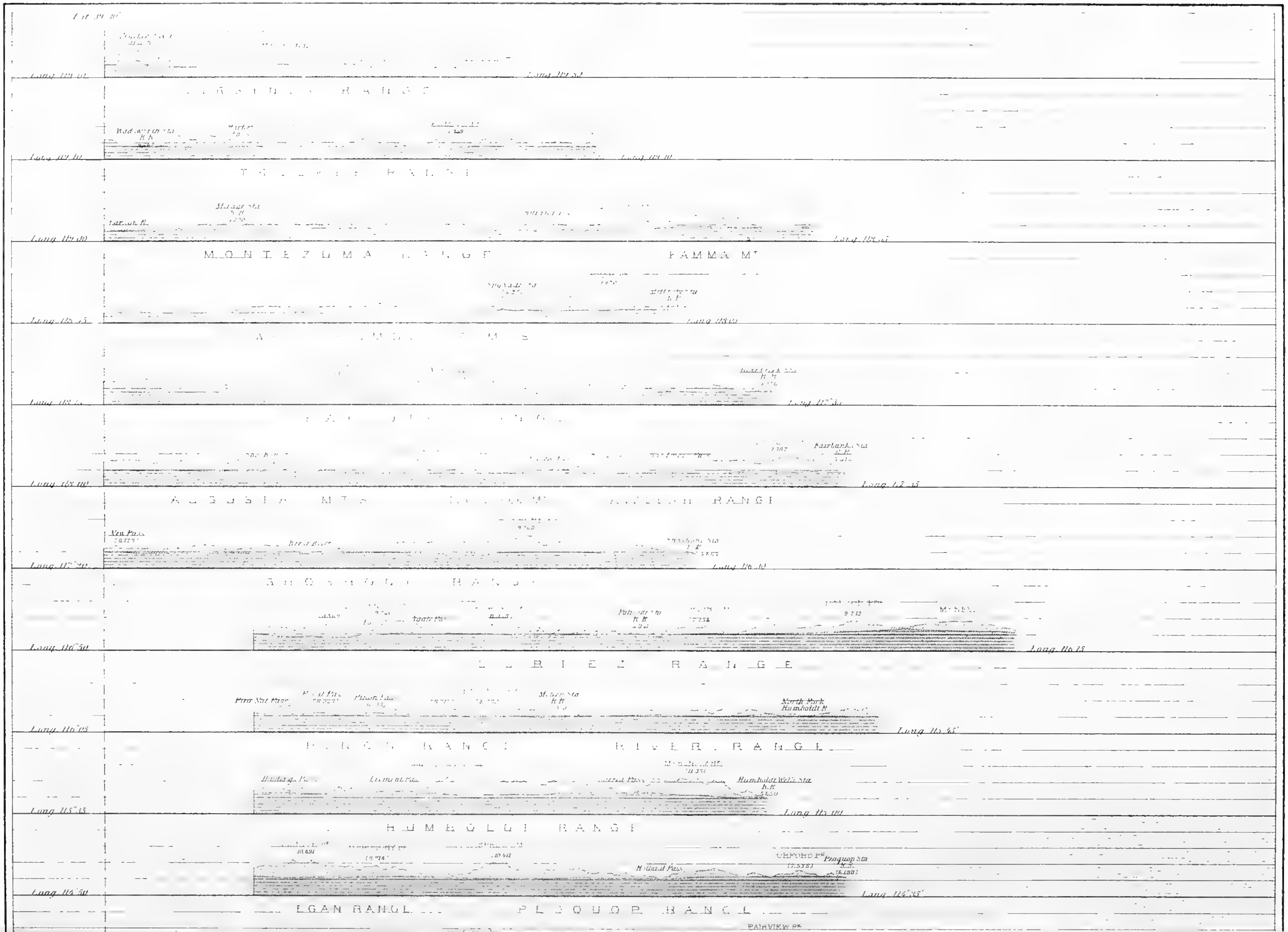
The area of this exploration ends with the 120th meridian, or the boundary of California. Immediately beyond is the high eastern face of Sierra Nevada Range, bounding the Great Basin in that direction. It will be seen that the Great Basin, as a whole, consists of two great mountain walls, their steep sides facing each other, about 500 miles apart. At the bases of each lie low, desert plains, into which flow considerable rivers, only to pour into shallow alkaline lakes, which have no outlet. Between the two basins is a central plateau, highest in the middle and declining in both directions, like the roof of a house, to the desert lowlands.

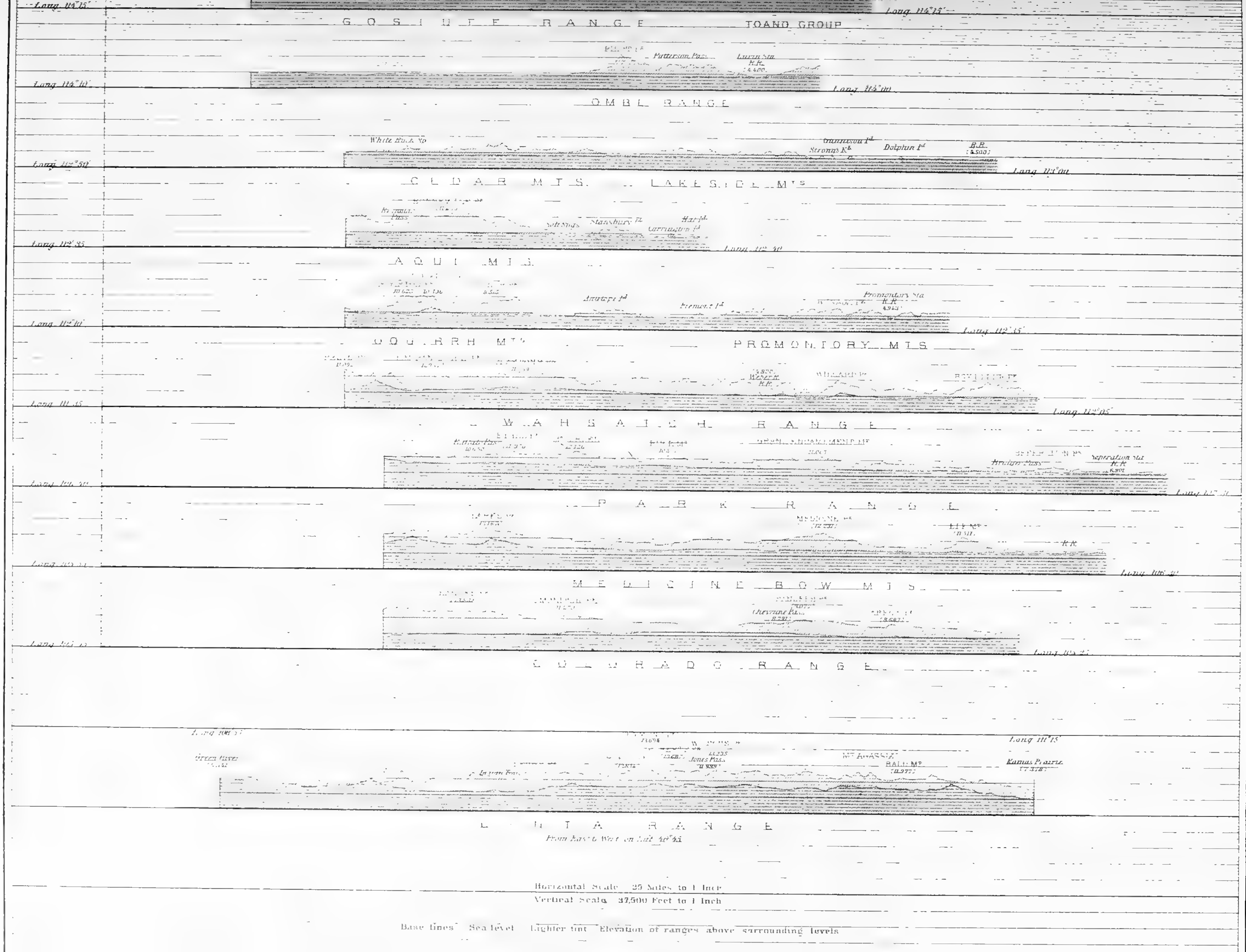
Appended to this chapter is a diagram of the longitudinal profiles of all the ranges shown on the Fortieth Parallel maps, from which the reader can obtain at a glance the relative altitude of summits and bases.

Thus, in the most general way, I have traced the leading geographic features of the field of work. In the descriptive volume, No. II. of this series, all the geographical details are treated with such fulness as to render further particulars unnecessary here.

DIAGRAM PLATE I

LONGITUDINAL PROFILES OF RANGES ON FORTIETH PARALLEL AREA




GOSIUTE RANGE
TOANO GROUP
Patterson Pass
Lucin Sta. R.R. 4,400
Long. 114°15'
Long. 114°10'
Long. 114°00'
OMBE RANGE
White Rock No.
Gunnison Id.
Strong's Kb.
Dolphin Id.
R.R. 4,500
Long. 112°50'
Long. 113°00'
CEDAR MTS.
LAKESIDE MTS
Stansbury Id.
Carrington Id.
Hat Id.
Long. 112°35'
Long. 112°30'
AQUI MTS.
Antelope Id.
Fremont Id.
Promontory Sta. R.R. 4,943
Long. 112°10'
Long. 112°15'
OQUIRRH MTS
PROMONTORY MTS
WILLARD Pk.
Long. 111°35'
Long. 112°05'
WAHSATCH RANGE
Bridger Pass
Separation Sta. R.R.
PARK RANGE
MEDICINE BOW MTS
Cheyenne Pass
COLORADO RANGE
Long. 111°15'
Jones Pass
Mt. AGASSIZ
BALD Mt.
Kamas Prairie
UINTA RANGE
From East to West on Lat. 40°45'
Horizontal Scale 25 Miles to 1 Inch
Vertical Scale 37,500 Feet to 1 Inch
Base lines: Sea level. Lighter tint: Elevation of ranges above surrounding levels

CHAPTER II.

ARCHÆAN.

SECTION I.—ARCHÆAN EXPOSURES.—COLORADO RANGE—MEDICINE BOW RANGE—PARK RANGE—UINTA RANGE—WAHSATCH RANGE—SALT LAKE ISLANDS AND PROMONTORY—RAFT RIVER MOUNTAINS—DESERT GRANITE RANGE—GOOSE CREEK HILLS—OMBE RANGE—GOSIUTE RANGE—PEOQUOP RANGE—WACHOE MOUNTAINS—KINSLEY DISTRICT—FRANKLIN BUTTES—HUMBOLDT RANGE—CORTEZ RANGE—WAH-WEAH MOUNTAINS—SEETOYA RANGE—TOYABE RANGE—SHOSHONE RANGE—AUGUSTA MOUNTAINS—FISH CREEK MOUNTAINS—HAVALLAH RANGE—PAH-UTE RANGE—WEST HUMBOLDT RANGE—MONTEZUMA RANGE—PAH-TSON MOUNTAINS—PAH-SUPP MOUNTAINS—GRANITE RANGE—TRUCKEE RANGE—LAKE RANGE—PEAVINE MOUNTAIN—CALIFORNIA BORDER.

SECTION II.—CORRELATION OF ARCHÆAN ROCKS.—METAMORPHIC ROCKS—GRANITES.

SECTION III.—GENESIS OF GRANITE AND CRYSTALLINE SCHISTS.

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SECTION I.

ARCHÆAN EXPOSURES.

Throughout the Cordilleran system in the western United States there is observed the usual distinct nonconformity between Archæan and subsequent formations. At intervals over the whole mountainous area west of the 100th meridian, masses of gneiss or crystalline schists, with their associated marbles, dolomites, and quartzites, and eruptive bodies of granites, porphyries, gabbros, &c., are found to underlie more recent strata. These Archæan bodies are made to outcrop in three modes:

First, the summits of Archæan mountain chains whose original elevation above the surrounding topography lifted them, if not over the level of subsequent ocean surfaces, at least above the plane of all subsequent deposition of detrital material. In spite of the powerfully accidented surfaces of Archæan areas, and of the distinct and lofty chains whose existence I shall in the following pages endeavor to demonstrate, these primitive summits are the rarest of Archæan outcrops. That they should exist at all is rather to be wondered at, when we remember that a series of later rocks extending from the earliest Cambrian to the present period, and amounting in extreme cases to probably not less than 40,000 feet, has been superposed upon them, and that the region as a whole has been repeatedly subjected to some of the severest mechanical disturbances of which we have any knowledge. Yet such uncovered primitive summits do exist.

Secondly, a type of occurrence due to local uplift or faulting, of less importance in a geographical sense than the last group. Archæan rocks are, indeed, here and there thrust through their younger covering; but these are limited blocks, the results of some severe local disturbance, crowded up to the surface or left upon the face of prominent fault walls, and although more frequent than original island summits, they constitute but a small part of the total exposure.

Thirdly, the predominating type of outcrop is a result of erosion either upon the axial areas of later elevated mountain chains, or along their flanks, or in those deep river cañons of which the system of the Colorado offers the strongest example.

At present we have no conclusive proof of metamorphism of Palæozoic strata to so extreme a point as to endanger a mistake between the resultant rocks and those of Archæan age.

So far, unless in California, the Palæozoic sedimentary series have only yielded limestones, quartzites, and slates, whose observed alteration-products do not in the least resemble Archæan forms. Perplexities like those in the Appalachian system are not yet brought to light; and the Archæan rocks themselves, as now known, present but a limited number of species. As a general result of this wide-spread petrological simplicity of areas, and the comparatively unaltered condition of Palæozoic formations, the relations between the two are exceedingly plain.

Details of the buried and partially exhumed Archæan continent must be accumulated very slowly; but there is still ample room in the remaining unexplored regions of the Cordilleras to find new features and perhaps to present many exceptions to the general laws which the writer is about to deduce from present data.

COLORADO RANGE.—That part of Colorado Range lying within the limits of the Fortieth Parallel Exploration, as shown upon Map I., is comprised between latitudes 40° 15′ and 42°. At the northern extremity of the map the range consists of low rolling hills, having a breadth from east to west of about fourteen miles. This width is maintained, with slight variations, down to the region of the railroad, where the range rapidly widens upon its west side, until at the southern line of the map it has reached 35 miles. North of the railroad, the physical characteristics are quite uniform, the range consisting of a moderately rolling upland, with but few prominent summits, the drainage divide being carried very near the western edge. Streams which for the most part flow eastward have carved out shallow, rocky valleys. The whole uplift is little more than a rolling plateau, of which the greatest elevations are in the neighborhood of 2,500 feet above the plains at the east base. The highest summits are a little north of Cheyenne Pass, on the west side of the range, about in the latitude of Laramie City, where the broad, undulating crest reaches the altitude of 9,077 feet. Northward, as far as the upper streams of the Chugwater, the average elevation of the plateau is between 7,500 and 8,000 feet, with peaks reaching 8,600 feet. Thence the plateau country falls off, but rises again in rugged, granite hills, just beyond the limit of the map. South of the railroad, where the pass-summit reaches 8,242 feet, the line of greatest elevation, as well as the watershed, deviates from the meridional line in a southwesterly direction, continuing about 45 miles to Clark's Peak, a high summit, which belongs more properly to Medicine Bow Range. This dividing summit is a broad, gneiss plateau of rolling, forest-covered surface, unrelieved by any high peaks, and unaccidented by any deep cañons. The eastward slope, drained by the various forks of the Cache la Poudre, partakes of this same undulating character as far southward as Monitor Peak, latitude 40° 45′. From this point a decided change in the configuration of the range takes place. Between the waters of the Cache la Poudre and the Big Thompson, a lofty, confused group of peaks, rising constantly to the south, occupies the whole broad area between the Great Plains and the North Park. Hague's Peak, latitude about 40° 30′, having an altitude of 13,832 feet, is the centre of a considerable area of drainage, from which flow northward the South or Main Fork of the Cache la Poudre, and southward and eastward, in deep cañons, the Big Thompson. From Hague's Peak, bold spurs slope to the south and southeast, down to the level of a picturesque basin in the mountains, known as Estes' Park. The country also slopes westward into a depressed region, and rises again at Mount Richthofen. South of Estes' Park, and south of the limit of the map, the summit culminates in Long's Peak.

In the northern part of the range, and indeed as far south as the head of the North Fork of the Cache la Poudre, 500 feet is the usual depth for cañons, and in consequence they offer but shallow exposures of Archæan rocks; while south of that point, corresponding to the greatly increased elevation of the peaks and general magnitude of the topographical features, the cañons also increase in depth, until between Monitor and Comanche peaks there is a depression of 3,500 feet, with an equal one on the upper waters of the Big Thompson, and the average drainage valleys of this region are not less than 800 feet between walls. Consequently it is in this part of the range that the best exposures of the Archæan rocks may be obtained.

Regarding the Archæan exposure as one, it will be observed, by referring to Map I., that owing to differences of upheaval, of original overlap, and of erosion, the relation between Archæan and later series varies from a contact at the lowest horizon of the Palæozoic up to the most recent of Pliocene conglomerates. For about 36 miles on the east side of the range, beginning at the southern limit of the map, the contact-line is between the red strata of the Triassic series and the Archæan. From that point, for about 40 miles northward, it is chiefly between Archæan and lower Palæozoic, which throughout this whole distance have a steep easterly dip; thence northward to the extremity of the range the Tertiaries sometimes overlie and entirely obscure the edges of the upturned Palæozoic and Mesozoic series, bringing the Pliocene conglomerates directly in contact with the Archæan. In this northern part, heavy promontory-like masses of the Archæan jut eastward from the main trend of the east base, throwing the upturned stratifeed rocks into sharp, complicated curves; the dip of these sedimentary beds varying from about 16° in the south, to a vertical position along the northern slopes, and in some rare instances a reverse dip. On the other hand, the western limit of the northern half of the Archæan exposure is observed to be in contact with the lower part of the Palæozoic series, which for the upper 55 or 60 miles of the map dip gently westward, with slight local disturbances. South of the railroad, at Harney's Station, the Triassic series have advanced eastward, and overlap, obscuring the Carboniferous, and the trend of the line of contact between the Trias and the Archæan is to the southeast, occupying a position on the flanks of the southwest divide before described.

From the region of Long's Peak Medicine Bow range deviates from the north-and-south trend of the Colorado body, in a direction about north 30° west, extending 100 miles to Elk Mountain, after which it plunges beneath the Cretaceous formations of the Platte Plain. For about 30 miles from Long's Peak it is essentially so united with Colorado Range as to be geographically inseparable; but from Clark's Peak to Elk Mountain it preserves a direction and a character quite its own. It varies in width from about 12 miles opposite the middle of North Park to 30 miles in the region of Marble Peak. Northwest of Clark's Peak a high rugged ridge is maintained for 8 or 10 miles, but it then falls off to a low rolling pass, utilized by the road from Laramie River to North Park. The leading characteristics of the country from Clark's Peak northward are not unlike those of the northern part of Colorado Range. In passing northward the range gradually rises to a culminating point about latitude 41° 20′, known as Medicine Peak, which reaches an altitude of 12,231 feet; but even here there is little of the rugged character usual at such heights, the cañons all exhibiting comparatively broad and gentle flanks. Still farther northwest, in the region of Cherokee Butte, the later sedimentary rocks on both sides of the peak approach within two miles of each other, and the mass of Elk Mountain, a semicircular Archæan body, is entirely surrounded by later stratified rocks. The broad angle between Colorado and Medicine Bow ranges is occupied by Laramie Plains, which consist chiefly of gently inclined Cretaceous strata, abutting nonconformably against the sloping foot-hills of the Archæan mass of Medicine Bow and overlying, along the eastern side of Laramie Plains, the Jurassic, Triassic, and Palæozoic, which dip at gentle angles from Colorado Range. The west side of Medicine Bow Range sinks into the valley of the North Platte, whose great expansion south of latitude 40° 50′ is known as North Park. With the exception of a fragment of Carboniferous and a few miles of Triassic, Jurassic, and lower Cretaceous strata, the whole western margin of Medicine Bow Range is covered with but slightly disturbed Tertiary beds. Near the southern extremity of the map the sedimentary margin of the range, as well as the edge of the Archæan core, is overflowed by a mass of rhyolite. It is therefore essentially an irregular, elongated body of Archæan rocks, having its flanks submerged beneath gently inclined Cretaceous and Tertiary series, with a few outcrops of the Palæozoic and the Mesozoic strata appearing at intervals under the more recent sedimentary series.

West of North Park, and west also of the valley of the North Platte, lies the northern extremity of a bold wall of Archæan rocks, which extends southward for many miles and forms the western boundary of the series of Colorado parks. To this elevation Mr. James T. Gardner has applied the name of Park Range. About 70 miles of its northern end are embraced within Map I. Topographically it may be considered as a north-and-south range as far north as Pelham Peak, from which point the main mass has a northwest trend approximately parallel to Medicine Bow Range. With the exception of a narrow strip of Triassic and Jurassic strata in the northern part of North Park, and a little Cretaceous against the middle of North Park, the whole eastern margin of this great Archæan body is formed by overlying Tertiaries of North Park and Platte Valley. On the west, however, it is chiefly margined by Cretaceous beds, which in one or two places give way to unimportant outcrops of the Jura, and in the region of Hentz's Peak to considerable outbursts of trachyte. Out of the rolling Cretaceous plains which lie west of the valley of the Platte, in the region of Fort Steele, is lifted a dome-like exposure of older rocks, consisting of the whole stratified series, from the middle Cretaceous down to the Silurian, with a long, narrow outcrop of Archæan core in the centre. Although it is remote from either of the main ranges and quite detached from all other Archæan masses, there seems little doubt that this exposure is really a part of the submerged continuation of Park Range, separated from the main mass in the same manner as Elk Mountain is separated from the body of Medicine Bow Range. The central ridge of Park Range varies from 11,000 to nearly 12,000 feet high, its loftiest peak reaching 11,976 feet. North of Mount Zirkel the summits are less elevated, and at the extreme northwestern end the greatest altitude is reached in Grand Encampment Mountain, 11,063 feet. These three Archæan bodies—Colorado, Medicine Bow, and Park ranges—should be considered as a single chain, whose varied folds and greatly diversified structure represent the top of a broad Archæan system; for the separating depressions—North Park, Platte Valley, and Laramie Plains—are really but the unimportant shallow basins in the Archæan topography in which the later material has been laid down.

That the granitoid and crystalline-schist cores of these ranges are truly Archæan in age, is indicated not alone by their characteristic petrological facies, but also by the fact that several actual contacts are exposed between the crystalline rocks and either the Potsdam sandstone or a series of conformably underlying slaty rocks presumably Cambrian. These exposed points of contact lie to the north and south of the area of Map I., but have been visited and studied by the writer, to make sure of their relation. With regard to the Archæan core of Colorado Range within our limits, independently of the relics of superposed strata, it may be said in general to consist of a broad central anticlinal, having along its axial summit a very flat arch, the dip increasing rapidly as the rocks recede from the axis. Considered in longitudinal elevation, the former crest which must have marked the summit of this Archæan fold was neither a horizontal line nor a simple inclined one, but possessed several prominent sags or saddle-like depressions; so that the ideal axis of the range, viewed longitudinally, was a deeply undulating line. Furthermore, from longitudinal pressure it was also deflected in plan into considerable horizontal sinuosities, and consequently the sides of the anticlinal were alternately thrown into broad convex folds (upon which the strata were brought into a state of strain), and recurved in broad reëntrant bays in which the beds were severely crumpled in secondary folds or confusedly dislocated. Added to these disturbances, was a third series of effects resulting from forces that tended to warp the anticlinal, which introduced an irregular shearing, and complicated not only the main fold but the secondaries. As a result, there is one broad central fold with numerous parallel subordinate axes, whose corrugations probably do not penetrate deeply into the strata.

It is assumed that all this dynamic action took place after the crystallization and consolidation of the rocks themselves—in other words, after they had attained their present phase of metamorphism and crystallization. Subsequently to this system of compound folding, and still before the Cambrian age, a wide-spread erosion took place, rounding off and smoothing down the general forms; but it was absolutely powerless to produce sharp cañons, or other abrupt features, and had the effect rather to reduce than to heighten the topographical effects of the folding and faulting.

Before proceeding to localize any observations within this Archæan body, it will be well to give a condensed sketch of the sequence of the rocks involved in this range. It would be difficult to find a corresponding area in any Archæan country of greater petrological simplicity and unity. The chief rocks are granites and granitoid gneisses, with a few subordinate mica-schists, and in the uppermost or gneissic members a few limited sheets of hornblendic gneiss, the main series being composed of quartz, orthoclase, and mica (chiefly biotite), with a slight admixture of triclinic feldspar. The lowest exposures in the heart of the anticlinal consist of massive pearly and reddish-gray granites, composed almost entirely of quartz and orthoclase, with a small but variable percentage of mica and a few minute crystals of triclinic feldspar, mostly oligoclase. These granites, exposed where erosion has deeply carved away the axial region of the range, or has cut profoundly into an especially disturbed portion of the flanks of the anticlinal, are remarkably uniform in appearance, and are only varied in the amount of crumbling and decomposition which they show, in the proportion of mica, or in the ordinary variability in the size of the quartz and feldspar particles. The latter, either simple or twinned orthoclases, vary from an inch and a half to a size invisible to the naked eye. This granite, which is a characteristic aplite, never presents a true bedding, but approaches a tabular formation as the mica increases. Followed over considerable distances, its texture and color are found to change constantly, and in the more crumbling parts, where the granite "malady" has acted most deeply, are found large spheroidal masses of more enduring texture, which have resisted disintegration, and remain either single or in confused heaps. Directly succeeding this formation, and with no apparent unconformity, is a series of more noticeably red granites, showing a distinct bedding which defines their structural relations to the anticlinal. This latter series is composed, like the former, of quartz and orthoclase, in this case usually quite red, and mica rather more abundant than in the earlier group, which shows a constant tendency toward a gneissic arrangement of particles. There are no signs of the granite malady; on the contrary, the rock breaks with a sharp angular fracture and shows no effects of rapid disintegration. As in the earlier reddish pearl-colored variety, mica is often wanting, and indeed this member throughout its lower beds may be called a true aplitic granite. At its upper limits only does mica become a prominent mineral, and here it passes by a series of irregular but gentle gradations into true mica-gneisses. Owing to the innumerable faults and complicated folding upon the flanks of the range in the region chiefly occupied by the mica-gneisses, it is impossible, without very extended labor, to arrive at their thickness. There cannot be less than 12,000 or 18,000 feet of them, and there may be twice that amount.

From the lowest exposures to the highest, there is a gradual passing from the structureless granitic form through simple broadly bedded granites—which even in the field, without close examination, appear to possess no parallel structure, but upon close following are seen to shade through a general tabular bedding—up to a zone occasionally interrupted by true gneiss beds, which become more and more frequent until the bedded granites are entirely excluded from the series, and thereafter for a great thickness there appear only dark mica-gneisses; these, however, present a very great variety. South of the line of the Fortieth Parallel work, in the region of Ralston and Coal creeks, the late Mr. Archibald R. Marvine, of the United States Geological and Geographical Survey of the Territories, brought to light an overlying group of quartzitic, ferruginous schists and quartzites, whose probable equivalents will be described in a later part of this chapter, in localities farther to the west. Equally with the gneisses and mica-schists, the above-described granites are held to be of metamorphic origin.

Of truly eruptive rocks, there are unmistakably intrusive granites, powerful outbursts of gabbro, and dikes of felsitic porphyry, the latter enclosing within the microfelsitic groundmass a varying proportion of crystals of quartz, triclinic feldspar, and lepidolite.

It was not within the scope or time of this exploration to cover ground with enough minuteness to map out boundaries of the various members of this series, and the above generalized sketch of the structure and sequence of rocks in our section of Colorado Range is only offered as a tentative explanation whose leading outlines may be relied on, but whose details will of necessity be found subject to slight modifications.

The central or oldest body of granite is well exposed on the railroad from a little east of Buford Station westward to about two miles down the west slope from Sherman. It is here characterized in color by a pinkish orthoclase, and is noticeable for its extreme disintegration. To the north and south of the road, rising above the gravelly plateau country, are seen several bold outcropping groups of the hard spheroidal nuclei before mentioned. Some of these forms reach 40 or 50 feet in diameter. Skull Rocks and Tower Rock are well known examples in the immediate vicinity of the railroad. The trend of this mass of granite is a little to the east of north, and so far as is now known it passes out upon the east side of the range. In other words, the axis of the modern range was slightly diagonal to the Archæan fold.

Passing southward from Sherman, the harder outcrops rise above the disintegrated material for a few miles, when there seems to be a gradual change in the character of the granite, which becomes harder, the feldspars larger and whiter, rather more mica makes its appearance, and the whole body seems to trend off to the southwest, probably parallel to the watershed. In the broader part of the range, at the head of the South or Main Fork of the Cache la Poudre, the sharply folded rocks of Medicine Bow

Range make contact with those of Colorado Range in a complex manner. The whole country, to the uppermost limits of the timber growth, is obscured by forests and glacial débris; but it seems quite clear that the older Colorado granite here passes under the Medicine Bow series and does not reappear at least as far south as Long's Peak. If it reappears at all in that latitude, it must be to the west and below the red granites of Estes' Park. The projecting mass in the northern part of the range, in the region of the Chugwater, which advances like a promontory into the eastern plains, seems to belong to the central and older mass of granite.

If this slight chain of observations is correct, and it seems to be essentially so, the axis of the Archæan fold is deflected westward from the meridian about 20°, from the northern limits of the map down nearly to Long's Peak, where it turns into the line of the meridian and continues southward on that strike for many miles. The second series, or the bedded granites, as before mentioned, possess several distinctive features in contrast with the older family, and many features in common. Like the older rocks, they are distinctly aplitic for the most part, but at their upper limit, by the rapid accession of mica, they pass into distinct mica-gneiss. They are more compact, more massive, show more bedding, and in weathering result in less distinctly rounded forms. The granite malady does not seem to have affected them, and there are none of those regions of fine granite gravel, with harder nuclei outcropping. In general, they are of deeper colors, dark reddish grays and reds prevailing. On the railroad they are well shown at Granite Cañon, and may be traced thence north and south, the northward extension disappearing beneath overlying Carboniferous limestones at the head of the North Fork of Crow Creek. Southward along the range they reappear at intervals, the red granite of Estes' Park and the lower Big Thompson offering well known examples. Besides biotite, these granites contain a second dark mica, which Zirkel identifies under the microscope as lepidomelane. A similar belt of granite bounds the west side of the older or central mass, appearing a few miles northwest of Sherman, and extending thence north along the west side of the range, disappearing in the region of the Sybille beneath westerly dipping beds of pearl-gray gneiss and black hornblendic schist. The same characteristics are observable in this mass of flanking granite as in its companion formation upon the east of the range, as typified at Granite Cañon. It is, perhaps, even more distinctly aplitic on the west than on the east. Passing southward, it crosses the railroad a few miles west of Sherman, and continues southwesterly for an unknown distance. West of the head of Fish Creek and Sportsman's Creek a similar red bedded granite is observed, which is probably the identical mass. About the head of the Main Fork of Cache la Poudre, overlying some obscure granite bodies, are found heavy masses of dark gneiss, which cannot be identified with any rocks lying to the north, but may be related either to the gneissic rocks of Medicine Bow Range, to be hereafter mentioned, or to those dark mica-gneisses which are developed farther south on Colorado Range, in the region of Clear Creek. A peculiar dark red granite is seen on the railroad at Dale Creek bridge, which in some respects is a little different from any other in the range. It is of an intensely deep-red color, and contains broad, tabular crystals of red orthoclase; gray quartz, which seems to occupy a very subordinate position in crystallization, being chiefly wedged into the interstices between the orthoclase crystals. Like the Granite Cañon rock, it contains lepidomelane. Under the microscope, Zirkel observed small triclinic feldspars. The bedded granite of Long's Peak is remarkable in a general way for the predominance of twinned crystals of orthoclase, very much elongated in the direction of the bedding. These strata have a dip of from 5° to 8° to the east. The directly underlying formation is of a distinctly bedded, coarse-grained, pinkish granite, much like that of Granite Cañon, and is probably of the same horizon. The gentle slope of these easterly dipping beds carries the formation down along the waters of the Saint Vrain's and Big Thompson nearly into contact with the overlying Trias. Near the modern rocks a gray granite, apparently the same as at Long's Peak, reappears. Southward over the Long's Peak rock are piled up the enormous series of gneisses, best shown on Clear Creek. Exposures on the upper Sybille, and those seen along the eastern base of the mountains in the region of Signal Peak, seem to be the representatives of the lowest members of this vast granitic series, the greater breadth and altitude of the range to the south retaining all the members of the fold, while to the north, owing to the gradual depression of the range and the constant encroachment of overlapping sedimentary rocks upon both sides, only the lower or core members are exposed.

Aside from the above-mentioned rocks which constitute the members of this great fold, there is a most interesting feature in the occurrence of an immense mass of ilmenite, near the east base of the range, just north of Chugwater Creek, about a mile and a half above where it flows out upon the plains. It has an irregular oval plan, with a sharp definition from the enclosing granite, and rises in a bold boss about 600 feet above the bed of the stream. Masses of granite invade the ilmenite for a short distance, and in their turn protuberances of iron are nearly enveloped in surrounding granite. The main mass is perhaps a quarter of a mile long, having a trend a little west of north, terminating quite abruptly to the north, but extending eastward, and followed by a train of irregular subordinate outcrops for about two miles toward Pebble Creek. In the vicinity of Horse Creek are smaller deposits, described by Mr. Hague in Volume II. Some normal magnetite and small amounts of hematite accompany the main body of ilmenite. In all these exposures titanic acid enters as a varying but usually very important component, ranging from 20 to 50 per cent.

Graphite in impure thin beds, mixed with a bronzy decomposed iron pyrites, is found in the later granitoid rocks of the west side of Laramie Hills, and elsewhere through Colorado Range, in small, scattered occurrences.

In eruptive rocks our section of the Archæan range under consideration is decidedly poor. The most important is the group of gabbros, found to the east of Iron (ilmenite) Mountain, and on Chugwater and Horse creeks, all within a narrow geographical area, where they come to the surface through granites and form low rough domes. It is essentially a bluish-gray labradorite, with a little finely disseminated hypersthene. A yellowish-white mica and some fine rounded grains of magnetite and ilmenite are also included with the mass.

This association of graphite, ilmenite, and gabbro in the granitoid rocks of Laramie Hills, first observed in the West by Arnold Hague, will be commented on later in this chapter.

Besides these there are distinctly intrusive granites and felsitic porphyries which occur along the southern line of our work and still farther south in the range.

The porphyries are a microfelsitic groundmass composed of orthoclase (as shown by analysis), quartz, and a little triclinic feldspar. In this are enclosed rounded grains and rudely dihexahedral crystals of quartz, both covered with an opaque coating of fine feldspathic material, crystals of feldspar (orthoclase as far as determined), and more rarely a white mica, doubtless muscovite.

Porphyry dikes appear usually not far from the middle or axial part of the range, and are found to trend either a little west of north or at right angles to that strike.

The intrusive granites are for the most part combinations of quartz, orthoclase in slender tables and twinned crystals, and, curiously enough, muscovite instead of biotite. Triclinic feldspars, though uncommon, are occasionally present.

Medicine Bow Range.—Viewed as a whole, the Medicine Bow offers more complexity, both of material and structure, than Colorado Range Although impossible to an exploration like this, a minute study of the superposition and flexures of its crystalline beds would furnish most interesting special results. While the data gathered by Mr. Hague seem to point with satisfactory agreement to a general theory of the range, on the other hand its exact relation to the contiguous body of the Colorado is not discovered, nor is it by any means certain that the whole series involved in the Medicine Bow is conformable throughout.

The materials of the range are composed of gneisses; hornblendic, often dioritic, schists; variable schists made of quartz, mica, and both systems of feldspar, in changing proportions; quartzitic schists; argillites; massively bedded quartzites and limestones which pass into quartzite by the giving out of calcareous matter; and lastly subordinate granites and eruptive diorites.

All the observed positions south of a line joining the mouth of French Creek and Sheep Mountain, with obviously local or superficial exceptions, indicate a northwest strike and southwest dip. North of this line two distinct axes, approximately parallel and trending about north 20° to 25°

east, are developed across the range; an anticlinal lying a little west of Medicine Peak, and the companion synclinal occupying a depression between Medicine and Mill peaks. Rocks having a northwesterly dip rise from the Platte valley up to the heights on Upper Brush Creek, pass over the anticlinal, and dip down and east through Medicine Peak, rising again with a westerly dip at Mill Peak ridge. These two transverse axes embrace within their folds the iridescent schists, quartzitic schists, argillites, quartzites, and limestones. Their relation to the older and underlying mica gneisses and various hornblendic schists and dioritic gneisses is apparently that of conformity—at least no nonconformity has been observed; forests, débris, and local folds conspiring to mask a relation obscure enough under favorable exposures. Whether conformable or not, there are here two series of rocks. The lowest, which have an enormous development, are the gneisses and hornblendic beds, all characterized by the important presence and the frequent predominance of plagioclase over orthoclase, by the general (though not unexceptional) absence of red color among the feldspars, the occurrence of silvery white micas in some gneisses, and frequency of beds with the composition of diorite. Above these the schists, quartzites, conglomerates, and limestones of Medicine Peak group form the second series. Neither of these seems to correspond, either mineralogically or in broader characteristics, with any portion of Colorado Range within our field. There is, indeed, an apparent resemblance between the Medicine Peak series and that described by Archibald R. Marvine* at Ralston Creek, but it disappears on close comparison The probable mutual relations of these members of the Archæan is reserved for a later section of this chapter.

In the region where this elevated mountain block comes in contact with Colorado Range proper, particularly where a high ridge is developed, culminating in Clark's Peak and Mount Richthofen, the geological relations of the two ranges are difficult to make out. Forests and glacial débris combine to offer serious difficulties to a more lengthened study than our exploration permitted.

Topographically, the most noticeable feature is the defined line of ridge

* United States Geological and Geographical Survey of Colorado (1873), p. 139.

and peaks which forms the extreme western boundary of the high mountain area, sharply descending beneath volcanic bodies and upturned stratified formations along the east boundary of North Park. The singular trough-like depression which separates this southernmost group of Medicine Bow Range from the chain of central elevations of the Colorado body is occupied by Cache la Poudre and Laramie rivers, which together define a line of depression parallel with the Clark's Peak ridge. East of this lies the anticlinal of Colorado Range already described. The Clark's Peak wave, as far as can be seen, consists of another and probably a later series of rocks. Structurally, these two series bear a relation to each other not unravelled by actual observation, but inferred, from their relative position, to be a nonconformity.

Along the eastern edge of North Park sedimentary border, with a universally obvious unconformable underlie, is seen a series composed for the most part of steeply dipping gneisses and gneissoid beds, which constitute the main west slope of the Clark's Peak ridge. Unlike the series of the Colorado, they contain, besides quartz, orthoclase, and biotite gneisses, a predominance of sheets in which hornblende and plagioclase are prominent if not the chief ingredients. Near the base of the ridge, a few miles north of Clark's Peak, are conspicuous beds made up of pale pinkish feldspar and bright green hornblende. Besides the predominating orthoclase, distinct small crystals of colorless plagioclase are present. With the exception of this limited belt, the feldspars, of whichever system, contained in these gneisses are usually colorless. A typical gneiss of the region occurs directly west of Clark's Peak, consisting of biotite, hornblende, quartz, orthoclase, and plagioclase, the latter two nearly white, and a little microscopic apatite. Near the base of the peak occurs a granite not far removed in composition from the orthoclase and quartz aplite of Laramie Hills.

Clark's Peak itself and the ridge in its neighborhood, as well as a broad area to the north, offer a variety of granites. That of Clark's Peak is quite devoid of any gneissic parallelism of minerals, and is of such uniformity and massive habit as indicate an eruptive origin. It is composed of limpid white quartz, orthoclase, plagioclase, biotite, and apatite. The mineralogical equivalency between this rock and the gneiss lying to the west and down the slope will be noticed, and will naturally suggest that the summit rock is only a structureless equivalent of the gneiss, representing a further condition of metamorphism. Hornblende in the gneiss, however, offers a permanent difference.

On the summit northwest of Clark's Peak is observed a dark gray granite, composed of colorless quartz; feldspar, both orthoclase and plagioclase; and a dark mica present in large proportion, and arranged in parallel layers.

Three or four miles south of the peak, in a coarse-grained granite which occurs near the foot-hills, carrying large crystals of vitreous oligoclase, Zirkel detected the presence of zircon in red grains very like those occurring in the zircon syenite of Norway. It is in this southern portion of the range only that true granites are observed.

North of this region the defined ridge breaks down into a broad rolling plateau heavily covered with forest and soil, over which little of the orographic structure can be learned. Observations along the Laramie, as well as on the edges of the park, indicate a region of varied gneisses, in which dioritic beds are prominent. While several confused folds seem probable, a prevailing dip to the southwest is seen. From the heights above the northeast edge of North Park a specimen was obtained representing a not unfrequent type, composed of almost blackish-green hornblende, bluish-white, brilliant plagioclase, in slender prisms, often a quarter of an inch long, and a little limpid quartz and biotite, the latter in very subordinate quantity. The northwest strike of these westerly dipping gneisses is often varied by sharp zigzags. Along the northeast region of the park, especially in the foot-hills, gneisses and schists, dipping rather steeply to the west, have their strike arranged *en échelon*, with the long member trained in a northwest direction, and short, abrupt cross-strikes more nearly in an east-and-west course.

Exposures on the east side of the Platte Cañon indicate a general easterly dip, at least toward the lower reaches of the river.

Between the upper cañon and Laramie River but little geology could be obtained; rounded, forest-covered knolls and ridges, showing but few outcrops, alternate with peculiar treeless, grassy glades, which seem to open pathways through the timber quite independently of drainage-lines. Along the Laramie valley, however, and northward, near the eastern limit of the Archæan body, as far as Sheep Mountain, dips were observed which indicate a general westerly slope for the gneisses.

Where the North Platte leaves its Archæan cañon to debouch upon the broad Tertiary valley, two prominent hills rise upon the left bank: Bennett's Peak, opposite the confluence of Brush Creek with the Platte, and River Butte, five miles below; the former about 600, the latter 900 feet above the river plain. Both are made up of steep, westerly dipping beds of dioritic gneiss.

Upon the hills east of the river, between French and Brush creeks, are sandy mica gneisses striking north 45° to 55° west, with a southwesterly dip, having a parallel arrangement of minerals and a banded appearance. Hornblende does not enter into the composition; transparent, colorless quartz, mica, orthoclase, and plagioclase complete the list of constituents, and make an association rather unusual in this region; plagioclase, when present in important percentage, usually implying a considerable amount of hornblende. In the oldest granite of the Laramie Hills there is indeed a little plagioclase without hornblende, but it is often discoverable by the microscope only, and never plays a rôle of importance.

Intercalated in the last-named group is a narrow sheet of dark, dioritic material, probably of a common origin with the other crystalline schists, but presenting some of the characteristics of an intrusion. It is a combination of hornblende, plagioclase, and a very little colorless orthoclase. It presents some interest under the microscope, for which the reader is referred to Professor Zirkel's Volume VI. of this series.

North from Brush Creek, mica gneisses with included sheets of hornblendic schist, usually of dioritic composition, and occasional beds of vitreous quartzite, continue for about fifteen miles. They show many discordant dips, but incline prevailingly to the north. This radical change of position from the rocks farther south and east is due to the development of a strong anticlinal, trending along the range in a northwest direction, roughly perpendicular to the northeast axis of the Laramie Hills.

Gneiss beds, similar to those described on Brush Creek, occur on the crest of Deer Mountain near the head of Cedar Creek. They are rather poor in mica, but are characterized by unusually white clear feldspars and small red garnets. Farther down on the peak are hornblende-plagioclase schists with a variable percentage of orthoclase, showing also under the microscope chlorite, titanite, zircon, and apatite.

Hornblende gneisses, which vary greatly in the proportion of quartz, and have a general strike north 40° west, with a southwesterly dip, are observed north of Deer Mountain, making a local exception of the northerly dip observed in this section of the range. A change takes place north of Cedar Mountain, light mica gneisses taking the place of the hornblendic variety which has prevailed along the western margin of the range.

An interesting gneiss occurs at Cherokee Butte, an eminence on the narrow Archæan isthmus connecting Elk Mountain with the main range. It is hard rock, composed of gray quartz, white and flesh-colored feldspar, both orthoclase and plagioclase, and a little scattered, thin, flaky mica. Zirkel calls attention to the condition of the quartz, which is made up of small worn and rounded fragments. Directly west of this body is a gray gneiss carrying a little hornblende and microscopic titanite.

Nearly half of Elk Mountain, whose detached mass forms the northern extremity of the range, is of Palæozoic and Mesozoic rocks. Archæan gneissic beds form the summit and southern portions, however, and unite it with the isthmus of Cherokee Butte. These beds strike from north 45° to north 70° east, and dip to the north and west at high angles, often approaching the vertical. Quartz and monoclinic and triclinic feldspars, intimately mingled, are the main constituents, but the gneissic structure is given by a chloritic mineral arranged in fine-grained bands. Where the materials are all very fine, as at the base of the series, the rock wears the aspect of an impure quartzite.

Thus far the southern portion of the range and the south and west flanks of its main mass have been briefly described. With the exception of the granites of the Clark's Peak region, these formations have been seen to consist of a varied body of gneisses, in all of which, with slight exceptions, both systems of feldspar and quartz have been present, with either hornblende or mica—rarely with both.

Dioritic gneisses, closely approaching the minuter characteristics of the eruptive diorites, are intercalated conformably in the general series, while in exceptional localities there are masses of a rock of dioritic nature, which are probably true dikes.

At Medicine Peak, which reaches 12,231 feet in altitude and is the culminating mountain of the range, appears a new geological feature. The peak itself, and the ridge from which it rises, are formed of a heavy body of remarkably white quartzites, approximately 2,000 feet in thickness, striking north 20° to 25° east, and dipping east at a high angle. The zone is irregularly stained a pale reddish hue by thin seams of oxydized iron minerals. Toward the bottom of the series is a zone of pale bluish quartzite, rather more coarsely grained than the overlying members, and intercalated with sheets of conglomerate holding smooth quartz pebbles in a fine siliceous paste. Cyanite in narrow veins, associated with colorless quartz, is characteristic of the quartzite belt. A more prominent and conspicuous feature is the series of diorite dikes cutting the quartzites at nearly right angles with the strike of the strata. The material of these unmistakably eruptive diorites is nearly identical with the dioritic schists.

South of Medicine Peak, on the head waters of French Creek, conformably underlying the quartzite series, is a body of argillaceous slates, which have a fine lamination but rather imperfectly developed cleavage in the direction of the strata-planes. A great deal of excessively fine mica is visible under the loupe. A thickness of about 400 feet is assigned to this group of rocks, from the plane of contact with the quartzites down; whence, becoming rather impure and more quartzitic, they pass abruptly into a series of harder quartzitic argillites enclosing beds of ferruginous, siliceous schists These in turn are underlaid by a more highly crystalline zone of schist, in which the original lamination appears to be for the most part obliterated. Exposed faces are seen to be dotted over with concretionary bunches or knots of fibrous hornblende, much of which is decomposed and coated with a bronze-green, red, and purple material of a peculiar and often brilliant iridescence.

Farther down French Creek are silver-white, muscovite, mica slates and quartzose slates, dipping 70° to 75° east and striking north 15° east. Over them appear heavy masses of quartzite, which are doubtless the southward continuation of the Medicine Peak beds. Still lower in the cañon appear the same heavy beds of light mica gneiss characteristic of the south flanks of the range, coming in under the schist zone with apparent conformity.

About ten miles east of Medicine Peak, and separated from it by a rolling timbered upland country, is a strong north-and-south ridge culminating in Mill Peak, which reaches an altitude of 10,596 feet. Here a series of quartzites, conglomerates, and schists, doubtless equivalent to Medicine Peak ridge, reappear, but with a reversed position, dipping west and defining the east side of a broad synclinal. The quartzites are more stained and infiltrated with iron oxyd than at Medicine Peak; the conglomerates also are more important and are somewhat different, being a red, and including large angular cherts and ferruginous quartzite pebbles. The actual summit of Mill Peak is of a light gray and white siliceous limestone, resembling a quartzite; indeed, the two rocks, by a varying of siliceous and lime particles deposited together, are made to shade through the intermediate gradations and illustrate a complete but gradual change of sediment.

Along the northern foot-hills of the range, and for considerable distances up Cooper and Rock creeks, are exposed dark schists and mica gneisses, the direct equivalents of those along the southern foot-hills. South of Little Laramie River, about Bellevue Peak, similar hornblendic and micaceous crystalline rocks are found, and among other forms white mica gneisses. Amongst them is one noticeable white or silver-gray gneiss, whose constituents are colorless, clear quartz; pearl-colored feldspar, in general very lustrous, but sometimes altered; a little brown mica, both generally disseminated and segregated in bunches and nodules; and minute grains of red garnet. On the northern and eastern slopes of this region occur banded and irregularly bedded rocks, made up of variable percentages of hornblende and feldspar.

Between the above-mentioned leading formations and those noted in the description of Colorado Range, a few common characteristics will have been observed, but noticeable differences prevail. The two ranges are singularly unlike. In the essential construction of the rocks are observed quartz, orthoclase, plagioclase, hornblende, mica, chlorite, and calcite. This difference is observable also in the general list of accessory products. Small quartz veins traversing the gneisses and hornblendic schists are often observed, particularly in the neighborhood of Brush and Cottonwood creeks, on the western foot-hills. They carry gold in small quantities, magnetite, pyrite, and massive epidote and cyanite. Red and reddish-brown grains of garnet are found, always associated with the light-colored gneisses, as at French Creek and Deer Mountain. Zircon, apatite, and titanite were detected by Zirkel under the microscope.

Park Range.—As an independent body, Park Range has its northern termination within the area of this work. Its eastern flank is sharply bounded by North Park and the North Platte valley; on the west it connects with the elevation of the Elk Head group and an irregular, hilly country about the upper Yampa River. As a range, it ceases a few miles northwest of Grand Encampment Peak. From our southern boundary, as far north as Pelham Peak, it is a distinct meridional ridge, with a sharp slope to North Park, and a broad summit, which was originally a plateau made up of strata gently dipping to the west, but now a mere net-work of plateau ridges, separated from one another by deep glacial cañons. Near Pelham Peak the range is abruptly bent round into a northwest trend, which it preserves for about thirty miles, and then plunges down under the Tertiary strata of the lowlands. The Archæan body which forms the most important geological feature of the range is bounded on the east by the Tertiaries of North Park and the Platte valley, with the narrow exceptions of a body of basalt outpoured in the region of Rabbit Ears Peak, short stretches of Cretaceous east of Ethel Peak and at the northern entrance to the Park, and a strip of Triassic sandstone exposed against the granitic tongue east of Arapahoe Creek. On the west the upturned Jurassic and Cretaceous rest along the base of the range and border the Archæan series. In the region of Hentz Peak, volcanic outbursts also edge the Archæan mass. The crystalline body itself is a single anticlinal fold, of which that portion of the range south of Pelham Peak is the westerly dipping half. The easterly dipping half shows only in the extreme eastern foot-hills and in the projecting spur which lies between Big Creek and North Park. The main body, therefore, is the half of an anticlinal, the other half having suffered a deep downthrow, which has left only traces of the easterly dip.

The western-dipping beds present their eroded edges along the steep eastern front of the range, and are seen to incline very gently, gradually rounding to a steep inclination along the western foot-hills. North of Pelham Peak the fold has been flexed round into a northwest strike, giving the topographical trend as well as the direction of strike. In this northern portion the complete anticlinal is present. In the angle of flexure between the north and northwest trending parts there is much local crumpling and the development of a secondary lateral axis which opens an inclined synclinal from the summit of the range near Pelham Peak in a southwest direction. The meridional part of the main axis indicates a horizontal profile for the original fold, but north of Grand Encampment Peak the axis dips to the northwest, and, aside from the bevelling off by erosion, actually inclines downward and under the overlying Tertiaries.

The series of Archæan rocks involved in this fold are bedded granitic gneisses of uniform constitution and material, but widely varied arrangement of internal structure, hornblendic schists, and dioritoid rocks, besides limited quartzites. Of Archæan eruptive rocks there are none, unless some obscure dioritic bodies are intrusive,—and all the evidence points the other way.

A granite occurring in the southern part of the range finds a characteristic expression on the summit of Ethel Peak. It is a rather coarse-grained mixture of grayish quartz, red orthoclase, sparsely but rather evenly disseminated biotite, and rare triclinic feldspars, the biotite often adhering strongly to the orthoclase faces. While the rock as a whole shows a broad, distinct bedding, there is no parallelism in the arrangement of individual minerals. On exposure, it crumbles rather readily and breaks with a rough, irregular fracture. It distinctly resembles some of the bedded reddish granites of Colorado Range.

Crawley Butte and the long, tongue-like ridge which juts southward from the range bounding the east side of Arapahoe Creek valley, the two being geologically one body, are for the most part composed of a similar red orthoclastic granite. Another tongue-like projecting ridge advances in a southeast direction from Park Range, forming the northwest boundary of North Park for a few miles. Here a variety of granites occur; among others, a coarse pegmatite consisting of pellucid or milky-white quartz, large groups of confused, imperfectly crystallized, red orthoclase, masses of biotite, and muscovite, the latter mica predominating and occurring in much larger sheets. Great variation is observed in the quantitative proportion and arrangement of the minerals. There are segregations of considerable size, altogether made up of one or the other mineral. One variety is essentially a feldspar rock, with the few grains and crystals of quartz or mica present only as segregated groups, while disseminated through the red orthoclase are irregular veinlets and waving lines of yellowish-green epidote, making a rock equivalent to that described by Frank H. Bradley* from Unaka Range, Blue Ridge chain, between North Carolina and Tennessee.

Between Bruin Peak and the Tertiary valley the granites assume a more regular type, composed essentially of quartz and orthoclase, with beds in which either mica or hornblende is present, rarely both. Gneisses are exposed in the same neighborhood. These also are variable as regards the presence and predominance of mica and hornblende, but the latter perhaps exceeds the former in importance. One special rock was found here, composed for the most part of brilliant black or dark-greenish hornblende, although carrying more or less white plagioclase and a very little quartz. It is distinctly bedded, and dips at a high angle a little to the north of east. Hornblende also appears in considerable prominence in the orthoclase-mica gneisses. A final variety of gneiss is almost a mica schist, in which feldspar and quartz are minor constituents, the micas, both biotite and muscovite, arranging their flakes in strictly parallel planes. Zirkel finds especial interest in the microscopic examination of this species, as the reader will see by reference to Volume VI.

Upon the walls of the glacial cañons around Mount Zirkel, as also upon the peak itself, there is a similar association of mica gneisses and hornblendic schists. A distinct bedding may be traced along the cañon flanks, gently dipping to the west. By the predominance of one or the other mineral, a black, white, or gray color is given to the individual sheet. Hornblende, combined with orthoclase, plagioclase, and very subordinate quartz, con-

*American Journal of Science and Arts, May, 1874; page 519.

stitutes the leading type of bed, and the hornblende prisms commonly lie with the bedding-planes. Mica gneisses are present, however, carrying always a little hornblende and triclinic feldspar. Feldspar bands, faintly striped with hornblende, zones of pure feldspar, segregations of amphibolite, and sheets of hornblende striped with a little triclinic feldspar and quartz, alternate in every variety of arrangement.

The trail up Grand Encampment Creek passes many excellent exposures of the Archæan series. Near the mouth of the cañon is a granitoid gneiss of orthoclase and quartz, with very imperfectly developed bedding. Biotite, instead of the ordinary parallel or banded arrangement, is grouped in large lenticular aggregations, whose longer axes are parallel with the general structure of the rock. Passing into a crude, coarse granitic form, this same rock distinguishes itself by the development of other segregations of quartz or feldspar not unlike those of Mount Zirkel. Overlying this series is a dark, hornblendic rock, in which white plagioclase crystals are scattered at irregular angles, as in a porphyry.

Farther up the creek is a granite nearly related to the red orthoclase granite of Colorado Range and those about Ethel Peak of the range now under consideration. In this coarse and variable granite are frequently seen what are usually reserved for the microscope to reveal, namely, fissures in the feldspars filled with quartz, in which are embedded other feldspars as well as quite perfectly developed micas. Flesh-colored orthoclases in these coarse granites often attain a size of four or five inches. The other extreme of texture is also sometimes shown in this rock, when it passes into an excessively fine-grained aplitic form, with little or no mica. When present, the mica is apt to show an obscure parallelism. Zirkel demonstrates that the red color of these feldspars is due to oxyd of iron infiltrations in the minute fissures of the crystals, and also that the mica is accompanied and sometimes replaced by a strongly dichroitic chloritic mineral. As in the kindred granite of the Colorado, the quartzes are poor in fluid inclusions.

On the slopes of the high peak southeast from Encampment Meadow is a series of hornblendic rocks and gneisses presenting the same varied petrographical habit as at Mount Zirkel. In one of the mica-bearing zones of true gneiss are observed red garnets; and so close is the resemblance between the garnetiferous gneisses in all three of these Rocky Mountain ranges as to suggest that they may not improbably represent a common horizon. On the peak are alternating beds in which first plagioclase and then hornblende predominates, with quartz containing in some instances liquid carbonic acid. Upon the summit of Grand Encampment Peak is also a dark-green amphibolite, quite free from other minerals, but carrying an interstratified bed of white, micaceous quartzite—an association of rocks to be hereafter noticed as recurring in Humboldt Range.

Gneissic beds having the same variations as have been already described form the whole northwestern part of the range, dipping from the axis northeast and southwest. At the extreme north end of the range, where the northerly dipping Archæan beds plunge down under horizontal Tertiaries near the mouth of Jack's Creek Cañon, interbedded in a dark, hornblendic schist, is a bed of pure, dazzlingly white quartz, 50 feet thick, of singular purity, vitreous and only varied by wandering vein-like clouds, which under a high magnifying power were resolved by Zirkel into regions immensely rich in fluid inclusions, partly of water and partly of liquid carbonic acid. There is also a hornblende, orthoclase-plagioclase rock, with but little quartz; orthoclase, the predominating feldspar, giving it the general composition of a syenite, which it would undoubtedly be considered but for the certainty of its belonging to the strictly metamorphic series. While planes of bedding and even the ordinary gneissic parallelism of minerals are sometimes wanting, there are seen such infinite variations in the internal arrangement of the crystalline series in these ranges that only the most positive evidence of intrusive origin should be accepted. This syenitic type, a most unusual one, is confidently referred to the gneisses, all of which are here metamorphic products.

Not far from the syenitic body of Jack's Creek are beds which are a crypto-crystalline mixture of dark-green hornblende, with white plagioclase, probably oligoclase, often in long, slender crystals. This again is a rock without appearance of stratification or parallel arrangement of minerals, to all intents a diorite, yet believed to be a member of the series of dioritic gneisses. Dense forests obscure the western flanks of the range; but enough is known to say that the prevailing rocks are hornblendic gneisses dipping rather steeply to the west and southwest.

Under the volcanic rocks at the head of Snake River is a red gneissoid rock made up of quartz, orthoclase, plagioclase, and minute flakes of mica, without general bedding or the true schistose structure, yet possessing a banded arrangement of the quartz and mica. Quartz is especially abundant, the grains welded together almost in continuous sheets. The orthoclase is red; plagioclase occurs in thin, colorless, acicular prisms. The same rock reappears at Camel Peak at the bend of Snake River. At Buck Mountain, near the head of Elk River, is a dioritic rock similar to the one already described on Jack's Creek, equally free from schistose or gneissic internal structure, equally like the eruptive rocks in habit, but still in all probability metamorphic.

The list of essential constituent minerals in the Park Range rocks is even more limited than that of the Colorado or Medicine Bow. It comprises quartz, orthoclase, plagioclase, biotite, muscovite, hornblende, and epidote. Accessory species are garnet, magnetite, and gold. Under the microscope Zirkel detected, besides these, chlorite and apatite. Epidote as an essential constituent was only seen in the red unakite of Bruin Peak; it appears in a subordinate rôle in several coarse granites. Garnet of a raspberry color occurs in several highly micaceous gneisses, always in rocks with a close family resemblance to mica schist. The garnet grains are commonly as small as a mustard-seed, but occasionally longer, as in the gneiss of the high peak southeast of Encampment Meadow. In the hornblende gneisses of the same peak are numerous microscopic apatites, associated with twinned orthoclase in elongated forms like those on Long's Peak. Unmistakably eruptive granites, or indeed other forms of intrusive rocks, do not exist in our part of Park Range.

An Archæan exposure northwest of Rawlings Station is without doubt an outlying dependence of Park Range. As before seen, the gneisses and granites of that ridge dip northwest and downward under the later sedimentary formations. Twelve or fourteen miles farther in the same direction, there is a local elevating disturbance at Savory Plateau, where a doming up of the Cretaceous takes place, with quaquaversal dip and an exposure of the underlying Jurassic series. No one can doubt the propriety of regarding this occurrence as an effect of the submerged continuation of Park Range.

A similar but more important doming takes place at the locality north of Rawlings Butte, involving all the strata from the middle Cretaceous down to the Archæan. The truncation of this dome by erosion has laid bare the entire series. Underlying the primordial sandstone is a long, narrow, nucleal mass of a granitoid gneiss, with comparatively distinct bedding, a northerly strike, and a dip of 45° to the west. A northwest valley has been eroded through the dome, doubtless on the line of some important fissure, leaving the best Archæan exposures on the east side of the valley. An interesting exhibition of the grinding power of wind-driven sands is here met with, the more exposed granite surfaces bearing a remarkable polish and grooving. The rock is a close-grained, strongly cohering mixture of quartz, plagioclase, a little orthoclase, and hornblende, the latter disseminated in light-green fibres through the mass and imparting to it a prevailing greenish color. Strictly speaking, the rock possesses the composition of a quartziferous diorite with a distinctly granitic habitus, and may be regarded as highly quartzose dioritic gneiss. Zirkel points out that the quartzes are rich in fluid inclusions, some of which contain salt cubes and others liquid carbonic acid.

Uinta Range.—From the last-described exposures, westward across the whole basin of Green River, as far as Wahsatch Range, within the limits of the Fortieth Parallel Exploration, the entire area is made up of rocks later than Carboniferous, and there is but one outcrop of Archæan age. This is a small body near the northern foot-hills of the eastern end of Uinta Range, and directly north of Green River, at the eastern end of Brown's Park. The exposure is from four to six miles across from north to south, and about seventeen miles east and west. On the south it is bounded by the great sandstone series of the Uinta, except where between Red and Willow creeks the Tertiary of Brown's Park abuts against it. Along the north it is chiefly bounded by Cretaceous rocks, which are probably brought into contact with it by a fault and a downthrow. A distinct nonconformity between the Archæan body and the Uinta sandstone is observed on the line of contact west from Garnet Cañon, and with equal distinctness and more satisfactory exposure north and west from the mouth of Willow Creek Cañon. This long, narrow body, having an east-and-west trend, is the only Archæan mass for more than 100 miles east or west, and for certainly an equal distance to the north, while to the south none is yet reported within a similar area. Garnet Cañon, cut by Red Creek directly through the mass, and giving exposures of over 2,000 feet on either wall, offers the best view of its interior structure. The general plan is that of a flexed anticlinal, or perhaps a double anticlinal, with converging axes, the fold of the northwestern portion being northwest-and-southeast, and that of the southern, northeast-and-southwest. The beds are very sharply uplifted, standing at angles of from 45° to 70°, and showing within the series much abrupt and severe plication.

The group consists of pure white quartzites, hornblendic schists, and hydro-mica (paragonite) schists, richly charged with garnet, staurolite, and minute crystals of cyanite. The black, hornblendic beds are essentially an amphibole rock, containing a little quartz and sparing triclinic and orthoclastic feldspars, the former predominating. Composed as it is almost entirely of distinct hornblende prisms, it might be fairly classed as an amphibole rock, and it is clearly to be correlated with that already described at Bruin Peak on Park Range. The association of paragonite with staurolite, garnet, and cyanite recalls many well known Appalachian localities and the classic St. Gothard of the Alps. The association of quartzite with hornblendic beds and cyaniferous schists suggests a resemblance to the series exposed on Medicine Bow Peak, which also carry cyanite; but the staurolitic-paragonite rocks are entirely wanting in every other locality examined by this survey. In a measure this exposure stands as disconnected petrologically as it does geographically. It is the single instance in the Fortieth Parallel Archæan area, aside from chloritic ingredients of certain granitoid rocks, of a hydrous rock; serpentines, steatites, damourite rock, and other hydrated silicates being altogether absent.

Minutely studied, the great white quartzite belt, with its intercalated beds of dark amphibolitic schists, yields the important fact, that while each individual stratum is most persistent in retaining its mineral and chemical character when followed longitudinally, adjoining beds may and do differ widely. A clean bed of spotless white quartzite between two dense black sheets of amphibolite preserves its purity even when followed for miles. Whatever, therefore, may have been the cause or mode of metamorphism, the resulting mineral combination was governed absolutely by the chemistry of the original sediment; nor did the process of change have power to transfer a single atom of a single element out of the horizon in which it was deposited.

Wahsatch Range.—The Archæan rocks in the explored portion of the Wahsatch are exposed at intervals along the west front of the range for nearly 100 miles, and are composed of granites, garnet rocks, aplitic schists, and a very extended series of gneisses and hornblendic schists, with subordinate quartzites. The manner of their exposure is of very great interest, involving the most extensive dynamic action observed within the limits of the Fortieth Parallel Exploration. The chain of outcrops clearly represents an old Archæan range of bold configuration, which has been buried beneath an enormous accumulation of Palæozoic and Mesozoic sediments. It was this buried Archæan range which controlled the position and direction of the modern Wahsatch Range. After the uplifts took place, and the Palæozoic and Mesozoic strata were thrown into their present inclined position, a great longitudinal fault occurred throughout this whole portion of the range, by which the entire western half of the ridge was thrown downward from 3,000 to 40,000 feet, and is now entirely buried beneath the Pliocene and Quaternary formations of the Salt Lake basin. The present abrupt west front of the Wahsatch is the standing face of this great fault, and here the Archæan rocks are seen to occupy the core of the range, unconformably underlying the Palæozoic series, and rising to different stratigraphical horizons in the overlying series. In the southern portion of Map III., in the region of Cottonwood and Little Cottonwood cañons, is exposed an approximately conformable series of 30,000 feet of Palæozoic strata, overlying the granites and schists which there together form a portion of the early Archæan surface. The origin and nature of the granites at this point are obscure. There seem to be two distinct types—a granitoid gneiss, having a decided stratification, and an apparently eruptive body, which possesses in an interesting degree the conoidal structure so prominently developed in the

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granites of the Sierra Nevada. About fifteen miles south of Salt Lake City the Palæozoic beds are thrown into a broad, semicircular curve, having a convexity to the east and a varying dip always away from the centre of this curvature. The ends of the strata of this great flexure advance westward until they approach the region of the great fault, their eroded edges forming the foot-hills of the range.

The centre and nucleus of this immense curvature is a body of Archæan rock, composed partly of schists, but principally of a great central mass of granite and granitoid gneiss, having its best exposures in Little Cottonwood Cañon and the peaks to the south, and again in the Clayton's Peak mass, where it rises like an island through the strata of the Lower Coal Measure limestone and the Weber quartzite. Plate I. is a view up among the summits of the Lone Peak mass, showing the rugged region near the head of a deep glacial cañon. Although in Clayton's Peak, and again near the lower end of Little Cottonwood Cañon, the rock possesses all the physical habit of a truly eruptive granite, and although in the Clayton's Peak region the granite has undoubtedly been a centre of local metamorphism and of metalization, yet, from the position of the overlying strata, a preponderance of evidence points to the belief that, whether eruptive or not, it is still of Archæan origin; hence its relations with the later stratified series are only those of rigid underlying masses, and the local metamorphism observed in the limestones near the granites is strictly mechanical, and not to be mistaken for the caustic phenomena of a chemically energetic intrusion. It should be mentioned, however, that it possesses, both in its interior composition and in a peculiar conoidal structure, close affinities with the unmistakably eruptive granite of the Sierra Nevada; and it is quite possible that subsequent study will determine the presence here of two distinct granites, the one having a regular bedding and belonging to the stratified Archæan series, the other of conoidal structure and eruptive origin. The main body extends about twelve miles northeasterly, from the trachyte slopes of the Traverse Hills to the head of Little Cottonwood Cañon. Its greatest north-and-south expansion is through Lone Peak, a line about eight miles long. South of the mouth of Cottonwood Cañon a narrow isolated patch of granite appears involved in the Archæan schists. The Clayton's Peak mass, at the head of Cottonwood Cañon, has an east-and-west extent of about three miles, and runs the same distance north-and-south. Near the mouth of Little Cottonwood the granite breaks with a sharp fracture, possessing no bedding-planes and but a few irregular jointings. It consists of quartz, which is seen under the microscope to be remarkably poor in fluid inclusions, orthoclase, a relatively high proportion of plagioclase, biotite, large and brilliant black hornblendes, titanite, and microscopic apatite. For western granites, the titanites are particularly large, not infrequently reaching one eighth of an inch in length.

Passing up Cottonwood Cañon, no sharp line of division between the structureless granite and the bedded gneissoid form is observable; but there appear gradually more and more planes having an easterly dip, until finally they approach the regularity of gneiss bed-planes, and the minerals are seen to possess a vague general parallel arrangement. There is no essential change in the mineral composition of the granite in passing from one to the other of these forms. If anything, titanite and hornblende are slightly less frequent in passing up the cañon and into the region of bedded gneiss.

The granite of Clayton's Peak, however, has some essential differences. It is dark, very fine-grained, and carries a very large proportion of hornblende and mica. Under the microscope the titanite crystals, which are present in large number, are seen to be much darker than in the other rocks. The feldspar and quartz, particularly the former, contain many microscopic impurities, chiefly plates of red and black oxyd of iron. The rock is proportionately rich in black magnetite grains, which penetrate the flattened crystals of apatite. The mineralogical differences through all these bodies of granite are indeed slight; changes of texture and arrangement produce a decidedly varying petrological effect, but in general they are granites, containing—besides the normal orthoclase, quartz, and biotite—plagioclase, hornblende, titanite, and apatite in high proportion; all but the apatite being visible to the naked eye.

The bodies of granite porphyry shown on the map in the neighborhood of Clayton's Peak are in all probability a dependence of the granite. They are always rich in hornblende and orthoclastic feldspar, which throws them into the class of syenitic granite porphyries. The body which comes to the surface in the bottom of Cottonwood Cañon, two miles below the bend, is remarkable for the high proportion of pyrites, which has penetrated in fine grains through the quartz and feldspar crystals. A granite-porphyry body adjoining Clayton's Peak on the north, and forming the divide between the head of Cottonwood Cañon and Parley's Park, is also richly impregnated with pyrites. Its groundmass is pale green, from the presence of epidote, here an alteration-product after hornblende, and is rich in plagioclase. The larger feldspars, which are chiefly orthoclase, have a red color derived from a microscopic dust of iron oxyd.

Lying to the west of the granite body of Little Cottonwood Cañon, and occupying the extreme foot-hills, is a belt of Archæan schists, varying from a mile to two miles in width, and extending from the Traverse Mountains north to the mouth of Cottonwood Cañon. The general strike of this body is northeast, with a dip of from 45° to 60° to the north and west. From 2,000 to 3,000 feet of schists and quartzites are laid bare.

A very good exposure is found in the second small cañon south of Cottonwood, where an estimated thickness of from 2,000 to 2,500 feet of highly metamorphic slates rests directly on the granite. Overlying these is a zone of quartzites, the uppermost members of which are blue, very hard, and schistose. A great deal of local contortion is observed in the strata; in one place they completely surround a small knob of granite, which is probably a submerged portion of the spur running northwest from Twin Peaks. Among the lower horizons is found a green hornblende schist, rich in quartz. It is almost a quartzite, and is thickly penetrated by small bluish-green hornblende prisms, which give the rock its schistose cleavage. There is also a little brown mica. At the mouth of the Little Cottonwood this Archæan zone is represented by about 1,000 feet of quartzites, which extend perhaps half a mile up the cañon, making a junction with the granite body. South of the mouth of Little Cottonwood Cañon the same quartzites extend down to the trachytes of the Traverse Mountains. In direct contact with the granite at the mouth of Cottonwood Cañon is a development of mica schist.

On Rhodes's Spur, at the head of Cottonwood Cañon, resting directly upon the granites of Clayton's Peak, is a curious garnetiferous schist. It is a coarse-grained quartz rock penetrated by delicate green fibrous epidote and carrying a very high proportion of brown crystals of garnet, which indeed make up the greater mass of the rock. Zirkel describes the garnets as showing under the microscope a peculiar schistiform structure, as if resulting from a continuous aggregation of layers. Besides the garnet and epidote, these rocks show an appreciable amount of specular iron and local concentrations of dark-green fibrous hornblende. Intermediate stages between the hornblende and the epidote are so evident that there can be little doubt that the latter is an alteration-product of the former.

There are present in this neighborhood, then, two distinct families of rocks: first, the Archæan, consisting of schists and granites; second, the vast, conformable post-Archæan group of sediments. Wherever observed, the region of contact between the two families displays no marked metamorphism on the part of the sedimentary series, and within the Archæan series no such transitions as would lead to the belief that the granite is only a more highly metamorphic form of the crystalline sedimentary series; on the contrary, the contact is so clearly defined, and the rocks are mineralogically so dissimilar, that it is very evident that the granite is either an intrusive mass or else an original boss over which the Archæan sedimentary materials were deposited. While the granite itself bears a very close resemblance to the Californian eruptive granites, its relation to the flexed Palæozoic strata would indicate that they were bent around a solid body, not that a plastic granite intruded into the bent Palæozoics. The absence of granite dikes penetrating the immense sedimentary series would strengthen the belief that the granite antedated it. It is also noticeable that the dip and strike of the Archæan schists west of the granite body are entirely discordant with the overlying Cambrian series, the former striking northeast and dipping northwest, the latter striking northwest and dipping southeast, this unconformability being preserved up to the contact. Supposing the whole Archæan body to have been thrust upward and eastward when the flexure of the Palæozoic series took place, the present dip of the Archæan schists and quartzites would indicate that before the great Wahsatch uplift they were in a nearly vertical position, flanked to the east by the granite mass. Intrusive dikes do in some instances cut the marbleized limestone, but they are middle-age porphyries, not to be confounded with the Archæan crystalline rocks.

The next Archæan body makes its appearance about eight miles north of Salt Lake City, in Sawmill Cañon. Here the Palæozoic strata, unconformably overlying the Archæan, trend diagonally in a northeast direction across the range. From the southern line of its outcrop the main mass is composed of an Archæan block extending 20 miles northward, and no doubt occupying the whole body of the ridge, except upon the eastern foot-hills, where it is overlaid by the beds of the Vermilion Creek Eocene group.

There seem to be two distinct series within the Archæan mass, the earlier occurring only at the extreme southern end of the exposure, and confined to the spur between Sawmill Cañon and that next north. Here is laid bare a small body of intensely metamorphosed material of an ashen-gray color, composed of quartz, orthoclase, and a very little muscovite. It weathers with an excessively rough surface, developing curious waving lines. It appears to have been a body of quartzitic schist, containing a little orthoclase and mica, which has undergone the most violent compression and crumpling, obliterating entirely the original bedding and leaving only obscure traces of short, abrupt, and extremely irregular corrugations. Northward, this body passes unconformably under the main series of gneisses and schists which form the range in that direction. The regular strike and dip of the gneisses and schists continue close down to the highly corrugated structureless body, but the exact contact was obscured by soil and a dense growth of scrub oaks. From the nature and position of the two bodies there is no doubt that they are actually unconformable, and that the bedded gneisses are the younger group.

The later series consists of beds of gneiss, quartzite, and various hornblendic schists, forming a great conformable group which always dips to the west at angles varying from 15° to 40°, and is admirably exposed in the various cañons which are cut down the two flanks of the range, and especially also in the transverse cut of the cañon of Weber River, where the whole range is severed. The series is characterized by great chemical and usually mineralogical persistence of individual beds for comparatively long distances, and by the absence of any important minor corrugations.

The group forms a simple monoclinal ridge, dipping to the west at angles increasing from 15° at the south to 25° and 40° farther north in the region of Weber Cañon, attaining still higher angles near Ogden. The trend of this series is somewhat sinuous. As developed in the summit rocks, from Sawmill Cañon to Farmington Cañon, the strike is about north 20° west; but near the head of Farmington Cañon the line swerves rapidly to the east, passing to 10° east of north, which it maintains for four or five miles, and then bends back again to the west, conforming with the strike of the southern portion from north 15° to 20° west. In the axes of these two bends of strike there is a good deal of local flexure and not a little dislocation. North of Farmington Cañon, where a deep exposure occurs, there are from 12,000 to 18,000 feet of conformable beds. Down the east slope of the range to the contact with the Eocene, the Archæan rocks are still seen dipping to the west. Of course no estimate can be formed as to how much farther down beneath the overlapping Eocene sandstones the conformable Archæan series descends. The lowermost exposed members are of intercalated gneisses and hornblende schists, with minor beds of quartzitic schist carrying more or less feldspar.

An interesting type of the coarse gneiss is observed near the head of Farmington Cañon. It is composed of large crystalline masses of flesh-colored orthoclase and partially decomposed, earthy brown magnesian mica, with irregular bodies of pure, milky-white quartz. This stratum is interesting as showing the transition from an evenly bedded rock into a structureless one. The original sheets of mica may be readily traced, though at present they all bend into wavy lines through the mass of the bed, or, what is rather less common, mica flakes all arrange themselves on a diagonal to the plane of the bed. Tracing this bed a few miles north from Farmington Cañon, the minerals are observed to be less and less disturbed, and finally not a single mica flake deviates from its original parallel position. Such changes as this are frequently observable in gneiss beds; but it has nowhere been the fortune of this Exploration to observe those peculiar rapid transitions from one species of rock to another which are so constantly to be found in descriptions of Archæan schists and gneisses. On the contrary, all the observations of this corps tend to prove that there is a remarkable permanence of chemical make-up within each bed, and that the only changes which take place within a given stratum are through the hydration of some of the contained species, or else mere physical changes in the relative arrangement of the species. A mica schist passing into a hornblendic schist, or a hornblendic schist into a granite, or a gneiss rock into an argillite, along the line of their longitudinal extensions, are phenomena which failed to appear on the Fortieth Parallel. It is believed that such observations, not at all infrequent in certain accounts of western geology, betray a talent for fiction which might find a more appropriate field within the domain of romance. While individual beds extend for great distances without chemical change, on the other hand in descending or ascending through the series there is the greatest variety of changes, every combination possible to the few mineral constituents being repeatedly illustrated.

Over these coarse Farmington gneisses are a series of fine gray gneiss, in which the feldspar and quartz are both white, and the mica muscovite. It is a rock made noteworthy by the presence of freely disseminated minute garnets, which Zirkel has shown under the microscope to be riven in every direction by infinitesimal cracks, and to be more or less altered into chlorite, sometimes attaining the complete pseudomorphism which has been so interestingly elaborated by Prof. Raphael Pumpelly in his description of the rocks of Lake Superior.

A little higher in the series is another gneiss, still containing a predominance of white mica (muscovite), but with a little hornblende. It is also rich in garnets, which likewise show the transition into chlorite. For a full account of the minute method of this pseudomorphism, the reader is referred to the pages on Archæan schists in Volume VI. of this report.

Above these is a heavy group of dark-green hornblendic gneisses, rich in feldspar and apatite; besides which, Zirkel has identified under the microscope a considerable proportion of zircons. They are never large enough to be visible to the naked eye. In the zirconiferous gneisses the hornblende is always more or less fibrous, from dark-green to black, and arranges itself with the broader surfaces of the prisms coincident with the bedding-planes. Quartz and feldspar hold a very variable position in this series, as they do in the hornblendic rocks of Medicine Bow and Park ranges. There is every variety here, from a pure amphibole, containing sparse grains of quartz but no feldspar, to beds in which either quartz or feldspar largely predominates, and in which hornblende plays a very insignificant part. Apatite is characteristic of those rocks in which mica does not exist. There are no means of closely determining the relative thickness of the various types of crystalline schists which repeatedly recur in this body. But it is evident that only the lower members are true gneisses, while by far the greater part represents a varying association of hornblende, feldspar, and quartz. There are narrow zones which may be called quartzite, though carrying not a little feldspar, but no large, true zone of pure quartzite. The most noticeable fact is the sequence of richly feldspathic gneisses and mica gneisses containing garnets, the two overlaid by a large series, which is prevalently hornblendic, but carries more or less zirconiferous beds. This seems to be a very nearly direct repetition of the sequence in the Rocky Mountain system, and of one which will be described hereafter in Humboldt Range.

Four miles north of the cañon of Weber River, the Archæan series is lost by passing under beds of the Palæozoic series. Two miles south of the mouth of Ogden Cañon it reappears, coming out from under the Cambrian quartzite, and it is exposed along the western foot-hills of the range in a zone about four miles long by half a mile to a mile wide. On the west it is bounded by the Terrace formation, and along the east it passes unconformably under the quartzites of the Cambrian. The rocks of this exposure are an intimate association of dark reddish-gray and dark-red gneisses, in which hornblende largely predominates over mica. Mica is variably present, but never reaches a high proportion, and is sometimes altogether absent. Both orthoclase and plagioclase are present, the latter predominating. Quartz occurs freely, sometimes segregating itself into sheets of pellucid grains. Zirkel describes a very interesting arrangement of the mica, seen only under the microscope, as well as the occurrence of apatite and zircon. The interesting method of isolating and determining zirconium in these rocks, as devised by Mr. R. W. Woodward, the chemist of this Exploration, will be found detailed in Volume II., Chapter III., under the account of Wahsatch Range. His method depends on the insolubility of zircon in hydrofluoric acid. Every variety of structure is noticed in this exposure of hornblende rocks, ranging from distinct lamination, in which the hornblende crystals are arranged in sheets separated by zones of feldspar and quartz, to a structureless condition in which the rock rich in plagioclase and hornblende might easily pass for an eruptive diorite. As a whole, they have a strike of about north 20° west, with a high dip to the west. Their unconformability with the overlying Cambrian quartzite is well shown along the whole front of the range, from Ogden Cañon to Eden Pass.

Directly north of Ogden's Hole, occupying a geological position similar to that of the last-described exposure, unconformably under the Cambrian quartzite, is another Archæan body. At its extreme northern end, four miles south of Brigham City, the Cambrian disappears and the Silurian limestone comes directly in contact with the Archæan. Here also the rocks strike about north 20° west, and dip at a high angle to the southwest. They consist of a series of micaceous and hornblendic gneisses, having rather a granitoid appearance, but for the most part clearly displaying the planes of bedding. A very characteristic hornblende gneiss is collected near the south point of the body, and consists of coarse-grained orthoclase, a comparatively large amount of plagioclase, quartz, a little brown mica, and much hornblende. Apatite is discovered under the microscope. Among the upper dioritoid beds are some which are decidedly poor in hornblende, but carry well developed microscopical crystals of zircon in considerable frequency. Almost all the lower members of the Ogden Point series are more truly gneissic than the upper ones.

It is very clear that the three last-described exposures—the great body forming the range from Ogden Peak south to Sawmill Cañon, the narrow body at the mouth of Ogden Cañon, and the exposure north of Ogden's Hole—are all parts of a single series, having a more or less flexed but generally northwest strike, accompanying the general trend of the range, and all dipping conformably to the west. Their contact with the overlying Palæozoic rocks varies from the Silurian limestone to a horizon 3,000 or 4,000 feet down in the Cambrian quartzites. It is further evident that when the easterly dipping Palæozoic rocks were in a horizontal position, the westerly dipping Archæan beds would stand at a much higher angle; and, comparing the points of contact between the Archæan and the Palæozoic, it is clear that the summit profile of the original Archæan ridge was eroded into peaks rising at least 4,000 feet above the general outline of the ridge, and that these peaks were not abrupt, but were rather gently rising domes.

Archæan of Salt Lake and the Promontory.—Promontory Range, which projects southward into Salt Lake, has exposed upon its southern extremity a body of slates and quartzites, together with minor hornblendic and mica schists. About five miles south of Promontory Point, on the trend of Promontory Range, lies Frémont's Island, which may be considered as a part of the same development of Archæan rocks. Still farther south, Antelope Island, a body of land twelve or fourteen miles in length by four miles in width, whose longer axis points northwest, seems by its material and position to be a southward continuation of the same Archæan mass. West of Ogden City, at the landing rocks northwest of the mouth of Weber River, there is also a slight development of westerly dipping Archæan schist. This latter exposure is surrounded by the mud beds of the lower Quaternary desert formation, and is of very slight importance. The two above-mentioned islands and the southern point of Promontory Range, taken together, represent a body chiefly composed of argillaceous, pyritiferous schists, mica schists, and granitoid gneisses, which, according to the accounts of Stansbury and the slight notes of our own topographer, appears to dip west on Antelope and Frémont islands, with a general northwest strike; while on the point of the promontory it is much more disturbed, but has, however, a prevalent northeasterly dip, with a northwest strike. The trend of these masses, if continued southward, would carry the body under the western side of Jordan valley. It would seem as if Promontory Range, the two islands, and the Oquirrh represent a range in a measure comparable to the Wahsatch, formed of an Archæan core and an overlying folded Palæozoic series.

Raft River Mountains.—North of Bovine Station, where the Central Pacific Railroad skirts the northern edge of Salt Lake Desert, rises the southern group of Raft River Mountains, a range which trends northward and extends beyond the limits of Map III. In the middle of the ridge, at Citadel Peak, and extending thence along the eastern side of the range for ten or twelve miles, is a triangular exposure of granite, the west and south sides wrapped around and overlaid by limestones, which have been referred to the horizon of the Lower Coal Measures. Quaternary beds skirt the eastern base of the granite, which here forms the foot-hills of the range. The topography is a series of irregular parallel ravines, eroded from west to east. Citadel Peak, the highest summit, reaches 2,500 feet above the level of the desert. The Quaternary of Clear Creek valley penetrates the range, isolating a northern mass of granite from the main body, as will be readily seen upon the map. The rock is nearly structureless, the few jointing-planes showing no indications of a parallelism which would suggest a gneissoid structure. It has a uniform and medium texture and a pearl-gray color, and is composed of quartz, orthoclase, and mica. The granite malady has taken hold of the surface very generally, and it is covered with crumbling débris. The main spurs and ridges present everywhere smooth, round outlines, with many small, fanciful forms of erosion.

Desert Granite Range.—About 25 miles west of the Cedar Mountains, and a few miles south of the southern limit of our Map III., is a narrow ridge extending on a north-and-south trend eight or ten miles, and scarcely more than a mile or a mile and a half in width. From this contracted base it rises fully 3,000 feet above the level of the desert. The northern half, where examined, consists exclusively of a variety of granite having a decidedly metamorphic habit, although the bedding-planes were not distinct enough to give a definite idea of the true orographical structure. In general, it is a fine-grained, nearly white mass, sometimes changing into a coarse variety in which the mica plates reach an inch in diameter. The central heights are intersected by veins of a dark-green hornblendic granite, which under the microscope is seen to contain very little unaltered hornblende, but a dichroitic green chlorite-like mineral, besides considerable dark hexagonal mica, titanite, and apatite. Its quartz and feldspars are rich in fluid inclusions. A gray variety, of medium-sized grains, contains both black and white mica. The fine-grained white varieties hold only white mica, quartz, and orthoclase, with a few scattered particles of the chlorite mineral, no biotite, titanite, and very little apatite and plagioclase.

Goose Creek Hills.—In the northeast corner of Map IV., directly west of the 114th meridian, is shown the southern termination of the Goose Creek Hills. Near the western foot-hills, at the head of the east fork of Passage Creek, is exposed a small body of granitic porphyry, occurring in some of the deeper ravines under limestones and quartzites which have been referred to the Carboniferous. In a fine-grained groundmass, consisting of hornblende, orthoclase, plagioclase, and quartz, are embedded large crystals of feldspar, which for the most part are altered into an opaque mass, showing under the microscope that they are mainly monoclinic, but in exceptional crystals displaying the traces of a former striation. In some of the earthy, decomposed feldspars are colorless acicular crystals referred to muscovite. Zirkel calls attention to the hornblende as noteworthy for presenting, as a product of decomposition, black, opaque, angular grains, which are doubtless magnetite, but which do not occur in the fresh, undecomposed hornblende. These porphyry outcrops are too limited to indicate anything about the structure of the mass.

Ombe Range.—In Ombe Range, about half-way between Pilot Peak and Lucin Station, there is a gentle depression or pass traversing the range from east to west. The hills to the north are composed of Upper Coal Measure limestones, reposing conformably upon a heavy development of the Weber quartzite, the whole series resting unconformably upon a granite body which appears exposed to the pass. The high hills southward, to Pilot Peak and beyond, are altogether made up of Weber quartzite. The exposure of granite in the pass is only about four and a half miles from east to west and two and a half miles from north to south. On the west the granite sinks under Quaternary slopes of Salt Lake Desert.

In so small a block, little can be learned of the structural relations of the granite, except that it is distinctly unconformable with the overlying sedimentary series. Since at least 3,000 feet of quartzite are in contact with the granite, and also a considerable thickness of overlying limestones, it would be evident that the topography of the original granite mass over which the sedimentary series was superposed possessed slopes of at least 4,000 feet. The granite mass may be considered a part of an underlying range, which was crowded up when the Palæozoic rocks were tilted, its rigid body perhaps determining the axis of the modern anticlinal. From so limited an outcrop it is impossible to decide between a metamorphic and an eruptive origin, but there is an absence of all appearance which would lead to the belief that it is metamorphic. The granite itself is a medium-grained but somewhat friable rock, of a mottled gray and red color, made up of quartz, large masses of white orthoclase, and a reddish triclinic feldspar. Mica in thin brown flakes is present, not infrequently adhering to the thick broad faces of the orthoclase. It is, however, an unimportant constituent. A determination of the alkalies of one of the white orthoclases gave, soda .34, potash 12.58.

Gosiute Range.—In Toano Pass, about four miles south of Fairview Peak, occurs a small, obscure mass of granite. It has a friable, much decomposed surface, and betrays no distinct lines of bedding. Like the previously described granite, it is composed of quartz, orthoclase, sparing plagioclase, and a little mica Its only geological interest is its accidental exposure in a deep pass. The region north of the old Overland Road, between Salt Lake Desert and the Humboldt Mountains, only shows its granites in inferior geological situations, as in passes, and it is usually evident that the exposed mass is the summit of a submerged range laid bare by erosion in the axial part of a fold, or brought to the modern surface by some extended fault.

About fifteen miles south of Toano Pass the hills of Gosiute Range fall away into a broad open pass, but rise again southward toward Pine Mountain. The Quaternary of Tacoma and Gosiute valleys sweeps up from the east and west well into the pass, covering the lower slopes of a granite mass. As at Patterson Pass, this depression is occupied by a body of granite overlaid by quartzitic series referred to the Weber period. The summit of the pass is about 500 feet above the Gosiute Valley and 1,500 feet above that of Tacoma, the two valleys having about 1,000 feet difference of level. The granite is rather coarse-grained, with loose, friable texture, and of a prevailing gray and yellowish-gray color. There are here again no appearances of a distinct bedding, nor do the constituent minerals show any gneissic parallelism of arrangement. The whole topography and lines of drainage show the rounded forms common to easily disintegrated rocks.

Peoquop Range.—Fifteen miles southwest of Middle Pass, there is a similar depression in the Peoquop Mountains, in which a still narrower and more limited development of granite is exposed. The pass, which nowhere rises more than 500 or 600 feet above the level of the valleys on either side, is restricted to a width of about two miles, the Quaternary rising on either side against the granite slopes. As in Middle Pass, the granite is overlaid unconformably by Palæozoic strata, that to the north being of Weber quartzite, while to the south the limestones of the Upper Coal Measures appear. In structure, in mode of weathering, and in lithological character, the granite is similar to the limited areas just described.

Taken together, the small granite exposures in these four passes possess interest solely on account of their position. As exposures of granite in a petrological way they are quite insignificant; but they are of the utmost importance as suggesting the topography of the underlying Archæan formation of this region, since they occur at points in the axial region of modern ranges and at points of deepest exposure. The significance of this will be shown in the concluding pages of this chapter. It is only necessary to say here that the position and character of these buried Archæan ranges have given importance and direction to the subsequent orography.

At Spruce Mountain there are some mica schists and slates which doubtless belong to the Archæan series. Their geological relations are quite obscure, and the exposure is so small as to be of comparatively little importance. Lithologically, they seem to be more nearly related to the schists of Humboldt Range than to those of any other locality. Indeed, they are only separated from the mass of Mount Bonpland by a single valley. The schists and slates are all distinctly bedded, are often finely laminated, and have always a ready cleavage. A characteristic specimen represents a silvery-white rock, composed of minute granules of clear quartz and small flakes of mica—both biotite and muscovite, but no hornblende. Under the microscope, however, Zirkel detected an abundance of crystals of zircon, which, though plentiful in series of Archæan gneisses and schists, are usually observed in connection with hornblende. Moreover, the biotite plates contain exceedingly minute microscopical needles, which Zirkel also considers referable to zircon. Coarser and more loosely compacted schists are also observed in the series. It is quite possible that further observation would confirm the presence of larger masses of Archæan than are now known along the foot-hills of this group.

THE WACHOE MOUNTAINS.—Between Gosiute and Steptoe valleys, in latitude about 40° 18′, rises an irregular group of mountains, whose main mass is composed of a granite nucleus, which is penetrated and surrounded by numerous modern outflows of Tertiary volcanic rocks. Granite gives shape to the northern mass of the range; the foot-hills to the south are made of a broad flow of rhyolite. Along the southern slope of the main mass is a development of limestone, extending four or five miles in a northwest-and-southeast direction, which is referred by Mr. Emmons to the horizon of the Lower Coal Measures. The usual distinct nonconformity is observed between the sedimentary and the granite mass. The main body of granite extends eight or ten miles in a north-and-south direction, with about four miles of lateral exposure in an east-and-west line. On the west side it descends rather abruptly under the Quaternary plain; along the east more gradually, and here it is interrupted by outflows of porphyry, andesite, and rhyolite. The top of the highest granite peak is about 2,000 feet above the Gosiute desert. From the family of granites which appear in the low passes lately noted, this granite differs in many interesting ways. Although topographically it gives rise to dome-like and gently rounding forms, there is not the same tendency to local disintegration which is observed to the north, and in consequence but very slight accumulations of granitic gravel upon the surface. Transportation seems fully to equal disintegration, so that the slopes are pretty hard and bare. Aside from certain irregular jointing-planes, there appears to be no distinct bedding, nor even any noticeable parallelism in the jointing-planes. As a mass, it is far removed from those granites which have been treated as of metamorphic origin. The configuration of the mountain group and the character of the granitic slopes, as well as the interior arrangement of the mineral constituents, combine to impress a belief in the eruptive origin of the mass. The rock is of a dark-yellowish or reddish-gray color, passing into lighter shades on the northeast spurs and foot-hills, owing to a diminished proportion of mica and hornblende. Quartz, orthoclase, plagioclase, and mica are the essential ingredients. In addition, there is a variable though large proportion of hornblende, and also a few dark granules which have been referred to specular iron. An appearance of cloudy impurity in the feldspars is seen microscopically to be due to the liberal inclusion of specular-iron grains and shattered fragments of hornblende and mica. A certain opaque dullness characterizes the general aspect of the feldspars. A few of the larger orthoclases have a brilliant vitreous lustre. The mica appears for the most part in smooth, well preserved plates of dark biotite. There are also flakes of a bronze color, which are referable to phlogopite. Under the microscope Zirkel detects titanite and apatite, the latter in short, thick prisms, which are rich in fluid inclusions whose mode of arrangement is perpendicular to the main crystalline axis. Salt cubes are also observed in the fluid inclusions of the quartz. Isolated from all our other granite areas geographically, it also stands alone as regards its chemical composition. Aside from the high proportion of titanite and apatite, and the inclusions of specular iron in the feldspar, it is closely related to the granites of the Sierra Nevada and of the Wahsatch. But by the extremely high proportion of mica and hornblende, the chemical analysis runs down to 55 per cent. in silica, a point lower by from 12 to 20 per cent. than in any of the other granites of the Fortieth Parallel. From their extremely earthy appearance it would seem that the feldspars also may fall below their normal equivalents of silica. This must always remain one of the most interesting granite localities of the Cordilleran system. Its only described parallel in Europe is the granite of Adara, in Donegal, Ireland.

Near the north base of the northern hills, the granite is cut by an irregular dike of a fine-grained dioritic porphyry having a purplish-gray color. It is a dense, compact rock, angular in its fracture, with a highly crystalline groundmass, in which are embedded both orthoclase and plagioclase; the latter, assumed to predominate, occurring as brilliant acicular needles. Fine fibrous green crystals of hornblende are pretty uniformly distributed through the whole mass.

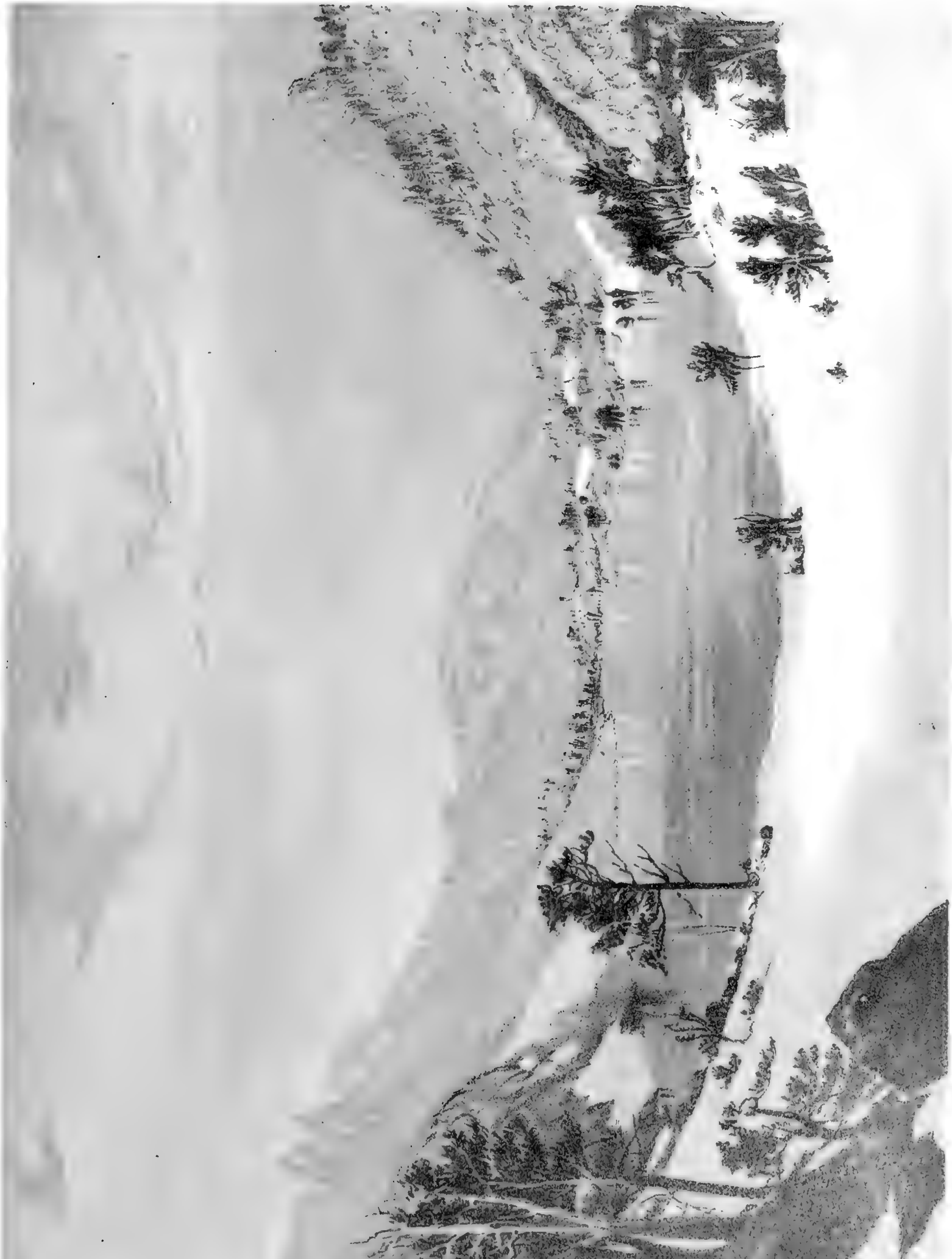
KINSLEY DISTRICT.—Southeast of the Wachoe Mountains, nearly in the middle of Gosiute Valley, is a north-and-south ridge connected by a low depression with the range to the west. It is composed of granite, granitic porphyries, and Archæan limestone, overlaid upon the west by limestones of the Lower Coal Measure horizon, which dip to the south and west. Southward the Archæan and Carboniferous are bounded by rhyolite hills. The Archæan series is made up, besides a limited boss of granite, of interbedded white crystalline dolomites and broad tabular masses of granitic porphyry. The conformably dipping series strike north and incline to the east about 25°. This interesting intercalation is well shown at Marble Hill, where no less than six different beds of the porphyry were observed between dolomitic limestones. The marble of all these beds is a remarkably pure, white, fine-grained, crystalline rock, approximately a dolomite, which upon analysis yields, carbonate of lime 56.54, carbonate of magnesia 41.12. Under the microscope the marbles are a crystalline-granular mass, the crystals of calcite having distinct striation, and carrying fluid inclusions. In appearance and in chemical nature they are closely allied to the dolomitic limestones of the Humboldt Range Archæan series. The intercalated granite porphyries consist of a rather homogeneous and compact groundmass approaching felsite in composition, in which are many grains of limpid quartz. The feldspars are very much altered, representing every grade of decomposition, from purely kaolinized bodies to quite unaltered crystals, some of which possess distinct triclinic striation, while others are clearly orthoclase. Hornblende occurs both porphyritically enclosed and as minute fibres in the groundmass. Large plates of deep-black mica are present, and are frequently pierced by microscopic apatite. In those varieties of which the groundmass is coarse-grained, microscopical titanite and well crystallized magnetite have been observed. Under the microscope the quartzes are seen to contain ragged inclusions of the groundmass. There are also many empty cavities and fluid inclusions, among which are some with liquid carbonic acid. There are, however, no glassy particles. A small body in the northern part of the ridge, colored as granite, is a microgranitic matrix, which contains brown mica, well defined needles of hornblende, rounded quartzes, and partially decomposed feldspars.

There is room for considerable difference of opinion as to the nature of these granitoid porphyries. Their direct interstratification with the marbles confirms the probability of their being metamorphic. When we compare this locality with the marble region at the top of Mount Bonpland in Humboldt Range, the limestones there are seen to be separated by beds of quartzite, and of rather porphyritical gneiss, which are not far removed from the interbedded porphyries of the Kinsley District I feel no hesitation, therefore, in assuming that these almost typical rocks are only a more highly developed gneiss-porphyry, and are equivalents, in petrographic make-up as well as in age, of the Mount Bonpland intercalations.

Franklin Buttes.—In longitude 115°, directly west of the northern end of Egan Range, are three isolated buttes rising out of the Quaternary plain. The extreme eastern foot-hills of the easternmost elevation are formed of limestones of the Lower Coal Measure period. Otherwise, with the exception of a small diabase dike in the middle butte, the three masses are composed of granite and granitoid rocks, which are chiefly of porphyritical habit, the latter closely resembling the porphyries of the Kinsley District. In the middle and western butte are true syenitic granites, consisting of quartz, the two feldspars (the predominating orthoclase flesh-colored, and the plagioclase greenish-white), bright, well crystallized hornblende, and titanite, which is often visible to the naked eye. There is no mica. For microscopical details the reader is referred to Zirkel's interesting memoir.

Humboldt Range.—In the middle of Map IV. appears the most prominent mountain mass in eastern Nevada. It is called Humboldt Range from its northern extremity as far south as Hastings's Pass, a distance of about 85 miles, and beyond that point receives the name of White Pine Mountain. The average trend is about north 18° east. Between Frémont's and Hastings's passes the main mass of the ridge is made up of easterly dipping Palæozoic rocks from the Ogden Devonian group up to the Lower Coal Measure limestones. North of Frémont's Pass it is essentially an Archæan body, flanked in a few localities by the remnants of upturned Palæozoic beds, which rest unconformably upon the central core of the range. With the exception of a small body of granite extending from Frémont's Pass a little north of Lake Marian, the whole Archæan series is made up of a body of conformable and westerly dipping gneisses, gneissoid schists, hornblendic and in some instances dioritoid schists, dolomitic limestones, and quartzites. Throughout its eastern side the range is bordered by a Quaternary valley, in which are three prominent depressions, occupied by Eagle, Franklin, and Ruby lakes. The entire western base of the range is overlaid by the horizontal beds of the Humboldt Pliocene series, which were deposited in a long northeast-and-southwest lake, occupying the whole of Huntington and Upper Humboldt valleys. The range is, therefore, detached from all other rocks earlier than the Pliocene, and its geological connections with the neighboring ranges can only be established inferentially. The fragments of Palæozoic rocks which skirt its western base at two or three points north of Frémont's Pass dip westwardly, while the large series of Palæozoic limestones and quartzites dip eastwardly. Both sets of Palæozoic strata rest unconformably upon the Archæan. The northernmost extension of the easterly dipping limestones curves from a gentle dip of from 16° to 20° east up to the vertical, near the base of White Cloud Peak. While no easterly dipping Archæan strata are exposed in the whole range, yet the anticlinal position of the two limestone series shows that a fold has taken place diagonally to the range, and the rapid increase of angle of the easterly dipping limestones indicates that the displacement along this axis was increasingly great toward the north. It is also observed that the eastern face of the Archæan part of the range north of White Cloud Peak is very abrupt, displaying either extremely metamorphic granitoid forms, or the edges of westerly dipping Archæan crystalline schists. By the entire absence of easterly dipping Archæan and of easterly dipping Palæozoic rocks north of White Cloud Peak, it becomes evident that a fault similar to that of the Wahsatch has cut down the core of the range from north to south, and that the eastern half north of Frémont's Pass is depressed below the level of the Quaternary plain. Unfortunately, the projection of Archæan directly east of Eagle Lake was not visited; and it remains uncertain whether this may not be a fragment of the eastern half. The writer has only examined the granites of the Frémont's Pass region, northward to the region of White Cloud Peak, where it is impossible to determine whether they are conformable or unconformable with the overlying westerly dipping crystalline schists. By the entire absence of any distinct and persistent planes of bedding, this granite bears an evident resemblance to the eruptive type. But there is a series of obscure planes, which strike with the range and dip west, dividing the mass into tabular layers which vary from 40 to 80 feet in thickness. This broad parallel formation only becomes apparent to the eye in the field. Hand specimens fail to show any characteristic differences between successive beds. A greater or less proportion of mica governs the appearance of these tabular masses; and the distinction is rather based upon the degree of whiteness which they show. The rock itself is composed of two types of quartz—a pellucid, white variety, and an equal amount of a smoky kind. There is orthoclase and plagioclase, the former decidedly predominating, while the microscope reveals apatite, whose prisms occur very plentifully, traced lengthwise, parallel with the direction of the micas. These are sometimes conspicuously flattened, and again they are broken into disconnected sections. Hornblende is entirely wanting, but zircon is abundant under the microscope. It cannot be said that the micas are parallel; that is to say, the flat plates are not arranged with parallel edges, but the longer axes of almost all the mica particles are in one direction, which gives the rock an indistinct but unmistakable appearance of parallel arrangement. The same obscure linear arrangement is observed in the feldspars and quartzes, yet this is not sufficiently distinct to give the rock at all the appearance of a gneiss. The triclinic feldspars are fresh, creamy-white albites, and resemble some of those found in Californian granites. This is one of the few occurrences we have of zircon in a rock entirely without hornblende.

From 1,000 to 1,500 feet below the summit, down the west side of White Cloud Peak, a decided change takes place in the rock, and the granite passes under the true gneissic series. Southward along this granite there is a decided change, and in the region of Frémont's Pass it is coarser and more truly structureless, yet the composition is the same, even to the zircon; and owing, first to the broad bedding above described, and secondly to the obscure parallel arrangement of the mineral constituents, I am inclined to throw this into the metamorphic type of granite. It bears a singular resemblance to some of the Huronian granitoid rocks of Canada, also conceived to be metamorphic. Northward, between Overland Ranch and



Sacred Pass, the eastern front of the mountain is an abrupt mural face, and is made up of varying masses of granitoid rock possessing always more or less traces of gneissic structure. With local exceptions in what seemed to be northward prolongations of the Frémont's Pass granite, making up in dome-like masses into the crystalline schists, the whole Archæan body of the range is distinctly a bedded series. In Sacred Pass, upper members of the Lower Coal Measures are seen to rest directly and unconformably upon the schists, while to the south, east of Camp Halleck, towers above them a group of high schist peaks. The sudden and commanding lift of these Archæan peaks, above the point of contact with the limestone, and the rapid overlap of the uppermost Palæozoic strata concealing lower members of the series, clearly indicate high primitive Archæan peaks around which the limestones were deposited.

Plate II. shows Lake Marian, a glacial bowl northwest from Overland Ranch in the heart of a group of granite crags, at an altitude of above 10,000 feet. Plate IV. is a look into one of the 2,000-foot glacial troughs wrought out of the rocks of the same region, but on the west slope, back of Camp Halleck.

South of Sacred Pass, among the schists, hornblendic varieties and quartzitic schists bearing mica predominate upon the outer flanks of the mountain. In the lowest horizons, as exposed in the deep glacial cañons, granitoid gneisses, gradually approaching the structureless form, are observed. They vary in their westerly dip from 20° to 40°. The granites before described appear to underlie conformably, and may, upon future study, prove to be only the lowest lying and most extremely metamorphosed of the series. At the head-waters of the South Fork of the Humboldt, a bold mountain promontory makes out from the range, extending westwardly twelve miles from the summit, and displaying about its base a margin of Devonian and Lower Coal Measure limestones, which are wrapped around the Archæan convexity in the shape of a horseshoe. The mass of the promontory itself is of heavy Archæan quartzitic schists, interstratified with micaceous and hornblendic beds, hornblende predominating.

Both the east wall of the northern part of the mountains, and the deep cañons which are carved down from Mount Bonpland to the western foot of the range, offer the best exposure of Archæan rocks. At its base the series is seen to be formed of mica gneisses of a bright-gray color and very great variety of texture and habit, made up of an association of quartz, black and brown micas, and a very variable quantity of orthoclase and plagioclase. Of the whole 8,000 or 10,000 feet, perhaps the lower 5,000 feet are predominantly micaceous, a few narrow zones of quartzite lying within the gneiss, but the upper members, while containing a few sheets of typical mica gneiss, are chiefly of hornblendic and dioritic schists, which are interesting on account of the number of minerals they contain. Plagioclase prevails over these hornblendic beds, but both feldspars are always present. Mica, too, frequently occurs, but it is of a dark earthy brown. The predominant hornblende is a dark-greenish black or a pure black. Apatite and titanic iron are very frequent constituents, but are only observable under the microscope. Enclosed between some of the upper beds of gneiss, which are rich in orthoclase and poor in mica, are some sheets of pure amphibole, which are noticeable as containing no other minerals whatever, not even microscopic quartz or feldspar.

A very interesting form of gneiss is found on the west slope of the range, just below Clover Peak. It is a fine-grained, brilliantly gray rock, in which the white particles of quartz and the black micas have a granitoid arrangement; but the rock at large has a distinctly fissile structure, and cleaves easily in sheets of an inch or more in thickness. Besides the hexagonal biotite, there are frequent plates of a brilliant coppery-bronze orthorhombic mica, and the rock is further distinguished under the microscope by containing a great deal of very fine zircon. It is also variably clouded and stained yellow and brown by infiltrated oxyd of iron. The planes which produce the fissile structure are developed by a parallel arrangement of bronzy micas, whereas the solid uncleavable sheets themselves contain biotite and phlogopite, but arranged without any attempt at parallelism. Mica sheets which define the cleavage-planes show a gently undulating surface and many marks of attrition, as if the rock had been subjected to a severe strain and had given way everywhere in a slight interior movement. Throughout the whole formation, with the exception of dioritic gneisses, quartz predominates over the feldspars in quantity. In general there is

more orthoclase than plagioclase when associated in the rock with mica, but in the presence of much hornblende plagioclase takes precedence of orthoclase. These gneisses are particularly instructive as to an interior change, probably due to pressure, which broke up the parallel structure of micas and hornblendes, resulting in a gradual approximation toward the granite form. As a general rule, the more the parallelism of the micas and hornblendes is broken up, the larger individual feldspars, particularly plagioclases, are developed. This whole change seems to have been brought about by longitudinal compression of the beds. At present the rock cannot be distinguished, in hand specimens, from a granite, except that there is even yet an indistinct cloudy parallelism of its dark constituents. Between this stage and the true schistose gneiss, in which all micas are strictly parallel and no crystals of quartz or feldspar break through the mica layers, there is every possible transition. The first symptoms of change are observed in a wavy arrangement of the micas. When carried a little farther, these wavy lines are broken and distorted. Feldspar crystals and grains of quartz are thrust in, breaking the continuity of the mica lines. Signs of compression are then visible in the squeezing of interstitial quartz and feldspar into a confused mass wholly devoid of parallel arrangement. In this condition also it is observable that all the crystalline particles of the rock, notably the micas, are broken into much finer flakes and fragments than in the original schisty stage. These changes are often local, and may or may not continue over any considerable longitudinal extent. Such is the variation of the material of the original beds, that while this breaking up of parallelism may occur throughout one bed, the enclosing strata may experience much less interior disturbance. The argillaceous and the more purely quartzitic beds suffer far less of this species of alteration than mica or hornblende beds. The observer is never at a loss to trace the planes of original bedding through these regions of molecular change.

One of the most interesting places for observing this phenomenon is on the great gneiss precipices forming the eastern front of the range under Mount Bonpland. As the probable result of a great fault, and partly also from the abrupt carvings of the glacial *névés*, fine precipices, 1,500 to 1,800 feet in height, are here exposed. As the gneiss beds dip to the west at an angle of 15° to 25°, the whole wall is formed of their abruptly cut edges, which are traced in nearly horizontal lines, striping the front of the precipice. So well defined are the original beds by the predominance of mica or hornblende, or by the more purely quartzitic nature of some zones, that there is never any difficulty in following a given horizon over long distances. At the same time, the whole series is seen to be clouded in peculiar irregular shadings across the stratification, like an irregular map in different shades of gray. These clouded portions are found to owe their peculiar shade to the greater or less interior disturbance in the mineral particles of the strata. Following the nearly level edges of the series for several miles, they are observed to form gentle up-and-down curves, and always within the concave side of a curve, as would be readily inferred, there is a maximum of interior disturbance of the minerals of a given bed. Simple uniform parallelism was unmistakably the original attitude of all micas. The hornblendes and feldspars lie with their longer prismatic axes in the plane of bedding, and the breaking up of this stage by local longitudinal compression has resulted in more or less comminution of individual crystals, besides crowding the fragments into utter disorder.

Parallel, vertical, longitudinal fissures, trending with this part of the range, are developed along the summit near Clover Peak and Mount Bonpland, apparently a series subordinate to and parallel with the great fault which has produced the eastern wall by dropping the eastern half of the range out of view. Erosion has taken advantage of these clefts and fissures in the rock, to produce a remarkable series of pinnacles 50 or 60 feet high, upon some of which are large, rounded, mushroom-like tops formed of beds which have successfully resisted the weathering.

Near the summit within the gneiss series, and at one or two horizons far below, the microscope reveals, as an occasional constituent of the rock, crystals of calcite; in some instances there are enough of these to cause it to effervesce under acids. There is usually associated with the calcite a predominating quantity of triclinic feldspar, also rich in lime. At the extreme summit of the gneiss there are several beds of thin, brittle, saccharoidal quartzite, among which are intercalated apparently very similar beds of highly compact dolomitic limestone of microcrystalline texture.

The entire limestone series is here not over 50 or 60 feet in thickness, and the individual beds vary from half an inch to six feet. Intercalated with the dolomites are gneiss porphyries nearly identical with similarly associated rocks in Kinsley District. The upper beds pass through transition-beds into the pure quartzite which always contains in its lowest members a little microscopical calcite.

The quartzite series, probably about 2,000 feet thick, appears chiefly along the middle and lower altitudes of the western side of the range, and also overlies the gray gneisses of Clover Cañon. It is very well developed along the upper waters of Boulder Creek.

The Clover Cañon quartzites are probably direct equivalents of the great quartzite formation of the western slope, but show some slight characteristic differences, not enough, however, to render a correlation improbable. They are either white or stained a light yellow-brown by infiltrated oxyd of iron. Quartz, which is both milky and translucent, forms the mass. Under the microscope it shows no trace of the original grains of quartz sediment, but is a confused crystalline aggregate. Garnets, from the size of a pea down to fine microscopical grains, occur in the lower sheets of the Clover Cañon quartzite, together with numerous flakes of white muscovite, which in general are disposed parallel to the bedding of the quartzite. The microscope also reveals fine black plates of hornblende and minute prisms of actinolite, more or less dislocated The Clover quartzites are distinctly fissile, and split with very smooth faces, upon which are seen a multitude of striations indicating longitudinal motion. The surface of these divisional planes is more or less discolored with iron oxyd and spangled with plates of muscovite. Occasionally, rare and minute crystals of feldspar rest on these smooth brown bed-faces. This appearance of striation is in no way due to the parallel arrangement of the mica, but is evidently the result of a true friction owing to longitudinal motion; for the striæ are traced on the strata surfaces in a variety of directions, indicating uneven, irregular, and evidently successive creeping motions. Although developed at intervals throughout the whole quartzitic series, these longitudinal movements have been very irregular, and there are considerable areas which present no evidence of their existence. Observing these marks of motion within the quartzites and gneisses, one is irresistibly led to believe that they are contemporaneous and the result of the same forces; that the effect upon the quartzite is great compression and interior shearing parallel to bedding, while in the gneisses the result is a crumpling within the limits of certain beds, breaking the continuity of the sheets of mica plates, comminution of crystals, and the production of a granitoid rock.

Along the western base of the range, in the vicinity of Thompson's Ranch, the quartzites are duller than those of Clover Cañon and grayer in hue, and though they are still characterized by the presence of muscovite, they carry also a little brilliantly black biotite. Evidence of motion is again observed upon the cleavage-surfaces, and here the mica itself is conspicuously striated. Plate III. shows a ridge of the quartzites east of Thompson's and near the range summit. Higher on the ridge, above Thompson's, there is an interesting case of diagonal cleavage, due to the restricted disturbance of a local fold in the quartzite. Here the muscovites are all diagonal to the induced cleavage, but parallel to the original bedding, the brittle character of the material preventing a rearrangement of micas parallel to the newly produced cleavage-planes. Toward the base of the quartzite series the mica is in some instances replaced by chlorite; and where, as is often the case, this mineral reaches a considerable importance in the rock, it may be properly called a chloritic quartzite. A few straggling garnets are observed in the low members of the quartzite, near the horizon of the dolomitic limestones.

In the rocks here described the reader will have observed a certain general family likeness to those in the main mass of the Wahsatch, in the Farmington region. The association of various mica gneisses and hornblendic, even dioritic schists, succeeded conformably by quartzites, marks an approximate identity of conditions with the Wahsatch and with Medicine Bow Range. The essential minerals of the range are quartz, orthoclase and plagioclase, biotite, muscovite, chlorite, calcite, dolomite, and hornblende, while the accessory minerals are garnet, zircon, actinolite, phlogopite, titanic iron, and apatite.

Cortez Range.—Among the many isolated mountain blocks which corrugate the surface of Nevada, few have greater geological interest than

Cortez Range. At Granite Cañon, directly northwest of Cortez Peak, one of the higher summits of the ridge, a little north of the parallel 40° 15′, appears on the western flanks of the range a solitary mass of granite, surrounded by Tertiary volcanic rocks, which on the north are immense outpourings of buff rhyolite, and on the south high hills of quartz-propylite, culminating in Cortez Peak. Southwest it comes in contact, for a limited distance, with the upturned quartzites which have been referred to the Weber group of the Carboniferous, and on the extreme west its spurs are overlaid by an outburst of diorite, which comes up in a synclinal of Carboniferous rocks. The longer axis of the granite exposure is with the trend of the range, northeast, and is about five miles long, with an extent of three miles in the opposite direction, making a rude parallelogram, with a sharp point invading the rhyolites. The main mass is a single high spur boldly rising from the Quaternary of Crescent Valley in abrupt slopes of about 4,000 feet. It is a rude pyramid lying between two sharp lateral cañons of the range. This granite possesses singularly few divisional lines. It is a remarkably solid mass of a pale cream-color, with shadings of gray and a faint pink. Nowhere else along the Fortieth Parallel is there an example of such extreme solidity with the absence of all planes of bedding or traces of conoidal structure. It is evidently of eruptive origin, and although no clew to its age beyond the unconformable superposition of the Carboniferous conglomerates was observed, for reasons to be educed later in the chapter, it is conceived to be Archæan. It is composed of salmon-colored orthoclase, frequently in broad crystals, slender white prisms of triclinic feldspar, apparently albite, quartz which appears both translucent and of a milky whiteness, long slim prisms of dark-green hornblende, and considerable biotite. Passages of granite which do not seem to be actual veins develop a coarse pegmatite in which the orthoclases reach two inches in length and the masses of quartz an inch. The pegmatite passages are of quite frequent occurrence, but they bear no apparent structural relations to one another. They cloud through the rock in various directions, and shade by perceptible gradations into the ordinary fine-grained variety. Hornblendes here gather in confused aggregations of needles. Besides the biotite, there also occurs an orthorhombic mica, doubtless muscovite. Under the microscope the quartz is seen to contain many fluid inclusions. The rock also shows under the microscope a little magnetic iron and some apatite.

South of this body, and obscurely occurring within the diorites of Agate Cañon, is an insignificant outcrop closely resembling the granite of the Sierra Nevada, and composed of quartz, orthoclase, plagioclase, biotite, a brilliant black hornblende, which is peculiarly cleavable, and macroscopical titanite. Owing to a considerable alteration in the feldspars, although both are clearly present, it is difficult to decide as to the predominance of plagioclase or orthoclase. Of this decay of feldspar Zirkel says: "The product of this decomposition is rather curious. It consists of broader or narrower prismatic, colorless rays, which, either orderless or confused, cross each other like a felt or are heaped together in forms of stars and bunches, presenting beautiful aggregate polarization." This little mass is entirely surrounded by diorites, and may be a granite dike subsequent to the dioritic outflow. Although classed by Zirkel as a granite, it seems to me quite possible to consider it as an unusually quartzose passage of diorite, since nearly all the diorites of the Fortieth Parallel contain, besides the prevalent hornblende and plagioclase, a little quartz, occasional mica, and a small proportion of orthoclase. It is only necessary to increase these to a very slight extent to reach the composition of a granite rich in plagioclase and hornblende and poor in quartz and orthoclase. Frequently in the great granite fields of the Sierra Nevada are observed passages which are unquestionably mere dependencies, in which plagioclase and hornblende predominate over orthoclase and mica. In such instances the quartz is apt to run low, and the rock, although a true granite, possesses the mineral nature of the abnormally quartziferous and orthoclastic diorite. It seems quite proper, when this same combination is found closely related to a dioritic outburst, to consider it rather as a diorite than as a granite, and such the Agate Pass body may well be. But since it has passed under Zirkel's microscope as granite it is here included with those bodies.

South of Cluro Station, on the Central Pacific Railroad, is a group of hills standing out in Crescent Valley and separated from Cortez Range by a broad, shallow pass. They are composed of a central body of granite invaded by syenites and overlaid on the west by a quartzite, which is referred, for the sake of convenience, to the Weber. The granite body is about five miles long by a mile broad, with a second outcrop near the western end of the hills, where a little dome rises through the horizontal Pliocene strata. The granite is essentially the same as that of Granite Cañon, in Cortez Range, lately described.

Near the southwestern terminus of Cortez Range stands a very high, bold peak, called by the Indians Tenabo, which signifies "lookout," a point commanding a very extensive view of middle Nevada. The main body of the range here is composed of a mass of granite which rises from the Quaternary plain of Crescent Valley, and extends to within 800 or 1,000 feet of the summit, where it is overlaid by a capping of somewhat crystalline limestone, which has been referred by Mr. Hague to the Upper Coal Measure series. The overlying lime strata which rest unconformably upon the granite extend down the southern slope of the peak for three or four miles, making an irregular oval body entirely surrounded by granite. It is one of those interesting relics left by erosion which give a clew to the relative topography of the modern and Archæan uplifts, for to that age the Tenabo granite is referred. The pass between Crescent and Grass valleys, which at Shoshone Wells has only an elevation of 1,000 feet above the plain, is also formed of the granite, which in passing westward is seen to be overlaid by the rhyolites of the Railroad Peak group. At its northern limit the granite is again overlaid by the limestones of the north flank of the range, also supposed to belong to the Upper Carboniferous. Mill Creek and the lesser streams on the north flank of Mount Tenabo flow through ravines of considerable depth, which offer excellent exposures of the granite, here seen to be a very tough rock, difficult of fracture, and with little tendency to disintegration. It varies very much in texture, from fine to medium grained, and from light to dark gray tones, the latter being due to the variability of the proportion of feldspar and mica. It is composed of rather small translucent grains of quartz, both orthoclase and plagioclase, with dark, partially decomposed biotites. The rock near the western end of the exposure, in the vicinity of the Shoshone Wells, is of a rather lighter color than the main body of Mount Tenabo, but otherwise shows little difference. Between the forks of Upper Mill Creek, under the western slope of Tenabo, a mass which comes to the surface as an intrusive body through the granite bears a close resemblance to the dioritoid granite of Agate Pass, already described. It is compact and fine-grained, breaking with difficulty under the hammer, and showing along its fracture a rough, uneven, angular surface, and has an almost cryptocrystalline groundmass, composed chiefly of quartz, plagioclase, and fibrous hornblende. Like the Agate Pass rock, however, it contains a considerable proportion of orthoclase and quartz and a little biotite. Titanite, which occurs in the Agate Pass rock, was not observed here. It seems rather to represent an intermediate link between the granite and the diorite, and, like some of the bodies already mentioned in the great granite fields of the Sierra Nevada, may be considered a dioritoid dependence of granite, or simply a granite in which triclinic feldspar and hornblende are present in abnormal quantity; the diagnostic point in such bodies being their association.

Wah-weah Mountains.—Directly south of Cortez Range, and only separated from the foot-hills of Mount Tenabo by the low pass of Gordon Cut, which connects Grass and Gordon valleys, is a narrow mountain group called the Wah-weah, of which only the northern eight or ten miles lie within our map. On the west side of this group, in latitude 40°, is exposed a small body of granite underlying quartzite. The granite extends about three miles in a north-and-south direction.

Seetoya Range.—North of Humboldt River, in longitude 116°, is an irregular range extending from six miles north of Carlin Station to the northern limits of the map, a distance of about 45 miles. At Nannie's Peak, the summit of the range, near the head waters of Susan Creek, is a granite outcrop coming to the surface through limestones of the Lower Coal Measures and brought in contact with a body of peculiar rhyolite. The mass is made up of a series of rude beds, having a strike from north to northwest and a dip of 65° westward, in conformity with the overlying limestone beds, which upon the west and south flanks of the body are wrapped closely around the granite. The bedding-planes of the granite are distinct. The higher peaks of the range are formed of very thick projecting strata of a granite which has all the interior lithological character of the eruptive type. It is composed of quartz containing numerous fluid inclusions, some of which bear salt cubes, distinctly striated plagioclase, which is quite undecomposed, rare apatites, and orthoclase, which slightly predominates over the other feldspar and is not infrequently quite decomposed, showing here and there a distinct zonal structure, resembling sanidins in the trachytic family. Parts of the rock consist of a fine-grained accumulation of small crystalline particles of quartz and feldspar like the groundmass of a felsite porphyry. One variety contains little particles of hornblende, which seem to have been formed at the expense of the mica. Both of these granites are entirely free from titanite. That on the eastern slope of the range has a tendency to split into thin slabs, probably from contact with a curious rhyolite which once overflowed it and is now found farther down on the spurs. At the southern end of the high peak, in contact with the granite, appears a small body of true granitic porphyry. Farther south, at Maggie Peak, a long, narrow mass of granite porphyry protrudes through the overlying rhyolite, extending six miles in a north-and-south direction, being two miles broad at Maggie Peak. It seems to be an original Archæan summit, lifted above the limits of the rhyolite overflow. The groundmass consists of a fine mixture of quartz and feldspar, in which the crystallization is unusually good. It contains infrequent clear granules of quartz, which Zirkel found, under the microscope, to be full of liquid inclusions, some of which contain salt cubes, both orthoclase and plagioclase, and an abundance of mica crystals. Apatite, very rare in corresponding German rocks, attains here a remarkable sharpness of crystallization. Green hornblende is occasionally found as an accessory mineral. At Maggie Peak itself is a light-gray variety, consisting very largely of a compact, homogeneous groundmass, containing a very few large feldspar crystals. It is a rock which macroscopically bears a close resemblance to rhyolite, but under the microscope the felsitic groundmass has the same structure as the other porphyries, and its quartzes are full of fluid inclusions.

Toyabe Range.—In latitude 39° 30′, longitude 117°, in the neighborhood of the town of Austin, near the western base of Toyabe Range, is a limited body of granite, upon which rest limestones and slates referred to the Carboniferous period, and which is partly environed by flows of rhyolite that evidently at one time entirely submerged the granite, but was eroded off at a later period, leaving traces of its former presence in a peculiar reddened and decomposed condition of the granite surfaces. This decayed condition of the surface is well shown on the divide above Austin. The undecomposed, normal granite is an even-grained gray variety, consisting of quartz, slightly flesh-colored monoclinic feldspars, and pale-greenish plagioclase in about equal proportion, both very well crystallized, dark-green brilliant hornblende, black biotite in sharply defined hexagonal plates, the last two minerals in about equal proportion, and a plentiful development of titanite, the crystals of which are sometimes one eighth of an inch long. The mass presents no evidence of bedding; on the contrary, it is altogether structureless, with the exception of innumerable faulting-planes, accompanied by veins of metaliferous quartz and granite dikes. The divide above Austin approaches more nearly to the source of the rhyolitic overflow, and is here penetrated by innumerable fissure-planes. Chemical decomposition has gone on to a great extent, resulting in the complete kaolinization of the feldspars, which, however, still retain their crystalline outlines. Hornblende, mica, and titanite have disappeared, leaving amorphous earthy spots. The quartz alone seems to have resisted decomposition. It remains unchanged, except by the development of innumerable cracks and the occasional infiltration of cloudy kaolinic matter.

Rare as caustic contact phenomena are, the commonest examples in western America are where granite has been overflowed by volcanic rocks, and the characteristic features in such cases are the development of innumerable vertical fissures and general infiltration of hydrous sesquioxyds of iron and manganese. In the Fortieth Parallel area there are no such extensive exhibitions as may be seen on the upper Stanislaus River in California.

Directly east of Austin, in the Park Mountains, occurs a similar granite, in which the two feldspars are distinctly marked. Hornblende decidedly predominates over the mica, titanite being absent. Here, also, to a certain extent, decomposition has taken place. Passages are exposed in which the feldspars can be no longer distinguished, and the hornblendes appear in light-green, partly decomposed fibres, the mica having almost entirely disappeared. While the interior decomposition of the granite is evidently due to deep-seated causes, such as the penetration of acid vapors and waters through the innumerable cracks and fissures, the peculiar superficial crumbling and peroxidation of the iron minerals is doubtless due to the effect of suddenly overpoured molten rhyolites.

SHOSHONE RANGE.—The meridian of 116° 45′ passes through an exposure of granite lying about six miles east of Shoshone Peak. It is a rudely oval body, with the longer axis extended about four miles in the direction of the meridian, and with an east-and-west extent of about three miles. Along the south it is overflowed by a great body of rhyolites which skirts the east base of Shoshone Range for many miles. Otherwise it is surrounded by upturned quartzitic strata, which have been referred to the Weber group of the Coal Measures. The relation with the uptilted strata is somewhat obscure; indeed, it seems to be one of the most difficult geological problems afforded by this region, to decide, in a locality where confusedly tilted strata come in contact with eruptive granites, whether the latter have protruded through the strata in a plastic state, or have been thrust up as an underlying solid point. The configuration of the granite topography of the Archæan surface prior to the deposition of the Palæozoic series, was that of an area of mountain ranges, possessing some very abrupt precipitous walls, sharp, lofty peaks, and broad, low domes. Where these came to be uptilted together with superjacent strata, and afterward exhumed by erosion, which brought to light granite peaks piercing through highly inclined beds, it often becomes absolutely impossible to determine the relation of the two. In the absence of any granitic dikes penetrating the stratified series, or of peculiar local metamorphism, or of general evidence of intrusion, the bodies are usually referred to the old Archæan topography. Only in cases where the granite is actually seen to penetrate either fissures or warped openings in the strata, is it safe to refer it to a later origin than the sedimentary series. This question, as applied to the majority of the granite exposures of Nevada, will be more thoroughly discussed later in the chapter.

Structurally the Shoshone granite develops in interesting perfection the broad conoidal bedding after the type of the Sierra Nevada domes. The rock is composed of predominant quartz, orthoclase and plagioclase in almost equal proportion, biotite, a great deal of easily cleavable black hornblende, and a little microscopic apatite. For uniformly mixed granite there is an unusual discrepancy in the size of the quartz and orthoclase particles. Quartz masses from half to three fourths of an inch in diameter are observed, carrying many enclosed plates of biotite and fluid inclusions. Excellent hexagonal biotite crystals were observed, whose faces are covered with an interesting iridescent tarnish. The color of the plagioclase is a clear white, and it appears in stout crystals resembling albite. The orthoclase shades from white to rusty yellow, owing to microscopic infiltrations of iron oxyd.

The cañon of Reese River severs Shoshone Range into two well marked divisions. The southern portion is a single broad flood of rhyolite, from which, at a few localities, rise isolated outcrops of older rocks. At Ravenswood Peak, certain of the Carboniferous beds, an intrusion of diorite, and small exposures of granite and granite porphyry occur. For eight miles south of that point, the summit is formed of one of these outcropping islands of older rock lifted above the slopes of the rhyolite. It is a narrow meridional mass of granite, about eight miles long and from one to three miles wide, flanked upon either side by narrow zones of steeply dipping schists. This stratified series dips east and west away from the central granite mass, which has rather the appearance of an intrusive core. From their likeness to other known Archæan rocks, and for the want of reasons to the contrary, these schists, together with the granite, are referred to the Archæan. Parallel divisional planes standing at a very high angle occur with considerable regularity in the granite, giving it almost an appearance of stratification. As the identical granite penetrates the schists in the form of a dike, there seems no doubt that the whole mass is of eruptive origin. It consists of quartz, orthoclase, a few scattered grains which appear to be minute crystals of plagioclase, and white orthorhombic mica—probably muscovite; but there is no hornblende, black mica, or titanite, and very little apatite. The dike which invades the schists is made up of a similar but coarser-grained material, in which there are clearly two feldspars (the predominating one a white or pale salmon-colored, smoothly cleaving orthoclase) and a few minute prisms of triclinic feldspar, large accumulations of grains of smoky quartz, and irregular bunches of muscovite.

There is something unusual and suggestive in the superior coarseness of the mineral components of the dike. Ordinarily, over the area of this Exploration, dike minerals have far greater fineness than those in the parent irruptive mass, due not unfrequently to friction and comminution during intrusion. Perhaps the state of things here is explained by supposing that within the walled and protected dike there was less opportunity for the intercrystalline attrition due to orographical movement than in the larger and more exposed body.

The accompanying schists are of two types. One is a very fine-grained compact rock, whose broken faces display a very steely crystalline shimmer, as from extremely small facets. Yet even the loupe does not discover any crystalline ingredients, the general appearance being that of a fine-grained anamesite; the microscope, however, develops an aggregation of very minute particles of quartz and two micas, biotite and muscovite. Besides these, on the western flank are found series of fine mica schists having the same composition as the more compact rock, except that the constituent particles are larger, and that parallel sheets of minute mica plates produce a bright, irregular reflection of light from the whole surface. They may be called spotted mica schists, and are not unlike those described in the neighborhood of the Irish granites by Haughton. These spots, which the microscope made out to be densely compacted grains of mica, are not thick enough to give it the name of "*Knotenschiefer.*" It seems probable that the spots represent the features of local metamorphism after the manner described by J. Clifton Ward in his article on the granitic, granitoid, and associated metamorphic rocks of the lake district.* These spotted schists are closely allied to the rocks of the Wright's Cañon mass in West Humboldt Range, the main difference being that here the constituent particles are finer, and there are interesting bronze passages of schist whose color is derived from infiltrated oxyd of iron.

Augusta Mountains.—On the eastern side of the Augusta Mountains, near the northern end of Edward's Creek Valley, is exposed a small body of granite about two miles in extent, overflowed and surrounded on the north and west by rhyolite, which here forms the dominant rock of the

* Part III., Quarterly Journal of the Geological Society, Vol. XXXII., page 1.

range, and separated from the Quaternary of the valley by a belt of sedimentary rocks of Alpine Trias age. Save that the Trias reposes unconformably upon it, there is no clew to the age of this granite. Lithologically it belongs with the older eruptive granites, and is composed of grains of varying size of pellucid or slightly smoky quartz, a very large amount of somewhat earthy orthoclase, considerable biotite, a small but varying proportion of hornblende, and a very little apatite. Some specimens show the orthoclase of a pale olive-green color, and peculiar strings of crumpled, decomposed mica. The biotite shows an unusual facility for decomposition, so that the exposed and weathered faces of the rock exhibit numerous hexagonal pits, out of which the products of decomposition have been washed.

Fish Creek Mountains.—Fish Creek Mountains, the northern extension of the Augusta group, are almost entirely formed of rhyolite. Along the western slope of the northern extremity of the range are a few limited basaltic outflows, and the extreme western base, to the west of Mount Moses, shows a narrow band of granite extending along the foot-hills for about four miles north-and-south, by less than a mile in width. It is overlaid unconformably by Triassic strata. It is a dense, compact rock, composed of quartz, orthoclase, and biotite, with a little plagioclase, and is destitute of structural indications of a metamorphic origin. It is doubtless to be classed with granites in the regions lying to the northwest, which represent a general Archæan highland over which the Triassic beds are laid down. Together with the limited exposure at Granite Point, where it is again overlaid by Triassic strata, these granitic foot-hills near Mount Moses represent a portion of an Archæan body which may be largely developed immediately beneath the immense flood of rhyolite now covering the surface of this early range.

Havallah Range.—A little north of latitude 40° 30′ Havallah Range, in passing northward, bifurcates like a rude letter Y, the most eastern arm trending off about 25 miles in a northeasterly direction, and sinking below the Quaternary plains in the region of Stone House Station. The upper fifteen miles of this arm are composed of a lofty mass of granite, which rises abruptly to its culminating points nearly 4,000 feet above the plain. On its southern edge, at Summit Springs Pass, the granite is overlaid by

Alpine Trias strata. The plain of Ragan's Valley on the west has an altitude of 4,500 feet, the highest summit of the granite body reaching 8,150. The topography is decidedly rugged, and it is more minutely varied than the usual exposures of Archæan rocks in Nevada. It is all but certain that even during the deposition of the Trias and the conformable Jura, parts of this range were lifted above the limits of deposition and suffered erosion from a very early period. The broken and serrated outline which characterizes the summit of this group renders it essentially different from the neighboring granites. Although not possessed of any distinct planes of bedding, this occurrence, in many of its physical aspects, recalls the metamorphic granite bodies described in Colorado Range. It is coarse-grained, ill-compacted, and readily disintegrates, leaving irregular-shaped fragments. There seems to be far less uniformity of texture than is usually the case in eruptive granites. The prevailing color is a dull gray. The essential constituents are quartz, orthoclase, plagioclase in brilliant but small crystals, bearing wonderfully fresh striæ, small dark plates of biotite, more or less decomposed, and a little hornblende in small, dark-green crystals. The orthoclase occurs in crystals of various sizes, some of them reaching three inches in length and having broad tabular faces with brilliant lustre. They are usually a bluish, smoky gray, near the ordinary hue of labradorite. Infiltrations of oxyd of iron have penetrated the rock in every direction, leaving a thin ocherous coating on many of the broad faces of the feldspars. Under the microscope Zirkel discovers many points of interest in this rock. Apatite, magnetic iron, and muscovite seem to be accessory minerals. The reader is especially referred to Zirkel's memoir for a description of the inclusions of the feldspar. He describes the quartz granules as containing three forms of liquid inclusions. simple water-bubbles, liquid carbonic acid, and compound bubbles containing both water and carbonic acid.

On the east side of the range, a little north of Summit Springs, the main body of granite is penetrated by a narrow dike which has clearly the properties of an intrusive body and bears a close resemblance to the granites of the Sierra Nevada type. The association of intrusive granite bodies with the older forms of Archæan granite is decidedly exceptional over the area of the Fortieth Parallel. In Colorado Range there are indeed some instances of bold intrusive masses penetrating the essentially metamorphic granites, and in the case of Mount Clayton and the Little Cottonwood mass, in Wahsatch Range, there is probably a repetition of this association; but it is extremely rare in the country west of the Wahsatch. The granite dike north and east of Summit Springs is a comparatively fine-grained rock, breaking with difficulty under the hammer, and leaving an uneven, angular surface. The constituent minerals have a fresh, unaltered appearance, and in color the rock is of a brilliant gray, of which the irruptive Californian rock may be considered a type. It is composed of quartz, orthoclase, brilliant, pearly plagioclase, biotite, and hornblende, and the microscope detects a very minute proportion of hair-brown titanite. Hornblende and plagioclase rise to considerable importance as principal constituents, almost to the point of shading the rock into those questionable bodies which appear to lie between granite and diorite. Indeed, we have only to increase these constituents a little to produce the dioritoid rock of Cortez Range. Biotite is in the form of brilliant, symmetrical, black hexagons. The hornblende is very dark green, and has an extremely fibrous structure, suggestive of the hornblende belonging to the propylite family. The quartz contains a few salt-bearing fluid inclusions.

Dikes of fine-grained diorite, composed of dark-green hornblende and triclinic feldspars, occur within a few miles of Summit Springs.

On the northwest side of Ragan's Valley, opposite the above-described granite body, is another exposure of the same sort. It is only about ten miles from north to south and four miles east-and-west. As the map indicates, it is partly overlaid by strata of the Alpine Trias period, the east base being wholly bordered by the Quaternary plain of Ragan's Valley. On the west it is about equally bounded by Quaternary of Rocky Creek, rhyolites which extend southward from Golconda Station, and Alpine Trias of the main Havallah Range. Though of much lower and less conspicuous topographical configuration than the body to the south, this second mass is, by its petrological nature, closely related to the Summit Springs body, and may be considered as the northern extension of it, merely separated from the main mass by a shallow covering of Quaternary. It is, perhaps, a little less loosely compacted, and is distinguished from the other body by distinct bedding-planes, which have a rather gentle dip toward the west. Near its southern extremity, directly north of Cold Run Creek, the granite is penetrated by a dike between 20 and 30 feet in width, which stands nearly vertical, striking with the trend of the Havallah. It is a dense, dark-gray rock of high specific gravity, with a fine microcrystalline groundmass, in which crystals of hornblende and occasional segregated groups of mica plates are porphyritically inclosed. Essentially made up of quartz and hornblende, it is probably another of those singular dioritoid dependencies of granite which are often seen connected with large bodies of that rock.

A third granite locality within Havallah Range is exposed upon its west base, between the mouths of Clear Creek Cañon and Bardmass' Pass. Here a strip of granite, nowhere over a mile wide, extends along the extreme foot-hills of the range, sloping under the Quaternary of Grass Valley and flanked upon the east by beds of the Alpine Trias series. Topographically it consists of the points of three main spurs of the range, weathered into rounded and conical hills. As usual, where forms are at all pointed, the granite is of a hard, compact texture and resists weathering most determinedly. It is of a dark, warm gray tint, and consists of quartz, orthoclase, brilliant striated plagioclase, a little dark-green hornblende, and a very little mica. In general, it may be characterized as of eruptive habit.

Pah-Ute Range.—Pah-Ute Range traverses Map V. from north to south with a remarkably sinuous trend, consisting mainly of a broad convex curve thrown to the east, with minor convexities at each end turned westward. It consists essentially of Archæan rocks, granites, and granitoid gneisses, overlaid by the immense conformable series of Trias, Alpine Trias, and Jura; and these in turn are overlaid and deluged at different points by Tertiary volcanic rocks. The granitoid masses in the neighborhood of Tarogqua Peak, in the southern part of the range, have been but little studied. The mass of Granite Mountain is in every way the most important Archæan body of our part of the range, and in consequence has received much closer study than the other.

Granite Mountain mass is an oval body, touched by the parallel of 40° 15′, having its longer axis of about twelve miles extended in an east-and-west direction, with a shorter diameter of about eight miles. This exposure is wholly composed of granitoid rocks having a distinct east-and-west strike and standing at very high angles—indeed, approaching the vertical. It is interesting to observe that, while these Archæan strikes are altogether in a direction approximating to the east-and-west line, the later sedimentary rocks of the range are all nearly in a north-and-south position. This Archæan strike makes itself particularly felt in the lesser topographical structure of the body. As may be seen by a glance at the map, the leading streams near the contact of the granite body with the quartzites to the north have nearly easterly directions. The granitoid rocks which constitute this exposure are made up of quartz, orthoclase, and plagioclase, with minute, unimportant additions of mica and hornblende. In short, it is essentially the same aplitic compound as that already described in Colorado Range. They are distinctly bedded, but without any observed parallelism in the arrangement of the individual minerals. The rock is a light, flesh-colored mass, generally medium grained, and is more or less clouded with stains of infiltrated iron oxyd. Decomposition has gone on to a certain extent in the orthoclase and mica, but the triclinic feldspars, which are probably oligoclase, have retained their original freshness and brilliance. The dark biotite is gathered into minute segregations of broken flakes, and it seems to be far more prevalent in some east-and-west zones than in others. Under the microscope, Zirkel detected liquid carbonic acid in the quartz. Black tourmaline occurs in veins of granite east of the geodetic station on the summit of Granite Mountain; also brown iron garnets associated with light mica. On the ridge east of the summit of Granite Mountain is a narrow band of feldspar porphyry, having an east-and-west strike and lying conformably with the granite zones. It consists of a microgranitic groundmass of a brilliant grayish-white, stained here and there by oxyd of iron, and carrying brilliant crystals of feldspar and irregular granules of pellucid quartz. It seems to be referable to the same origin as the granite itself, and is to be classed with the granitoid porphyries of Kinsley District and Franklin Buttes. It is an exceptionally fine-grained zone of metamorphic granite, not an intrusive dike.

About fifteen miles to the north, along the east side of the range, is another important exposure of granite. At Granite Mountain the Triassic beds are flexed around the eastern end of the granite mass, but here they bend around the western side, the whole line thus describing a sort of sigmoid curve about the two granite centres. The topography of the Spaulding's Pass mass is that of lofty conical hills and high rugged spurs, the slopes of which descend to the level of Grass Valley. It is a hard, compact, medium-grained, light-red granite, without the evidences of bedding or the variability of zones seen at Granite Mountain. It is probably an eruptive rock, related to the small body at the western base of Havallah Range, directly across Grass Valley.

West Humboldt Range.—On the west side of West Humboldt Range, about six miles north of Sacramento Cañon, is exposed in the body of the range a mass of granite and accompanying crystalline schists. They are well seen in Wright's Cañon and in the two cañons next north. The whole exposure is in the form of a broad oval, about four miles in its longer direction of northwest-and-southeast. The southern two thirds are of true eruptive granite, the remainder a variety of crystalline schists. This body is evidently an old Archæan summit, over which the quartzites, argillites, and limestone beds of the Alpine Trias were deposited. At the post-Jurassic period of folding of this range the Archæan mass was somewhat driven through the strata and slightly shoved to the west, throwing the strata into sharp curves, the Alpine Trias limestones and quartzites wrapping completely around the north and west sides of the body. In the region of Wright's Cañon the granite is more or less intersected by jointing-planes, which strike mainly northeast or northwest, standing nearly vertical. At the top of the cañon are developed certain broad conoidal bodies, not unlike those of Shoshone Knob, by no means comparable with the Sierra Nevada domes, but still suggesting the true conoidal habit. These two localities and the so-called City of Rocks in Southeast Idaho offer examples of fairly regular cones, which on the whole seem to be the result of a kind of weathering due to a soft and rather decayed exterior. There are none of the characteristic conoidal shells which are developed in so symmetrical a mode throughout the domes of, for instance, the Merced region in the Sierra Nevada. The rock is composed of a very coarse-grained association of colorless and dusky quartz, yellowish and white orthoclase, either very little plagioclase or none at all, and two species of mica—a white muscovite chiefly included within the quartz masses, but now and then scattered in minute white spangles through the orthoclase, and a normal proportion of biotite, which is at times a good deal decomposed into a brownish-green fibrous condition, suggestive of the transition into chlorite. Black hornblende occurs, but it is segregated into bunches not well disseminated through the rock. Neither titanite nor apatite was observed. The contact of the granite with the associated family of schists is very interesting; it shows in horizontal plan an irregular, angular intrusion of granite into the schist, with outlying insular masses of schist wholly enclosed within the granite, or promontory-like masses jutting from the schist into the granite. One of these points extends 400 or 500 feet into the granitic mass. On the edges of these included bodies of schist, and indeed along the whole contact between granite and schist, there is no tendency toward a passage by gneissoid gradations between the two rocks; the line of demarkation is always sharp and clearly observable. In the vicinity of the schist the granite is penetrated by a great number of structural planes, having a strike partly with the bedding of the schists, as if the partings of that rock had somewhat controlled the lines of fissure. There is also another set of joints, with a direction of north 36° west, or approximately at right angles to the schist. A few dikes of granulitic material, containing rare crystals of feldspar and a few raspberry-colored garnets, invade the schists. As a whole, the schists strike about north 50° east, and are either vertical or dip at a high angle to the northwest.

The lower members of the altered sedimentary rocks are excessively fine-grained mica slates, carrying coarse limpid granules of quartz. It is a *Knotenschiefer* in which the nodules are aggregated heaps of mica flakes or nuclei of large grains of pellucid quartz, around which the flexible, matted mica scales are bent. The mica appears to be chiefly muscovite, although small flakes of a black variety, probably biotite, are present. An interesting peculiarity of this rock is the minute corrugation of the sheets of mica, which are flexed between the mica and quartz nodules. The whole surface of one of these sheets of felted mica is corrugated in the most minute wrinkles, of which fifty or sixty can be traced in an inch.

An irregular decomposition has taken place between the laminæ of the rock, resulting in a bright, almost orange-colored oxyd of iron. The lower mica schists are dark silver-gray. Above these occurs a zone of creamy-white or yellow-stained mica schists, made up almost wholly of minute quartz grains and excessively small plates of muscovite, embedded in which, as in the last described lower series, are large grains of limpid quartz, sometimes one fourth of an inch in diameter, and disposed like pebbles in a conglomerate, the mica bending over and enclosing them. In this also the same minute, interesting corrugation bears witness to an internal compression of the whole series. An association of excessively fine muscovite with such large angular fragments of quartz is not found elsewhere in the Fortieth Parallel area. Passing up in the series, the muscovite gradually gives place to minute quartz grains, but it still contains a few of the large pellucid quartz fragments. Here again the internal corrugation is seen upon every fracture-surface, and the rock becomes a quartz schist. These quartz individuals are somewhat difficult to account for. At first glance they might be explained as the small pebbles of a conglomerate whose argillaceous matter had passed by metamorphism into muscovite. Such unaltered conglomerates are not unknown in the Rocky Mountain Cretaceous—rocks in which small pebbles are thickly interspersed without the ordinary arrangement parallel to the stratification. Another, and doubtless a sounder hypothesis, is the aggregation during metamorphosis of like particles with like, as is seen in the Archæan gneisses of Humboldt Range, where groups of orthoclase form in the midst of a felt of rusty biotite.

MONTEZUMA RANGE.—In the Montezuma Hills, Archæan rocks play a very important rôle. The range is topographically divided into several groups, separated from each other by considerable depressions and distinguished by great geological variety. A prominent depression in the region of latitude 40° 30′ severs the range and permits the beds of the Miocene Tertiary to stretch through from valley to valley. North of this pass the range rises to a high granitic summit in Antelope Peak, and dipping away from either flank of this are great masses of rocks which have been referred to the Jurassic period. On the extreme northern and eastern edge it is in contact with the Quaternary beds of the Humboldt plain, and also with a limited outflow of basalt which skirts its base. The body lying to the east of Antelope Peak is of rather less extent, though similar in position, being flanked on the west by the slates of the Jurassic series and on the east by the basalt and the Quaternary plain. About its southern point are wrapped the disturbed strata of the Truckee Miocene.

South of the pass the range again rises to a lofty ridge characterized by quite complicated topographical forms. It is made up of a middle band of granite, accompanied upon either side by flanking belts of Archæan schists. This composite body has an extent of twenty miles in the direction of its trend, by about twelve miles in extreme breadth. The isolated knob of granite rising out of the Humboldt plain west of Lovelock's Station, called Lovelock's Knob, may be regarded as a dependence of the main Montezuma granite. So also the several granite outcrops from which erosion has removed the general covering of basalt in the spur west of Granite Point are subordinate parts of the larger block. For a distance of fifty miles, therefore, granite is a frequently recurring feature; and, together with the crystalline schists in the region of Trinity Cañon, it may be said to constitute the core of the range. South of Valley Cañon the whole range consists, with but unimportant exceptions, of volcanic outflows which have overwhelmed and submerged all the older rocks. The slight exposures in the vicinity of Lovelock's Knob and Granite Point are chiefly of a coarse, crumbling granite, very rich in orthoclase, and in rather large, irregular grains of pellucid quartz, together with a sparing quantity of more or less decomposed biotite

The most important Archæan exposure is that which culminates in Trinity Peak. Here the granite belt, from twelve to fifteen miles long by four miles broad, occupies the higher portion of the range. It is deeply sculptured by erosion, and the sharp cañons lay bare a depth of from 1,200 to 1,500 feet of granite slopes. The general surface shows a great deal of the results of easy disintegration, in the form of granitic gravel which often masks the more solid portions of the rock. At the northern extremity of this body, west of Rye Patch Station, the rock is a uniform fine-grained mass composed of quartz, orthoclase, a little oligoclase, and plentiful mica and hornblende, the latter of a dark-green color and decidedly fibrous crystallization. Biotite is present in well developed hexagonal plates, which are usually more or less decomposed and stained an earthy brown.

Directly south of this body, and four or five miles northwest of Oreana, in the midst of a broad field of rhyolite, is an isolated hill of granite, which is of interest as forming the country-rock of the Montezuma Mine. Like the granite west of Rye Patch, it consists of quartz, both feldspars, hornblende, and mica, but, if anything, it is rather more decomposed. It belongs to the decidedly basic granites, and although more siliceous than that of the Wachoe Mountains, approaches it in composition. This whole Trinity body of granite is undoubtedly of eruptive origin, as may be determined from its general habitus and from its penetrating the Archæan schists in well defined dikes.

From this granite core the two bodies of Archæan schists dip in contrary directions, forming a steep anticlinal. The eastern body, well shown in Trinity Cañon, has a dip of 60° to the east; that on the west side of the range, directly west of Trinity Peak, dips from 50° to 60° to the west, with a well defined strike of about north 45° east. In these schist bodies there are 4,000 or 5,000 feet of conformable beds of a remarkably uniform appearance. Their color ranges from dark steel-gray to black, with a fine but brilliant lustre on the freshly fractured and cleaved faces. The naked eye is only able to detect a fine microcrystalline mass, but the microscope resolves the body into a compact admixture of quartz, biotite, muscovite, and magnetite. In all the specimens we obtained there is a total absence of both feldspars. Throughout the upper part of Trinity Cañon the schists are penetrated in different directions by small granite dikes, petrologically allied to and doubtless depending upon the main, middle mass of granite.

The second large body of granite already indicated as lying east of Antelope Peak in that portion of the range north of Indian Pass, so far as our slight geological observations go, appears to be a petrological repetition of the larger body. The two are of medium texture and of a variable light color, being made up of quartz, orthoclase, and large amounts of well developed brilliant hexagonal plates of biotite. It would seem, therefore, that the central body, which is associated with the Archæan schists, differs from the other granites of the range in its considerable proportion of hornblende, while that of Lovelock's Knob and that of Granite Point seem to be more nearly uniform with the two northern bodies in the low percentage of hornblende and the presence of well developed hexagonal biotite. These bodies are referred to the Archæan age simply on petrological evidence. This mode of correlation is dangerous, but a general study of the whole region has strengthened the belief that in the Palæozoic series as a whole there are none of those results of extreme metamorphism which in the Appalachian system are described by some geologists as closely approximating to Archæan forms.

Pah-tson Mountains.—From the Quaternary plain west of Indian Pass rises an isolated body of mountains extended about twenty miles a few degrees east of north, and having an extreme width of about eight miles in the middle of the body, near Pahkeah Peak, the highest point of the range. This summit rises about 3,300 or 3,400 feet above the desert plains at its base. The group consists essentially of a small mass of granite and Archæan schists, extending from near the northern limits of the hills southward for ten miles along the west side of the range, rising toward the centre, and occupying the summit in the region of Pahkeah Peak. Eastward, the entire Archæan series is surrounded by outflows of Tertiary volcanic rocks, chiefly rhyolite and basalt. The Archæan nucleus itself consists of three distinct members: crystalline schists closely resembling those already described in Trinity Cañon on Montezuma Range; a limited amount of granites; and a subsequent granite which has broken through the older granite and schists, overflowing them in a broad field to the north. All the crystalline schists occupy a region from the mouth of Crusoe Cañon to the mouth of Frost Cañon, with a breadth of about three miles, culminating in Pahkeah Peak. To the unaided eye they closely resemble the fine granular-crystalline condition of the Trinity Cañon schists, but under the microscope Zirkel found them to be composed of quartz, biotite, and muscovite, with, in one instance, thin laminæ of a third mica, having an oil-green color. As in the Montezuma schists, there is no trace of either feldspar, and no tendency either to a minute schistose arrangement of the beds or to interior parallelism between the constituent minerals. There is, however, a distinct broad bedding, which defines a very high dip and a north-and-south strike. Associated with these is a further development of a fine-grained homogeneous rock, which, though possessing little outward resemblance to the quartz and mica rock, is nevertheless nearly related to it. It occurs near the head of Crusoe Cañon, the high ridge southwest of Pahkeah Peak, and has the aspect and fracture of a quartzite, but the microscope shows it to consist of minute crystals of delicate green hornblende and quartz. Feldspars are again totally wanting. The rock appears to be exactly like the other schists, with the substitution of hornblende for mica. In contact with the schist body is a limited exposure of granite, whose original northward extension is wholly unknown, since it is overlaid by a more modern granite, to be described later. Near the head of Crusoe Cañon this older granite appears with a surface characterized by great decomposition, resulting in rusty earthy débris, and even the more solid parts of the rock have an extremely friable texture. Quartz, orthoclase, and muscovite form the chief constituents.

Both this granite and the accompanying schists are more or less intersected by dikes, likewise supposed to be of Archæan age. One in particular is observed in Crusoe Cañon, a very fine-grained, pearly-gray granite, in which are coarse passages of pegmatite, carrying the quartz both in broad irregular masses and fine-grained passages; orthoclase crystals, not infrequently four inches long, and having the lustrous appearance of pure, undecomposed feldspar; muscovite, lepidolite in thin laminæ, brilliant black crystals of tourmaline, and garnet intimately associated with colorless muscovite. Neither biotite nor hornblende is present. Other dikes traversing the schists in the same region possess a very fine-grained association of the same minerals, the tourmaline especially rising to so high a percentage as to carry the rock into the schörl granites. Whatever may have been the origin of this dike, whether distinctly eruptive, or, as seems to the writer far more probable, the result of hydrothermal secretion, it is an interesting fact that in its body are included noticeable masses of the crystalline schists, which have either fallen in during the process of formation or in some manner been involved while the rock was in a plastic condition.

Lying to the north of Pahkeah Peak is a stretch of granite extending for four or five miles, which apparently overlies and masks the older granites already described. It is a very fresh, clear, bright-grained stone, with none of the evidences of decomposition and ferric infiltration which characterize the underlying variety. Quartz, orthoclase, a high percentage of plagioclase, mica and hornblende in variable quantities, and titanite enter into its composition. Under the microscope considerable apatite, specular iron, and occasional bodies of magnetic iron are seen. In the petrographical scale it comes near the basic limits of granite, having of silica 64.02, while there is twice as much soda as potash, which indicates either a predominance of plagioclase or that the orthoclase belongs to that group in which the proportion of soda rises to unusual prominence.

North of the Pah-tson Mountains, and lying in the gap between Grass Cañon and the Kamma group, are three isolated outcrops of granite coming to the surface through the Miocene beds. They are of no interest, except as indicating the northward continuance of the Pah-tson granite, which in the region of Grass Cañon is undoubtedly buried beneath the Tertiary volcanic rocks. Finally, it may be said that the entire habitus of both species of granite is distinctly that of an eruptive product bearing no resemblance whatever to those we have classed as metamorphic.

Pah-supp Mountains.—West of the Pah-tson group, and entirely surrounded by broad fields of Quaternary, is a very irregularly shaped group, which has been called the Pah-supp Mountains. It consists of a prominent, bold ridge, extending in a well defined line along the eastern margin of the body, and a long, irregular slope to the west, invaded on the north and south by bay-like regions of Quaternary. The main sharp ridge, which has a trend of 15° or 16° east of north, attains an altitude of a little over 3,000 feet above the desert, and is flanked on the eastern foot-hills of its north and south extremities by narrow bands of highly inclined slates and calcareous shales which have been referred to the Jurassic age. The main body of the range is of a uniform granite, not to be distinguished in its mode of occurrence and general features from the more recent of the granites of the Pah-tson. It consists of quartz, orthoclase, plagioclase, hornblende, and mica, and only differs from the other in the absence here of macroscopic titanite. Under the microscope Zirkel observed in the quartz a great number of fluid inclusions. The granite is frequently traversed by fine narrow seams of quartz and thin veins of fine-grained, massive feldspar, varied by a few scattered grains of quartz. Toward the north end of the group, opposite the Kamma Mountains, the granites are more compact and rather lighter colored, owing to the diminished proportion of mica and hornblende. The quartz, too, occurs in rather larger transparent grains. An isolated body of granite lies to the south of this group and establishes a geological connection between it and the Sahwave Mountains. The single specimen brought in from this knob distinctly identifies it with the Pah-supp hornblende-plagioclase-bearing granites. Like the Pah-tson body, and indeed like the neighboring granites of Truckee and Granite ranges, this mass is unmistakably structureless.

Granite Range.—The region in the northwest corner of Map V., representing the limit of our labors in that direction, is occupied by an extensive table-land of basalt known as the Madelin Mesa. Its eastern boundary abuts against a sharp, high ridge of granite which enters the area of the Fortieth Parallel Exploration from the north, and extends southward twenty-five miles to the region of Mud Springs and Granite Creek Station. It is a from eight to twelve miles wide, rising at its culminating points to 6,000 feet above the level of the desert Excepting the volcanic rocks which skirt its base upon the east and west, it is wholly composed of a single mass of granite, of decidedly uniform texture, and producing, both in the spurs and in the dominating peaks, only rounded and dome-like forms. On the extreme heights northwest from Granite Peak Station, imperfect conoidal structure is developed. From Truckee Range, whose extreme northern point almost comes in contact with the Granite Range body, it is separated by a strip of level desert. This is rather a topographical than a geological separation, because Truckee Range for many miles to the south is itself made up, as will be seen hereafter, of a precisely similar granite. So far as examined, Granite Range consists of a rock having all the features of the neighboring masses of the Truckee, Pah-tson, and Sahwave Mountains. The rock possesses an even, middle-grained texture, breaking quite readily under the hammer. In composition it is a mixture of either white or translucent grains of quartz, orthoclase, plagioclase (probably albite), biotite, hornblende, and frequent hair-brown and golden-yellow titanite. Many of the plagioclases have extremely brilliant surfaces, upon which are traced the characteristic twin striations. As usual in this family of granites, the hornblende and mica are most variable.

TRUCKEE RANGE.—The Archæan exposures of Truckee Range lie wholly to the north of Nache's Pass. From that depression to its northern extremity in the region of Mud Lakes, the range is nearly a continuous body of granite, with a few limited outcrops of Archæan schists and an unimportant mass of Triassic slates, together with a great development of Tertiary volcanic rocks in the region of Nache's Pass. The Archæan body is composed of schists and of granites representing two periods of formation. First in order will be described the limited occurrence of schists.

In the region of Nache's Peak, directly on the 40th parallel, at the east side of the range, and lying in immediate contact with the main granite body, is a development of Archæan schists which occupy the eastern foothills of the range for about nine miles. Among these, one from the summit of Nache's Peak deserves special mention. To the naked eye it presents the appearance of a fine microcrystalline stone, in which no individual particles are determinable. Under the microscope it appears as a fine-grained mixture of plagioclase and hornblende with a little quartz. Although without much doubt a metamorphic rock, and essentially a member of a series of schists, it has exactly the composition of a slightly quartziferous diorite. It is indeed mineralogically the counterpart of those dioritic gneisses already described in Medicine Bow and Park ranges, as well as in the Wahsatch and Humboldt. But it has this distinction, that its particles are relatively very much finer than those of any of the dioritic schists in the ranges far to the east. South of Nache's Peak the series seems to be made up of dark mica schists having a decidedly fissile structure, and composed, like the dioritoid rock above mentioned, of exceedingly fine-grained particles. It is essentially made up of minute granules of quartz, with biotite and muscovite. Zones of fine, dark, steely-gray quartzitic schists are also interstratified with the other beds. In some of the banded quartzitic rocks, in which white and nearly black layers repeatedly alternate, the microscope discovers that calcite is present in numerous brilliant crystals. Two or three miles west of Luxor Peak, in the northern part of the range, is exposed a small body of Archæan schists; and again twelve miles to the north the granite is flanked by a narrow belt of schists, a mile and a half wide by six miles long, placed with the strike of the range. Both these unimportant northern exposures are accompanied by outflows of basalt, which mask their dip toward the plains of Mud Lake. Neither outcrop possesses any especial geological interest, except as indicating a considerable extension for the schists of the range. It would seem that in many of these western Nevada ranges the structure is that of a simple anticlinal, having a broad, massive granite core with crystalline Archæan schists dipping away from either flank. Subsequent erosion has removed a great amount of the schists, and the horizontal Tertiary and Quaternary beds have so buried the flanks of the ranges that only small portions of the old schists are visible. Could the horizontal and overlying beds be all removed, there would doubtless be found a great amount of crystalline schists. The lithological resemblance is so intimate, and the area over which they are exposed is in reality so limited, that all these detached outcrops of schists may be thrown into one series, which formerly extended over the whole country. Their resemblance is more intimate when correlated by the mechanical condition than by their mineral composition.

Southeast from Winnemucca Lake is a small body detached from the main granite mass of the range, flanked along the east by strata referred to the Trias, and on the north and south by outflows of rhyolite, the western slope plunging beneath the Quaternary plain. The rock bears the aspect of a readily crumbling metamorphic granite, and is composed chiefly of quartz, flesh-red orthoclase, and a few minute crystals of plagioclase. The only mica is muscovite, and that occurs in so small a percentage, and is so unevenly disseminated through the rock, as to justify the term "aplitic granite." A further specimen from the same body is made up of quartz, partially decomposed orthoclase and plagioclase—the former much the more abundant of the two—and a little regularly disseminated biotite. The muscovite-bearing granite of this body seems to be the older of the two.

North of Nache's Peak, the main range, as well as the accompanying body of the Sahwave Mountains with which it is solidly connected, is composed, so far as known and wherever we have visited it, of a dioritoid species of granite. It is of a medium grain, varying from a yellowish-gray to a pure bright-gray, and is noteworthy from the rarity of its disconnected divisional planes. It is made up of quartz, orthoclase, plagioclase, biotite, hornblende, and titanite. The microscope, as usual, also shows a few small crystals of apatite. Here, as in the other bodies of this particular type, every mineral component of the rock seems to be nearly uniformly disseminated through the mass. As a whole it is a granite characterized by relatively very high percentages of hornblende, mica, and plagioclase. The minerals are comparatively fresh and undecomposed, and the plagioclase is more nearly related to albite than to oligoclase.

Quartz veins and fine-grained granite dikes traverse the coarser mass of Truckee Range, in many places carrying more or less massive black hornblende. Hot Springs Butte is a detached continuation of the range just beyond its northern extremity, near the borders of Mud Lake Desert. It is a single knob of granite, of the dioritoid type, rising 1,000 feet above the Quaternary plain.

Lake Range.—That portion of Lake Range which lies north of Pyramid Lake consists essentially of a central body of granite broken through and surrounded on the south by fields of basalt which slope to the shore of the lake. On its eastern exposure, from near the lake shore to a point four miles north of Pah-Rum Peak, it is overlaid by a series of dark shales, which have been referred to the Jurassic age. Northward, save for a few basaltic interruptions, the granitic mass extends between the two valleys of Mud Lake Desert until it is bounded on the north by a body of gneisses, which it penetrates like a tongue. The Archæan body is about twenty-four miles from north to south, with an extreme width, in the neighborhood of Pyramid Lake, of ten or twelve miles. The granite is of the hornblende-plagioclase type, and does not differ from that so frequently occurring in contiguous ranges. In gneisses at the northern end is observed a singular mineralogical analogy to the associated granite. But they possess a distinctly gneissoid structure, and are distinguished from the near granite by the absence of titanite. They are composed of a very fine-grained mixture of quartz, plagioclase, parallel-arranged mica (probably biotite), and considerable hornblende. The microscope reveals apatite, and also the fact that the quartz granules are very poor in liquid inclusions; two characteristics which would seem to establish a parallelism between the granite and the gneiss. It is, however, quite similar in composition to many of the gneisses already described in the Wahsatch, Humboldt, and Rocky Mountain regions, except that it is very much finer-grained, as are all the metamorphic sedimentary rocks of the Archæan in western Nevada. It is essentially a dioritic gneiss, containing considerable quartz and mica. The mineral constituents have a remarkably fresh, brilliant appearance, common to nearly all the schists of the neighborhood.

Peavine Mountain.—In the southwest corner of Map V. is an Archæan body, lying a few miles north of Truckee River, and sweeping up from the valley of that stream in bold slopes to the dominant point of Peavine Mountain, which has an altitude of 8,217 feet. The body measures a dozen miles from east to west, by about seven miles from north to south. On the north it is entirely surrounded by granite, on the south the inclined strata of the Truckee group of Miocene rest against it, and the eastern end is overflowed by a mass of Tertiary andesite. The whole mountain is built of a series of conformable, highly altered beds, striking from north 50° to 65° east, which consist for the most part of fine-grained quartzite strata, riven in every direction with minute fissures, which are filled with a ferruginous material. The less decomposed parts of the quartzite carry small grains of magnetite and occasionally a little yellowish-green epidote. It is obviously the decomposition of magnetite which produces the iron infiltration, giving the prevalent yellow color to the body. The felsitic beds contain similar iron seams, and are likewise much discolored by the products of decomposition. In the region of the Bevelhymer Ledge there is an obscure occurrence of rock which retains a fresh, undecomposed appearance, made up of dull, opaque orthoclase, some plagioclase, a little hornblende, and mica. It seems to be of eruptive origin and to indicate a sort of connecting link between syenite and diorite.

California Border.—From Peavine Mountain Pass to State Line Peak, and from the western boundary of the map as far east as Louis' Valley, extends an irregular mass of granite which is topographically varied by winding ridges, the whole being invaded by irregular valleys of Quaternary, which are, in truth, nothing more than the modern material disintegrated from the neighboring granite hills and washed down into basin-like depressions. The region has not received sufficient study to make it certain that all the granite is of one type; but as far as observed it seems to consist of quartz, orthoclase, plagioclase, biotite, and hornblende; and in all thin sections examined the microscope reveals a plenty of apatite crystals. There are no indications of a metamorphic origin of this general body; on the contrary, it possesses all the appearances of a granitic extrusion, and is no doubt intimately related to the granite mass of the Sierras. On the ridge opposite Spanish Springs Valley occurs an exceedingly fine-grained variety of granite porphyry, in which the individual minerals cannot be recognized by the naked eye. The microscope reveals quartz, orthoclase, beautifully striated plagioclase, biotite, and shattered, imperfect crystals of hornblende. It would seem to be a porphyritic condition of the neighboring granite, differing only by the minuteness of its particles.

SECTION II.

CORRELATION OF ARCHÆAN ROCKS.

By referring to Analytical Geological Map I., at the end of this chapter, the reader will observe five Archæan districts where exposures are indicated in the characteristic map-color of that age, namely: the Rocky Mountains, including those portions of Colorado and Park ranges within the limits of this Exploration, as well as the whole Medicine Bow Range; Red Creek region, on the north flank of the eastern end of the Uinta Mountains; the Wahsatch core and neighboring Archæan islands; middle Nevada District, comprising the Humboldt Range body, Kinsley District, and Franklin Buttes; and western Nevada District, embracing the schists of Montezuma and Truckee ranges and the quartzite of Peavine Mountain. All other exposures of Archæan age are colored as granites. The intention of this distinction is to separate those formations which are of sedimentary origin from the class of eruptive rocks.

Two causes prevent the drawing of such a line with entire precision: First, there is a frequent doubt as to the true nature of certain granitoid rocks which are allied on the one hand to eruptive granites by mineralogical constitution as well as by a broad concentric structure, but related on the other hand to a series of gneisses whose bedding and passage into demonstrably sedimentary beds mark the granitoid member as only the extreme form of a series increasingly metamorphosed in depth. These questionable rocks, where well shown, as in the case of the Laramie Hills, have almost invariably been considered by us to be of metamorphic nature and classed with the series of clastic origin. A second difficulty is encountered where limited bodies of granite are exposed under unaltered sedimentary beds, as throughout Nevada. Such masses, showing no trace of sedimentary origin, and quite disconnected with any crystalline schists or other Archæan sedimentary rock, especially where the arrangement of their constituent minerals is after the granitic habit, have been called simply granite, with a general belief that they are of eruptive origin. The further erosion of overlying rocks might in many cases reveal such relations with crystalline schists and gneisses as to compel the belief that the granites are metamorphic. Again, among those colored as granite a majority are instances of unmistakably intrusive origin. The distinction indicated on the map is therefore only approximately true.

It is not easy to analyze those subtle appearances which lead the observer to incline to one or the other of the two possible modes of origin of a granite outcrop. Parallelism of bedding, and even parallelism of the arrangement of minerals, are consistent with the theory of an eruptive origin. Certain passages of gneissoid granite appearing in the great eruptive granite body of the Sierra Nevada show quite as much parallelism of bedding and internal arrangement of minerals as the Rocky Mountain granites to which we have assigned a metamorphic origin; yet the Sierra field, as a whole, is clearly eruptive. But at the same time, in the intimate arrangement of the mineral particles, and in the mode of contact between the various mineral ingredients, there is a certain broad uniformity in all the eruptive granites which produces a characteristic impression upon the eye. On the contrary, the granites which we conceive to have been of metamorphic origin, no matter how simple the mineralogical composition, have always a peculiar variability of arrangement; and even in the absence of any pronounced parallelism, they show the effect of interior compression and irregular mechanical influences. On the one hand, in the eruptive granites there seems to have been a steady expansive force, doubtless due to the heat and elastic fluids, which gave to all the particles a certain independent polarity, while in the metamorphic granites they seem to have been crowded into constantly conflicting positions. As the result of this, the crystalline particles of the metamorphic granites are much less apt to have completed their crystallization, or, if it was completed, they have been crushed and torn asunder and their particles scattered, while in the case of the eruptive granites crystallization seems to have been more perfected. The result of this is to give to the eruptive granites something of the uniformity of texture of a volcanic rock, while all the metamorphic granitoid rocks, when once the gneissoid parallelism of minerals is broken up, have a crushed, irregular, and confused mode of arrangement. Under the microscope especially, there is usually observed a considerable difference between the two types, in the amount of dislocation and of intercrystalline movement or crushing, the structureless granites often containing perfect hexagons of biotite or completed hornblende, while in the gneissoid granites a defined crystal of one of the less coherent constituents rarely if ever appears.

METAMORPHIC ROCKS.—In Colorado Range are two typical series which in all probability are unconformable. The lower, as already shown, consists of gray and pearl-colored aplitic granites with metamorphic facies, overlaid by a red granitoid member, having little parallelism of interior arrangement or evidence of stratification beyond a general tabular bedding, also decidedly aplitic, though carrying rather more mica than the gray variety. Over this lies a third member, very red, with an extremely variable but small amount of mica broadly but distinctly bedded. A similar series is observed in the Black Hills and recurs in Park Range. A small granitoid body in Mill Cañon, Wahsatch Range, is referred to this series. The whole group is essentially made of quartz, orthoclase, oligoclase, very little biotite, rare muscovite and lepidomelane, and extremely little hornblende, with accessory masses made up of labradorite, diallage, ilmenite, graphite, and magnetite. Taken with the dependent development of gabbro, ilmenite, magnetite, and graphite, the resemblance to known Laurentian bodies is so strong that we have little hesitation in referring our series to that age. In this connection the assignment by Dawson of closely similar rocks in Manitoba and British Columbia should be remembered. If, as we suppose, these exposures represent all the metamorphic Laurentian within our area, it is a very noticeable fact that limestones, dolomites, quartzites, conglomerates, pyroxene rocks, and the various hydrated Laurentian forms are wanting, and that among the irruptive species gabbro and felsitic porphyries only occur. A little chlorite is the only representative of the hydrated minerals. A rude estimate would place the thickness of the series at about 25,000 feet.

A second and equally well characterized series of metamorphic rocks is found in the upper horizons of the Medicine Bow, and also in the higher members of Park Range, Red Creek in the Uinta, the Wahsatch and Salt

Lake islands, and the exposures in the Humboldt Mountains, Franklin Buttes, and Kinsley District. Probably to these localities should be added a portion of the gneiss, schist, and quartzite formation of Colorado Range, south of our map.

This series consists of true gneisses, often decidedly granitoid, and made up of quartz, orthoclase, biotite, rare muscovite, and plagioclase, associated and repeatedly interstratified with mica schists, both of biotite and muscovite, the white mica beds sometimes carrying garnets; hornblendic schists, in places pure amphibolite, and again amphibole and quartz, with either orthoclase alone or plagioclase alone, or the two associated. Sometimes the hornblende unites with plagioclase to form a true dioritic gneiss. In several of the hornblende rocks where mica is either absent or plays a minor rôle, zircon is present in minute crystals, visible under the microscope only, but freely disseminated through the mass. The above described series is exposed certainly 12,000 or 14,000 feet thick in Wahsatch Range, about the same in Humboldt Range, and probably somewhat less in Park and Medicine Bow ranges; but in the Clear Creek region of Colorado Range it shows not less than 25,000 feet.

Conformably overlying this group is a thick development of argillites, siliceous schists (carrying in places a hydrated chloritic mineral, and verging toward the nacreous schists of Canada), jaspery conglomerates with a fine siliceous matrix, iridescent hornblende schists, quartzites more or less rich in minute feldspar crystals and carrying also a variable amount of muscovite and chlorite, and finally white or gray dolomitic marbles.

The upper part of the series seems to be variable in the sequence of its members and in thickness. The best exposures occur in the Medicine Bow, where there must be between 3,000 and 4,000 feet.

The whole series—gneisses, amphibolites, dioritic gneiss, garnetiferous mica schist, and zirconiferous amphibolite schist, quartzite, and limestone—occurs in the Medicine Bow and Humboldt. The lower or gneiss and amphibolite schist portion is represented in Park Range, in the Wahsatch, as also probably in the schist zones overlying the granitoid Laurentian part of Colorado Range.

At Kinsley District and Franklin Buttes are observed only the upper limit of the gneiss (here porphyroidal), together with white dolomite; the same association and intercalation as at Mount Bonpland in the neighboring Humboldt Range. The Archæan islands of Salt Lake, which were not especially examined by us, evidently belong to the same series.

Argillites are best developed in the Medicine Bow and Salt Lake islands. As a whole, this second series bears more than a superficial resemblance to the Huronian of Canada, and to that age, with some hesitation, it is provisionally referred. G. M. Dawson, finding essentially the same two series in the Rocky Mountains, near the 49th parallel, makes the same reference. With the Huronian is classed also the Red Creek exposure of quartzite, dioritic schists, and paragonite rocks, carrying garnet, staurolite, and cyanite; so also, a limited area of intensely metamorphosed quartzite at Peavine Mountain, near the California boundary.

Between the rocks thus referred to Laurentian and Huronian ages, there is a characteristic difference in the intensity of metamorphism and obliteration of original structure. The former are essentially granitoid in type, and show lithological changes only when examined over considerable areas, or up and down through a rather wide vertical range. Bedding is wanting, except in the upper members, and even there it is rather of the character of a tabular structure, made up of beds varying from a foot to five feet in breadth, than a true stratification. On the other hand, the supposed Huronian zone is always distinctly, often minutely, stratified; and, moreover, a conspicuous feature is the permanence of the mineral character of beds over considerable distance.

Gradual changes are observed in the mechanical condition of single beds. They may be characterized in one place by fine-grained, minute crystallization, in another by the assemblage of very coarse, large particles. Here is seen a strict parallelism of the mica or amphibole particles; a little way off, owing to inequalities of pressure and consequent interior mechanical rearrangement, the constituent minerals may possess the mode of aggregation of a granite or porphyry. Observed over great distances, it is true that changes are detected in the chemical character of a given bed, but here the limit of change ends, and we fail entirely to observe any of those rapid mineralogical fluctuations so frequently noted by some other students of Cordilleran geology.

As between the different contiguous beds of the series, there is indeed a constant variability shown. Every conceivable permutation possible to quartz, mica, hornblende, orthoclase, and plagioclase seems to be brought out and repeated again and again; but within the limits of a single bed the chemical and generally the mineralogical constitution are rigidly preserved. Even in the single exception to this, where chloritic matter replaces by pseudomorphosis either garnet or mica, the alteration is strictly confined to the affected bed, never in a single instance clouding off into the bounding strata.

Where the stratification is thin, and where irregularly crumpled regions have been eroded, there is often great difficulty in identifying or following a given bed, existing surfaces often showing a very gentle bevel of the edges of the members of a series of strata. So in passing from one to another it is many times hard to determine the divisional plane, and hence probably the cause of such expressions as "this mica schist passes rapidly into a syenite," or "this hornblendic schist in a few feet passes by imperceptible gradation into an orthoclase granite."

Whatever changes occur within a given stratum of the crystalline schists, even including the pseudomorphism of hydrated chloritic minerals after anhydrous silicates, are due to a mere mechanical or chemical rearrangement of particles within the bed, and there is no tendency whatever to break up the chemical constitution of a given stratum, no disposition on the part of a stratum to scatter its minerals up or down into adjacent beds. Instances of this permanence of constitution are constantly seen in single zones of dioritic gneiss or of pure black amphibole rock, lying between white quartzites, without a trace of hornblende one inch from the main bed; or a garnetiferous muscovite gneiss enclosed in a biotite gneiss, never with the least tendency for the garnets to straggle up or down. In the heavy white quartzites of Humboldt Mountain there are garnetiferous zones and muscovite-bearing zones, but they are rigidly confined to their own horizon. Whatever, therefore, may have been the cause which rendered the original sediments crystalline, it failed to impregnate one zone with the chemical elements of its neighbor. Evidences of metamorphic alteration, such as results in other Archæan regions in the production of talcose bodies, are almost altogether wanting. A protogenoid granite of limited extent indeed occurs on War Eagle Mountain, Owyhee District, Idaho, and also in immediate contact with mineral veins in Colorado Range; but these are obviously due to the action of very modern causes and are restricted so closely to fissured regions as rather to fall under the head of vein phenomena.

The appearance, on a microscopic scale, of chlorite after garnet in the beds of the Wahsatch and Humboldt, is paralleled in a large way in Archæan schists observed by the writer near the head of Santa Maria River in Arizona, where large garnets, equal in size to those described by Pumpelly on Lake Superior, are changed into a pale-green chloritic mineral.

Slaty hematites are seen feebly represented in the schists of Ralston Creek, Colorado Range, under the quartzites. The specular-iron schists which occur in the region of Prescott, Arizona, are wanting in the Fortieth Parallel area.

The mechanical disturbances that have taken place within given beds which are simple and comparatively unchanged as to their chemical nature, seem to be worthy of a second mention here. In treating of the Wahsatch and Humboldt, it was said that certain beds show a passage from a parallel arrangement of minerals to a granitoid mode of disposition of particles. In the varying dip, sinuous strike, and deep bellying down of certain folds, there is abundant evidence of irregular mechanical strain. The general shrinkage of beds by superincumbent weight is a phenomenon too well known to need description here, but besides this there is often ample evidence of longitudinal compression. The strata of dioritic gneiss, true gneiss, mica schist, and even so compressible a rock as quartzite, show an interior crumpling, already described in detail, which breaks up the parallel schistose arrangement of particles and squeezes the minerals into a granitoid irregularity. It is evident that great longitudinal compression, due to the sagging down of a very thick series when brought to bear in a group of beds, does not meet so sharp a resistance as to produce a crushing, or even a very localized effect; but the strain is relieved by a wide-spread readjustment of particles, after the manner of granite.

In the Humboldt gneisses, and conspicuously in the dioritic gneisses at the mouth of Ogden Cañon in the Wahsatch, this phenomenon may be most interestingly observed. It should be said that this effect has gone no further in our Huronian rocks than the destruction of parallelism within beds. This being true of rocks which have not been subjected to very intense and complex disturbance, it would seem only necessary to heighten and magnify the action to obliterate the parallel structure through great masses and produce out of bedded rocks, by mechanical means alone, many of those puzzling granitoid forms which by certain subtle, difficultly analyzed appearances, give to the field observer the impression of a metamorphic origin. How else than by crushing of the constituent particles can we account for those grains of quartz which have upon their peripheries the open pits that could only have been formed as the walls of fluid inclusions? The above suggestions are not intended to have a positive application beyond the gentle action described in our supposed Huronian beds, but only to indicate that the precise limit of purely mechanical action on already crystallized schists is at present unknown, and that it may possibly include the comminuted granitoid Laurentian rocks.

It would be altogether unsafe to make from the character of the Archæan outcrops of the Fortieth Parallel a generalization as to the fundamental rocks of the whole United States Cordilleras. In the wide areas which are still unexamined geologically, there is ample room for a repetition of all the Appalachian phases. At the same time one cannot fail to notice the widespread simplicity of petrological forms, the prevalence of granites, granitoid gneisses, and dioritic metamorphic rocks, the paucity of argillites, quartzites, limestones, and zirconiferous and staurolite schists, the infrequence of large bodies of magnetic, specular, or spathic iron, and the complete absence of corundum, chrysolite, serpentine, steatite, pyroxene rocks, the true nacreous schists, and other minor forms observed in the Appalachian system.

Without doubt, the most interesting laws which come out of the comparison of these exposures are, that when considered in depth, from the uppermost limits of our so called Huronian to the lowest Laurentian exposure, there is, first, a regular, steady increase of the intensity of metamorphism, and secondly, a pretty regular increase in the thickness of individual members of the series. The lowest Laurentian aplitic granitoid bodies of the Laramie Hills are the heaviest beds and the most changed from their original sedimentary condition. The higher Huronian group of gneisses, quartzites, conglomerates, dolomites, and argillites are at once the most thinly bedded and least metamorphosed. Individual beds remain as specialized as the day they were deposited. At the lower exposures of the whole Archæan formation well defined crystals are of great rarity; even microscopic apatite, the best presented species, is generally crushed and dislocated; micas are distorted, and all feldspars are more or less fragmentary. A marked contrast is observable at the upper extreme. Here many micas, hornblendes, garnets, and even feldspars are nearly if not quite completed crystals. The exceptions to this are those places already described, where local compression has broken up the original arrangement of the crystalline ingredients.

The western Nevada schists are exposed as a series, never over 4,000 or 5,000 feet thick, of rocks whose constituent particles are in a fine state of subdivision. They are largely compounds of quartz, muscovite, and biotite, or quartz and hornblende. Feldspars are rare, and in most cases all the crystalline ingredients are only resolvable under the microscope. Appended to this section is a table of analyses of metamorphic rocks.

Granites.—Leaving out of consideration those forms which are deemed to be of metamorphic origin, the eruptive granites will be seen by reference to the map accompanying this chapter to be, so far as the belt of the Fortieth Parallel is concerned, situated west of longitude 111° 30′, or west of the east base of Wahsatch Range. Nearly every considerable mountain body between the Wahsatch and the California line shows in the lower horizons exposures of one or more bodies of granite. A petrological comparison of these exposures leads to a classification into four distinct groups.

The first type consists of quartz, orthoclase, a few minute and unimportant crystals of plagioclase, and *muscovite*, with a small but variable percentage of microscopical apatite. The granites of this type are all west of Reese River, longitude 117°, and in each case are associated with the western Nevada type of Archæan schists, consisting of a very fine microcrystalline combination of quartz, biotite, muscovite, and magnetite, or quartz, hornblende, and magnetite. Muscovite granite occurs at the Ravenswood Hills in Shoshone Range, and in the Pah-tson Mountains, where it contains pegmatite passages made up of the same minerals as the granite, only on a far larger scale of crystallization. A third outcrop of muscovite granite is in Truckee Range, in the body southeast of Winnemucca Lake. This last named locality has been but little studied, and is chiefly surrounded by outpourings of Tertiary volcanic rocks, and its relation with other members of the Archæan series is altogether unknown. As to the age of the granites of this type, we have practically no adequate data. At Ravenswood Peak the muscovite granite is intimately involved with the upturned crystalline beds, and is clearly overlaid unconformably by the rocks of the Carboniferous. There is little doubt of its Archæan age, but its reference to that period is only on general lithological grounds.

The second type consists of quartz, orthoclase, little plagioclase or none at all, *biotite*, and microscopic apatite. It is essentially a granite, like type the first, with the substitution of biotite for muscovite. It has a rather wider range than the other, making its first appearance in Ombe Range, west of Salt Lake Desert, and reappearing westward to the California line. It is found in Ombe Range, at Nannie's Peak in Seetoya Range, at Mount Tenabo in Cortez Range, in the neighboring Wah-weah Mountains, in the granite body of Montezuma Range lying east of Antelope Peak, and finally in the hills southeast of Winnemucca Lake, Truckee Range, where it is associated with the muscovite granite of the first type As in the first type, the microscope always reveals a small but varying proportion of minute apatite.

The third type consists of quartz, orthoclase, little or no plagioclase, *biotite*, *hornblende*, and microscopic apatite. Its distribution is co-extensive with that of the second type. It makes its first appearance in the Goose Creek Mountains, a little east of the 114th meridian, and reappears at intervals (often in close proximity to the granites of the second type) westward to the 120th meridian. It is developed at Goose Creek; at Granite Cañon in Cortez Range; near the head of Susan Creek in Seetoya Range; at Shoshone Knob and the Wood Ranch Cañon, both in Shoshone

Range; at Granite Point, Augusta Mountains; in the Havallah; near Spaulding's Pass, Pah-ute Range; at the Montezuma mine, and in Montezuma Range west of Rye Patch Station. It is distinguished from the second type by the presence of hornblende.

The fourth type presents the most complex petrological features of any of these families of granite, and consists of quartz, orthoclase, *plagioclase*, which is often equal in quantity to the orthoclase, and sometimes exceeds it, usually a high percentage of biotite, with an equal proportion of *hornblende, titanite* visible to the naked eye, and a high proportion of microscopic apatite. The rocks of this group display their minerals usually in a very fresh, undecomposed condition. In general, the rocks differ from those of the third type by the presence of macroscopic titanite, and by the high proportion of plagioclase and hornblende, which sometimes dominate over the orthoclase and biotite, and throw the affinities of the granite toward a diorite. Indeed, there is but little difference between those diorites that are unusually rich in orthoclase, mica, and quartz, and the granites of this type, which have an uncommonly high proportion of hornblende and plagioclase. The presence of titanite is not a distinguishing feature, for some of the diorites possess that mineral in the same proportion as the rocks of this group. So, too, microscopic apatite is common to both rocks. In the previous type the plagioclase always, or nearly always, approaches oligoclase; in the present type it is often albite. While the granites of this group are perhaps the most prominent as regards geographical distribution of the truly eruptive varieties observed by the writer in the system of the Cordilleras, and while they possess a great uniformity of appearance from the Wahsatch to the Sierra Nevada, it is true that those dependences of diorite which mineralogically approach it are of extremely rare occurrence, and are always so related to dioritic masses as to be clearly recognized as a dioritic variety. There is therefore little danger of ever confounding the granitoid diorite with the extremely dioritic members of the fourth type.

This classification, based upon field observations, is interestingly carried out by Zirkel, whose microscopic examinations in every way confirm the field arrangement. To his interesting chapter on granites the reader is referred for those minute yet important interior phenomena which characterize the granites of all these families. The table of analyses of the eruptive granites accompanying this section gives a single instance of the second type, that of Nannie's Peak; two of the third type, from Shoshone Knob and Wright's Cañon; and the remainder of the table is devoted to the rocks of the fourth type. Of these latter it is seen that the range of silica embraces the extreme members of the series, that of Agate Pass reaching 75 per cent.; while in the Wachoe granite the silica is only 55½ per cent., representing with one exception the most basic granite of which there is any published analysis, and with the one referred to, that of Ardara, described in Haughton's paper on the rocks of Donegal,* it is almost identical in composition, both chemically and mineralogically. In general the granites of the fourth type in Western Nevada are rather basic, the rock of El Capitan in Yosemite Valley furnishing about the normal chemical type.

When seen in appositions which give a clew to the relative ages of the several types, it is found that they occur in the order given, the muscovite being the oldest, the dioritoid variety the youngest. Passing from muscovite to dioritoid species, the chemical acidity declines to a minimum in the Wachoe occurrence.

In denominating these groups of granite as eruptive, it is only intended to indicate that in their relations to the contiguous Archæan schists they have the appearance of intrusive bodies, and that in their interior structure and general mode of occurrence there are none of those evidences of alliances to the crystalline schists which are observed in the granitoid gneisses of so many localities, especially in the Rocky Mountain region. In so-called eruptive granites there is neither parallelism of general bedding nor of interior arrangement of the minerals, and the most ordinary phenomenon of structure is the development of conoidal shapes formed of concentric layers varying in thickness from a few inches to 100 feet. This structure, so far as observed, is strictly confined to the hornblende-bearing granites, and never makes its appearance in those of the first and second types.

While among the rocks of the Fortieth Parallel this phenomenon of conoids is only obscurely shown, in the great hornblende-plagioclase body

* Transactions of the Royal Irish Academy (1859), Vol. XXIII., p. 608.

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TABL LEL.

Number of analysis.	Locality.	Remarks.
14	Wachoe Mountains -	aring liquid inclusions, orthoclase l. unaltered plagioclase, large indi- ide and biotite, microscopic apatite, black microlites.
15	Granite Peak, East R Mountains	ions, orthoclase, much plagioclase, tite, and frequent macroscopic titan- apatite.
16	Hills west of Granite Cr Nevada	in inclusions than granite given he same mineral composition.
17	Shoshone Knob, Shosho	ery little plagioclase, hornblende, roscopic apatite.
18	Yosemite Valley, El Ca	nclusions, orthoclase, albite, biotite, , apatite.
19	Cañon north of Wrigh West Humboldt	nclusions, orthoclase, rare plagio- opic apatite, zircon!!
20	Egan Cañon, Egan Ran	nsiderable plagioclase, biotite, spar-
21	Nannie's Peak - - -	lusions, carrying salt cubes, ortho- ttle biotite, microscopic apatite.
22	Cottonwood Cañon, Wah	clusions, orthoclase, much plagio- e, biotite, titanite, apatite.
23	Agate Pass Cañon, Cortez	ch plagioclase, hornblende, rare

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of the Sierra Nevada, which is both geographically and mineralogically the characteristic occurrence of this type of granite, the dome forms assume a most imposing scale and become some of the most prominent topographical features in the granite area. So far as these concentric conoidal shells throw light upon the outbreak of the granite, they seem actually to indicate something like the original form due to violent extrusion of the plastic though not fluid bodies.

Although instances of each granitic type are found unconformably underlying the low members of the Palæozoic series, this is not the case with each outcrop; many granitic masses are found unconformably underlying Mesozoic or even Tertiary volcanic rocks. But there is absolutely no evidence whatever in favor of the belief of granitic extrusions later than the Archæan age. With so many mountain ranges deeply fissured and faulted, broken and thrown into all conceivable positions, there would seem to be abundant exposures to find intrusions of granite into the crevices and fault-fissures of the post-Archæan formations, if such existed. None have been discovered in the Fortieth Parallel area.

Great simplicity is given to the relation of the two series by the unaltered and conformable conditions of the whole Palæozoic strata. Intrusions of granite into sedimentary strata other than Archæan crystalline schists, such invasions as are brought to light by Whitney in the Sierra Nevada, where granite invades the highly altered Triassic and Jurassic strata, are wanting.

As an instance of how dangerous any attempt to correlate age by petrological features alone really is, may be cited the Jurassic granite of California and the granite of the Cottonwood region on the Wahsatch, which is unmistakably Archæan. They are positively identical down to the minutest microscopical peculiarity.

Very many of the exposures laid down on the map are known to be Archæan by position. In the remaining cases there is no proof that they are not Archæan. The absence of evidence of disturbance throughout the Palæozoic, or of granitic intrusion anywhere in the post-Archæan formations, strengthens the belief that all the granites and crystalline schists are pre-Cambrian.

SECTION III.

GENESIS OF GRANITE AND CRYSTALLINE SCHISTS.

After so much detail, it would seem only appropriate to convey the impressions I have gained as to the comparative genesis of the crystalline schists and allied granites. Considering as a whole the later series which I have referred to the Huronian, there can be no doubt that they were formed by the development of their various crystalline minerals out of preëxisting sediments, in such a mode that the chemistry of the original individual beds was unchanged. The same conclusion is doubtless true of the older series which are here assumed to be the equivalents of the Laurentian.

Purely siliceous beds, either those composed of fine material or siliceous conglomerates, have retained their chemical simplicity even where highly basic beds, as of hornblendic gneiss, are interstratified with them. Had there been the slightest tendency toward chemical reaction between the materials of adjoining beds, the highly basic layers would inevitably have combined with the contiguous quartz strata and developed minerals of resultant composition. On the other hand, the original forms of the clastic particles of which the beds were sedimented are entirely lost; the interstitial space which must necessarily have separated the irregular-shaped particles of detritus is totally obliterated, and the sole figure of the original sedimentary particles is now shown in the pebbles of the conglomerates.

In zones of simple material, like carbonate of lime or quartz, metamorphism has been confined to an obliteration of interstitial space and crystallization. In beds originally of mixed mineral character, chemical affinity has resulted in the production of various new minerals, identical ultimate composition often failing to produce identical results; as, for instance, in the Huronian schists we find a bed in one place composed of quartz, orthoclase, and biotite, while in another, the ultimate constitution remaining the same, are developed quartz, orthoclase, iron garnet, and muscovite. Further, all metasomatic changes observed by us in the Huronian series are in like manner confined to individual beds.

The presence of water, carbonic acid, and saturated solutions of salts at the time of crystallization is evidenced by the minute presence of these bodies as inclusions in several of the component minerals of the schists.

It would seem, therefore, that we are authorized in assuming an approximately complete knowledge of the chemical materials and their stratified condition at the time of crystallization. Pressure and heat being the only known exterior causes which could have coöperated to induce the observed compression, chemical combination, and crystallization, the vital question is as to their mode of action. Evidence of excessive heat seems to be wanting, at least of such temperature as could produce the slightest even local liquefaction, for the phenomena of groundmasses and bases which have invariably resulted from crystallization out of liquefied magmas, and which are thoroughly characteristic of known eruptive rocks, are altogether wanting among the schists; so, too, the entire absence of glass inclusions in the component minerals is in a measure conclusive of the absence of molten or glassy passages during crystallization. The behavior and effect of great heat, however, are, as is well known, disturbed and rendered altogether abnormal by the presence of high pressure, as may be seen in the volcanic rocks, where the relative points of fusibility of various minerals, as determined at the earth's surface, are not strictly held to in depth. One of the most common features in many of the rocks known to be eruptive is the envelopment by minerals of high fusibility of those of lower fusibility, and *vice versa.*

If other forces can thus upset so apparently rigid a physical property as the temperature of fusibility, it is perhaps unsafe to argue from the absence of the products of fusion that a degree of heat adequate for liquefaction was absent while the crystalline schists were in process of formation. On the other hand, if post-Archæan geology offers any analogy, it is, that in periods of metamorphism and the development of crystalline rocks, the crust has been subjected to the most severe pressure, and it would seem that pressure, whether exerted downward by the building up of a superincumbent mass on terrestrial radii, or as developed in the tangential strains due to the earth's shrinkage, has been at least the invariable accompaniment of diagenesis.

While thus theoretically, in the present stage of knowledge, it is impossible to assert that a temperature sufficient to liquefy was absent, it is quite safe to assume that either the temperature was below the degree necessary to melt any single ingredient, or else its effect was annulled by pressure, the fact being that in the formation of the schists there never was fusion, and that many minerals are present in a molecular condition which they are known never to retain if subjected to high temperature; Sheerer, in this connection, having shown the presence in granite of what he terms pyrognomic mineral species, namely, those which under high heat undergo a permanent molecular alteration, but which in granites and schists are in the unaltered state. Thus for all intents and purposes pressure becomes the dominant power in bringing about the condition necessary for the developing of such chemical affinities as will produce the resultant minerals. A considerable degree of heat, with the presence of moisture and alkaline solution, was doubtless essential to the excitation of chemical affinity.

In the development of the schists, what was the predominant pressure, and what the mode of action? For reasons which have been expressed before, I am undisturbed in the belief that the crystalline schists are sediments spread out in the bed of the early Archæan ocean, for the most part mechanical, perhaps in some exceptional instances, such as the magnesian silicates, chemical precipitates as contended for by Hunt, or, as seems to me more probable, the results of mechanical separation by washing. I assume that they were the detritus of then existing land masses swept into the oceans and arranged in precisely the manner of subsequent aqueous formations.

As beds of heterogeneous sediment, the heat to which they were subjected by conduction from the floor on which they were laid down could not have been sufficient, since it permitted the existence of oceans, to induce the chemically inert particles to break up their then existing combinations and begin a new chemical activity. It is only when subjected to enormous pressure from above or increased heat from below that the particles would be forced into new mineral combination.

A simple inspection of the prominent crystalline schist and gneiss areas of western America shows, first, that as a whole they are among the thickest known bodies of conformable sediments. The geognostic behavior of subsequent great bodies of conformable sediments may be profitably compared, and their dynamic laws applied to the ancient sediments of the Archæan series.

Post-Archæan sediments of detrital origin are well known to be thickest nearest the source of supply and to thin out over the more remote portions of the oceans. A section normal to a great sedimented coast region, as in the case of the Appalachian Palæozoic series or the corresponding series in the Cordilleras of the Fortieth Parallel, shows a great accumulation near the ancient shores and a rapid thinning out toward the middle of the seas. It is difficult to suppose the conditions of deposition to have been otherwise for all detrital materials during Archæan time.

A further law in the great conformable sediment of later time has been, that heavily loaded regions sink into the subjacent crust. This subsidence, as is evident from an inspection of sections, is a direct displacement of a part of the underlying floor and a gradual pressing downward of the accumulating sediments, by the weight of the continually piling up series.

In the case of the conformable Palæozoic series, as exposed in the Wahsatch, where a section of 30,000 feet is displayed, it is evident that before disturbance, and while yet in the horizontal attitude of deposition, the lower Cambrian beds were under the pressure of a column of 30,000 feet of rock, that as marine sediments they were imbued with saline water, and that from mechanical compression and consequent loss of volume there must have been a considerable raising of temperature.

A further increment of heat must have been caused by the inevitable rising of the earth's concentric surfaces of temperature into the mass as it displaced crust and sank into the hotter depths of the earth. Yet with all this there is in the lowest Cambrian beds only the very slightest tendency to the production of crystalline schists. We have no reason to suppose that the thickness of Archæan conformable groups was enough greater than the series just cited to create a downward pressure so superior as by weight alone to bring about the totally dissimilar result of true schist crystallization.

Between the two sets of conditions there was one radical difference, namely, the secular cooling of the earth and consequent secular recession of isothermal surfaces.

Supposing sedimentation, consequent subsidence of a series of beds, and the accompanying displacement of subjacent crust to take place in the same direct ratio of quantity now and in the earlier stages of the earth's refrigeration, given beds arriving at the same depth would in Archæan time find themselves raised to a temperature greater than at the same depth to-day, by the actual amount of secular recession of temperature through the whole vast interval of time. The Archæan beds might easily find themselves, when pressed into the crust even to a moderate depth, in presence of those conditions essential for the processes of diagenesis.

From all the well known synthetic studies of chemical combination under pressure, moderate heat, and alkaline solutions, it would seem that with a considerably hotter condition of the superficial crust of the globe the amount of subsidences known in post-Archæan time might be sufficient to carry strata down into a region where chemical activity should begin.

If this view of the probable history is correct, fair deductions are, first, that somewhere below the surface, varying with the thermal state of the earth, there will be a horizon with the necessary heat condition and required superincumbent weight to urge the material present into chemical activity; secondly, that with the refrigeration of the globe this horizon will recede deeper and deeper toward the centre of the earth; thirdly, that so long as this horizon is within the depth to which bodies of sediment are brought by displacement of crust and subsidence, so long will crystalline schists continue to be made; fourthly, that when by secular cooling the required horizon passes below the possible levels to which strata may be sunk by displacement of crust due to accumulation of sediment, then forever afterward there will be no formation of the schists. Supposing no objection to be made to this hypothesis when applied to the gneisses, true schists, quartzites, marbles, dolomites, and chrysolites, there still remain to be accounted for the rocks characterized by the presence of hydrated protoxyd minerals and hydrous magnesian silicates.

The view of Hunt that they were originally hydrous magnesian silicates, of which an example is furnished by the sepiolite of the Paris Basin, is no longer tenable as regards most serpentines and chloritic rocks. Modern microscopic research has proved that these are direct pseudomorphs after anhydrous silicates, such as garnet and chrysolite, every stage of the whole process of pseudomorphism being shown beyond all doubt. Their origin is therefore relegated to the common origin of the anhydrous schists. The discovery in Appalachian schists of great bodies of chrysolitic formation, making an integral part of the crystalline schists, is sufficient answer to the question, Whence came the anhydrous magnesian silicate out of which to make the pseudomorphous serpentine?

Without attempting to examine the validity of Hunt's claim that the early magnesian silicates are chemical precipitates from the acid ocean of their period, I see no reason to seek for a different origin for the magnesian silicates from that of the commoner aluminous minerals. Olivine-bearing rocks are among the oldest irruptive bodies; why may not olivine sands, like those now seen on the shores of the Hawaiian Islands, have been then as now accumulated by the mechanical separation of sea currents and subsequently buried by rushes of feldspathic and quartz sands? Be that as it may, the whole tendency of microscopic research is to prove that the hydrous magnesian silicates are plainly pseudomorphic after anhydrous forms, and the problem of genesis, as Hunt very justly remarks in this connection, is, Whence the anhydrous ones? There is little present necessity, it seems to me, for the invocation of aqueous precipitates, when the sea bottom and shores of to-day offer such varied chemical materials which are so obviously detrital.

From these considerations, so far as the gneisses and crystalline schists are concerned, I am led to give in a complete adhesion to the hypothesis of diagenesis for the anhydrous silicates and of subsequent pseudomorphism for the hydrous magnesian rocks. My views approximate closely to those of Dana, and, if I rightly comprehend him, of Gumbel, rejecting on the one hand the plutonic hypothesis of Naumann and his followers, and on the other the all but forgotten theory of direct crystallization from solution, as advanced by Delabeche.

In the crystalline schists and gneisses are found identically the same anhydrous minerals which characterize the granites. The characteristic features of the schists are, the parallel-bedded arrangement, the strict retention of chemical materials in their original zones, and the intercalation of beds made of simple materials like quartzites and limestones. Granite possesses the same minerals, and furthermore their microscopical structure and the character of their foreign inclusions are identical. The sole difference seems to be, that granite is often demonstrably a plastic intrusion, and possesses no parallel arrangement of minerals, its various components lying more or less evenly distributed throughout the mass. In the granites and schists alike there is invariably a total absence of the phenomena of base, groundmass, and glass inclusions. The geognostic position of the schists is exactly like the other strata which were deposited horizontally and afterward disturbed. On the other hand, granite, in an immense majority of cases, is found to be exposed either in the hearts of mountain ranges or in ridges which have been evidently subjected to immense orographical or tangential pressure. When the points of Archæan mountain ranges protrude through gently inclined and subsequently unaltered strata, as is very often the case, the true orographical relations of the granite cannot be known. It is only when we can observe granite in direct connection with the strata into which it has intruded or out of which it has been made, that the true relations can be seen; and it is safe to say that wherever these intimate relations are observable, the granite occupies a region which has been subjected chiefly to horizontal or circumferential pressure. The frequent phenomena of the under-dip of the strata flanking a granite mass, as in the great granite body of the Sierra Nevada, are prominent instances of the intimate relation spoken of. If in such cases an unconformable overlying and unaltered series were to cover all but the summits of the granite hills, the granite would appear simply as an unconformable underlying body, whose genetic relations are absolutely unknown. Into this category a vast number of granite exposures of the Cordilleras have to be placed.

It is an invariable law, then, that where the genetic relations are clearly perceived, eruptive granite is always found in connection with very great horizontal pressure and consequent disturbance. Suppose, now, a deep-lying series of varied sedimentary beds, covered by sufficient superimposed mass to exert a pressure powerful enough to sink them to the necessary thermal horizon for the induction of crystallization in the material of the beds. As long as the attitude of these beds was undisturbed by horizontal compression, the result would be a series of crystalline schists and gneisses. But the moment horizontal or tangential pressure either overcame or disturbed the action of the downward pressure, the horizontal arrangement of these crystallizing materials would be broken up, and their resulting arrangement would depend upon the interaction of the two forces. In case the horizontal force were the slighter, the result would be simply those corrugated schists which are characteristic of certain regions. But if the horizontal force suddenly or even gradually overcame the radial pressure of gravitation, the original arrangement of the strata would be broken up and their component beds crowded into a structureless mass. In that case the tougher and stronger minerals, and those whose crystalline forms were most compact, would suffer the least dislocation, while the long and slender bodies (or those whose crystalline nature developed easy cleavage or fracture) would be torn asunder, and the particles often widely distributed. Granite then would be made out of any sediments or rocky materials of the necessary chemical combination, carried down to the required thermal horizon, whenever tangential pressure overcame the effects of the downward thrust of a superincumbent mass.

If this preëminently mechanical theory of granite be correct, we should find every gradation between the corrugated schists and gneisses and the uniform granites. Supposing the schist beds to be partially formed and in a more or less plastic condition, or even supposing them to be wholly crystalline when the horizontal pressure came to be exerted upon them, it is evident that if the breaking up of horizontal position which I have described took place, the beds would be ruptured and torn asunder, and that certain regions would be converted into a uniform granite, while others retained the traces of the original beds. Accordingly, we find in certain instances long tongue-like masses of crystalline schists mechanically entangled and embedded in structureless granite. The case already described in Wright's Cañon is a conspicuous example of this. A further stage of the obliteration of the original bedding would be found in the very great variations of a mass of granite where the materials had not been perfectly commingled, and accordingly in some great granite precipices the homogeneous granite includes masses having the most extraordinarily irregular form, whose mineralogical composition is totally different from that of the surrounding mass.

There is not another such fine example of this in America as the wall of El Capitan, in the Yosemite Valley, which is a precipice 3,200 feet in height, the result of fracture, so smooth and so near the vertical plane that erosion has scarcely affected the fissure-surface. Upon the face, which in general is of a uniform gray granite, are seen irregular cloud-like masses and rudely lenticular bodies which seem to be made of segregations of certain of the mineral components of the granite. The rock as a whole belongs to our fourth type, and is characterized by a high proportion of plagioclase, hornblende, and titanite. The irregular included bodies referred to are in some instances nearly black, and are made up of accumulations of brilliant black hornblende and quartz, absolutely without feldspar, and again with quartz in such low proportion that it may be said to be strictly a black amphibole rock, in which quartz is an accidental occurrence. Others of these segregations are of black mica and orthoclase, with a little quartz, to which the greatly predominating biotite gives a generally black appearance. Still others are of an aplitic type, being composed of orthoclase and quartz. A study of this precipice would convince any observer that, whatever may have been the origin of the body as a whole, uniform commingling has failed to take place, and that the sharply defined inclusions are mechanical, not chemical, accidents.

Suppose erosion to lay bare a horizontal face of this rock on which should be observed at intervals these various included bodies. A field observer, coming upon them and finding their boundaries very sharply defined by the enclosing granite, would naturally suppose them to be intrusive masses of different nature, and they would be mapped according to their mineralogical composition. Whereas in this magnificent Capitan section, which lets us into the nature of these deep-lying masses, it is seen that they are mere local dependences of the granite, and they may be regarded as enveloped bodies which for some reason or other have resisted the tendency to become merged in the main granite.

Were the chief factor in the genesis of granite to be, as I suppose, tangential, or, as I like to denominate it, orographical pressure, there must of necessity be all the transitions from a uniform homogeneous granite down to those rocks in which radial or gravitation pressure has produced the ordinary bedded schists; and it would seem that such envelopments as are seen upon the front of El Capitan, and also in a less conspicuous way in many of the granites of the Fortieth Parallel, might be considered parts of the original beds, which the accidents of pressure have failed to commingle into a general mass of uniform granite.

Finally, this distinction between the action of the forces of gravity and those of tangential compression, as accounting for the characteristic differences between bedded schists and mineralogically identical but structureless granite, is offered, not as a rounded theory, but as an hypothesis which to the mind of the writer best accounts for the present known facts.

SECTION IV.

PRE-CAMBRIAN TOPOGRAPHY.

After the consideration of the mode of occurrence of the Archæan bodies and their petrological correlations, there remains a further and still more interesting feature of the Archæan age, namely, the configuration and general relief of the area of the Fortieth Parallel at the close of Archæan time and prior to the deposition of the unconformably overlying Cambrian beds. I am aided in this interesting enquiry by the relations of the Palæozoic, which, as already repeatedly said, are observed to be conformable from the lowest members of the Cambrian to the top of the Upper Coal Measures. Over the whole distance from the Rocky Mountains to western Nevada, in almost every prominent range, the contact may be observed between the Archæan and the Palæozoic series. At times Archæan summits are seen to rise above the level of the deposition of the Upper Carboniferous, and the contact is exposed at various points all the way from that horizon down to the lowest exposures of the Cambrian, an extreme range of over 30,000 feet. It is obvious, therefore, that in any single mountain range the exposure of a contact between the Archæan and the Palæozoic, covering a given number of feet in thickness of Palæozoic strata, represents just that much actual topographical slope of Archæan hills. Assuming the deposit-plane of the Upper Coal Measures to have represented a uniform level, this level, closing as it does the great conformable Palæozoic series, forms a datum-surface from which the features of Archæan topography may be worked out.

Over the Rocky Mountain system as exposed from Rawlings' Peak to the east base of Colorado Range, the entire Palæozoic series, from the Cambrian to the Upper Coal Measures inclusive, is not over 1,000 feet in total thickness. Passing westward from this region, a maximum thickness of 32,000 feet is reached in the Wahsatch. In other words, the Palæozoic has thickened from 1,000 to 32,000 feet between the meridians of 105° and 112°. Now, if the plane of deposition of the uppermost member of the Palæozoic had represented throughout an actual level, the difference of depths of the ocean in which the Palæozoic sediments were laid down would probably be equal to the increase in the thickness of the series. But from all that may be observed of the present mode of deposition in ocean basins, as well as the data obtained from the study of extended exposures of the earlier rocks, it is in no wise probable that a given geological horizon necessarily represents a level plane of deposition. On the contrary, over an ocean of greatly varying bottom it would seem that there must of necessity be some tendency on the part of deposited beds to follow the larger depressions of the bottom. The proximity of shores and the force of currents must of necessity greatly vary this law; but it should be at the same time recognized that there is a constant tendency to approach a level. It is true that the Cambrian formation as displayed on the Fortieth Parallel has been very unevenly deposited, and has shown a general tendency to fill up the lowest depression with enormously thick accumulations of detrital material. I leave out of consideration the continued deepening of the Palæozoic ocean bottom, because, although important in an orographical sense, it does not bear upon the question of detailed topography of the ocean bed, the only enquiry here pursued. Rising in the Palæozoic series, a horizon of deposition would represent constantly a nearer approximation to the level; so that at the close of the series it is not at all improbable that the Upper Coal Measures showed no very great deviations from a general plane.

In assuming the top of the Palæozoic as a plane from which to work out the forms of the Archæan bottom, it is true that we arrive at minimum results of the depth of the ocean; we simply obtain the depth of deposit below a fixed surface. The Palæozoic series represents the material accumulated in the bottom of the pre-Triassic ocean, and gives no clew to the real ocean surface of the period. In consequence, the Archæan topography represents only that which was buried under the bottom of the Palæozoic ocean, and leaves us entirely in the dark as to the heights to which the continental and insular bodies rose either above the plane of deposition or above the actual surface of the ocean. When, therefore, I assign to the Archæan mountain peaks a height of 30,000 feet, it is obvious that there is to be added to this a certain unknown quantity which will give them a still more imposing height.

Some vague ideas of the additional altitude of the land masses of the Archæan above the plane of deposition may be obtained in the Rocky Mountains and in the country west of Reese River. It is clear that in the case of Park Range there are at present 5,000 feet lifted above the horizon of the Carboniferous contact. This is demonstrated by the overlap of the Trias and Jura, which are shown along the flanks of the range. To this 5,000 feet must be added the elevation which has been removed by erosion—an element that cannot have been unimportant. So, too, west of Battle Mountain, in western Nevada, Archæan land rose above the limits of deposition of the Carboniferous and formed a broad area extending westward into California, over which no Carboniferous has been deposited. Within Nevada there is no evidence that this was in general more than a land mass of moderately rolling topography; and, as will be seen in a later chapter, its area and extent must remain entirely problematical. A few known points were lifted fully 6,000 feet above the lower regions.

From the westernmost exposures of the Palæozoic, it is evident that the series has lost none of its thickness in passing westward from the Wahsatch. On the contrary, those members whose limits are clearly defined in western Nevada are even thicker than in the Wahsatch. It is natural that there against the shore of the continent of Pacifis, the area directly delivering its detrital material to the ocean which covered America, all sediments should be at their maximum; but that they should retain a thickness of 32,000 feet as far east as the Wahsatch, 300 miles from the continent which mainly furnished them, is most surprising. The special configuration of this broad ocean bottom was diversified by enormous mountain ranges, far exceeding in height the elevations of modern chains. The greatest single mountain slopes now exposed in the Fortieth Parallel territory are those in Colorado Range, where the extreme peaks are lifted 9,000 feet above the Great Plains. The highest known slope of the old Archæan peaks is shown in the Cottonwood Cañons of the Wahsatch, where a single, highly inclined, almost precipitous face of 30,000 feet was presented to the west—a mountain wall far exceeding that of any known modern example. At Red Creek, on the north base of the Uinta Mountains, the contact between the Uinta sandstones and the old quartzitic Archæan mountain shows a nearly vertical precipice of not less than 10,000 feet, with some actually overhanging cliffs. Besides these observable and measurable slopes there must have been a considerable amount removed from high summits by erosion, and we have no means of knowing whether the lowest exposure of the Cambrian really represents the base of the series, or whether there may be a still further addition to reach what was the true base of the great Archæan peaks. In the northern part of the Wahsatch the topography was that of broad dome-like peaks with more gently inclined sides; yet their average elevation must have been very great, since they touch the Silurian and Devonian level, and we know the Cambrian to have been at least 15,000 feet thick. The height of this range above its base must therefore have been from 17,000+ feet to 30,000+ feet. In a later chapter will be discussed the influence of these immense underlying ranges upon subsequent mountain folds, and it is expected to show that they have entirely controlled the subsequent topographical features.

At the bottom of the map of the Archæan exposures, at the close of this chapter, is drawn a section representing the various members of the Palæozoic series, starting in the region of the Rocky Mountains at the west base of Park Range, where the whole Palæozoic does not exceed 1,000 feet, and thickening westward to the region of the Wahsatch, where it reaches nearly its greatest expansion. It will be seen that Park Range is given an elevation of 5,000 or 6,000 feet above the level of the Carboniferous, that being its present proven height above the point of Carboniferous contact. In the region of Red Creek is shown the great Archæan peak, whose outcrop appears upon the map on the north base of the Uinta. Unfortunately the precipitous face of 10,000 feet is turned toward the south, so that it cannot be shown in an east-and-west section. In this region the outlines given in the section are entirely hypothetical, and are based upon the indications of the east-and-west slope as given at the points of contact between the Archæan and the Weber quartzite. Between Park Range and Red Creek there is no Archæan exposure, and the configuration of the bottom is therefore not known. So too between Red Creek and the Wahsatch it is quite unknown. At the Wahsatch is given the immense mass, having its culmination in Clayton's Peak, which rises nearly to the top of the Weber quartzite and sweeps downward to the west beneath the 15,000 feet of conformable Cambrian. Westward the Archæan masses of Wachoe, Humboldt, and Cortez ranges are seen rising to their proper elevations, as shown by the local sections observed in the field; while between these different mountains are deep valleys whose bottom strata are afterward upheaved into intermediate ranges, as for example in Piñon Range, between the Cortez and Humboldt Archæan bodies; and finally to the west of Battle Mountain is shown the sweeping up of Archæan land above the level of the Palæozoic series, forming a barrier in that direction. West of the Piñon the lower Cambrian is entirely unobserved, no section penetrating deeply enough in the mountain cores to expose it. There is no evidence, however, that it may not exist, under the exposed strata of the Piñon, or anywhere between the Wahsatch and the western limits of the Palæozoic, as thick or even thicker than the Wahsatch development.

While, therefore, there is much in this section that is hypothetical, there are still many fixed quantities, such as the great slope at Red Creek, the enormous precipice at the Wahsatch, the towering peaks of the Cortez as lifted above the lower strata of the Piñon, and the depth of Cambrian as shown in the ranges of the desert west of Salt Lake. We are amply warranted in assuming the heights thus given for the Archæan mountain bodies, and it is further evident that while much of their elevation is due to originally eroded surfaces, the great mountain wall in the Wahsatch, and also that at Red Creek, can only be the result of faults. It is impossible to suppose a precipice of Archæan schists like that exposed at Red Creek to be the result of other than absolute fracture. Therefore upon the Archæan bottom of the ocean in which the Palæozoic strata were deposited, there were mountain ranges of magnificent proportions, whose flexed beds and faulted precipices show all the orographical phenomena known to modern ranges. Their great importance consists not only in their being features of the Archæan surface, but in the fact that in them is found the local cause of modern ranges, and that in their nature and origin, as well as in that of subsequent uplifts, is to be studied the deeper and primal cause of mountain building.


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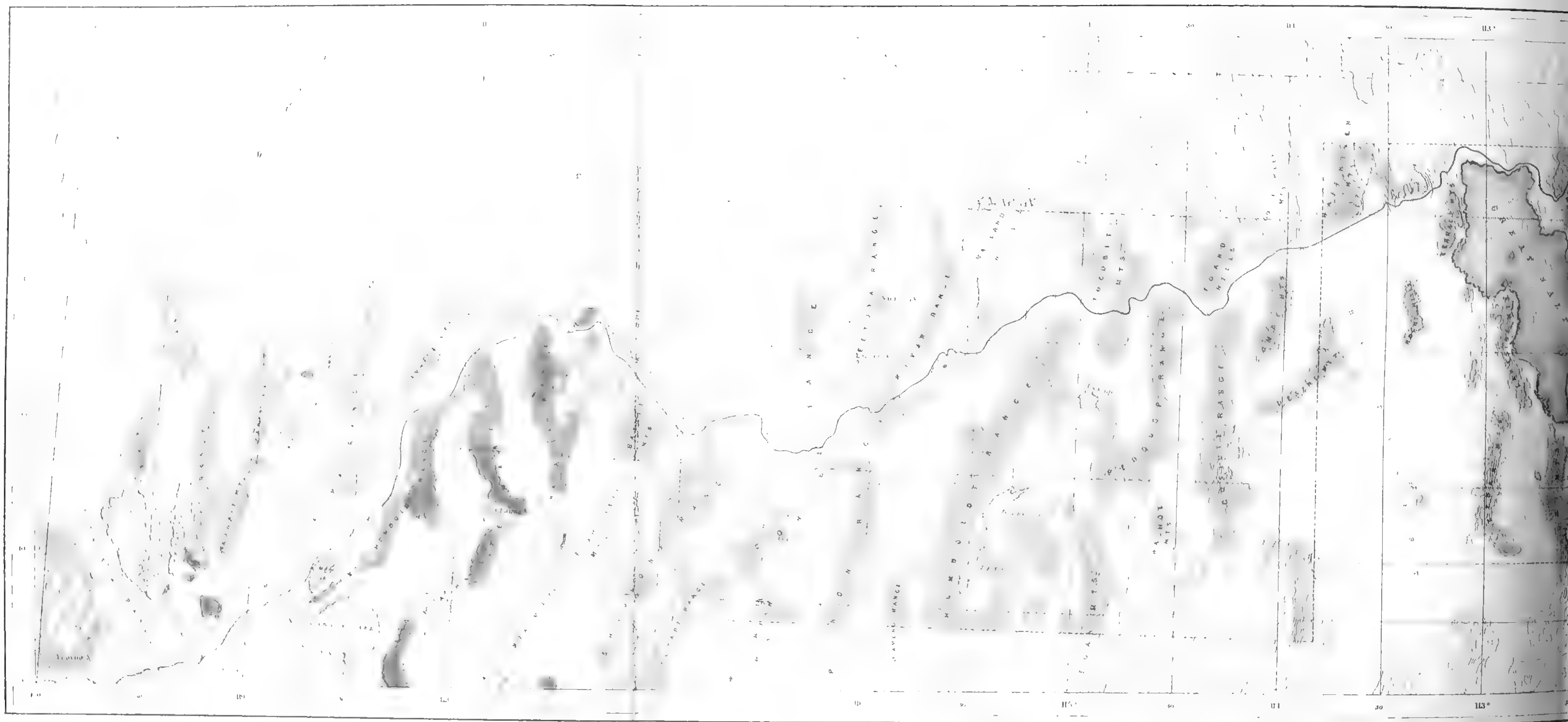

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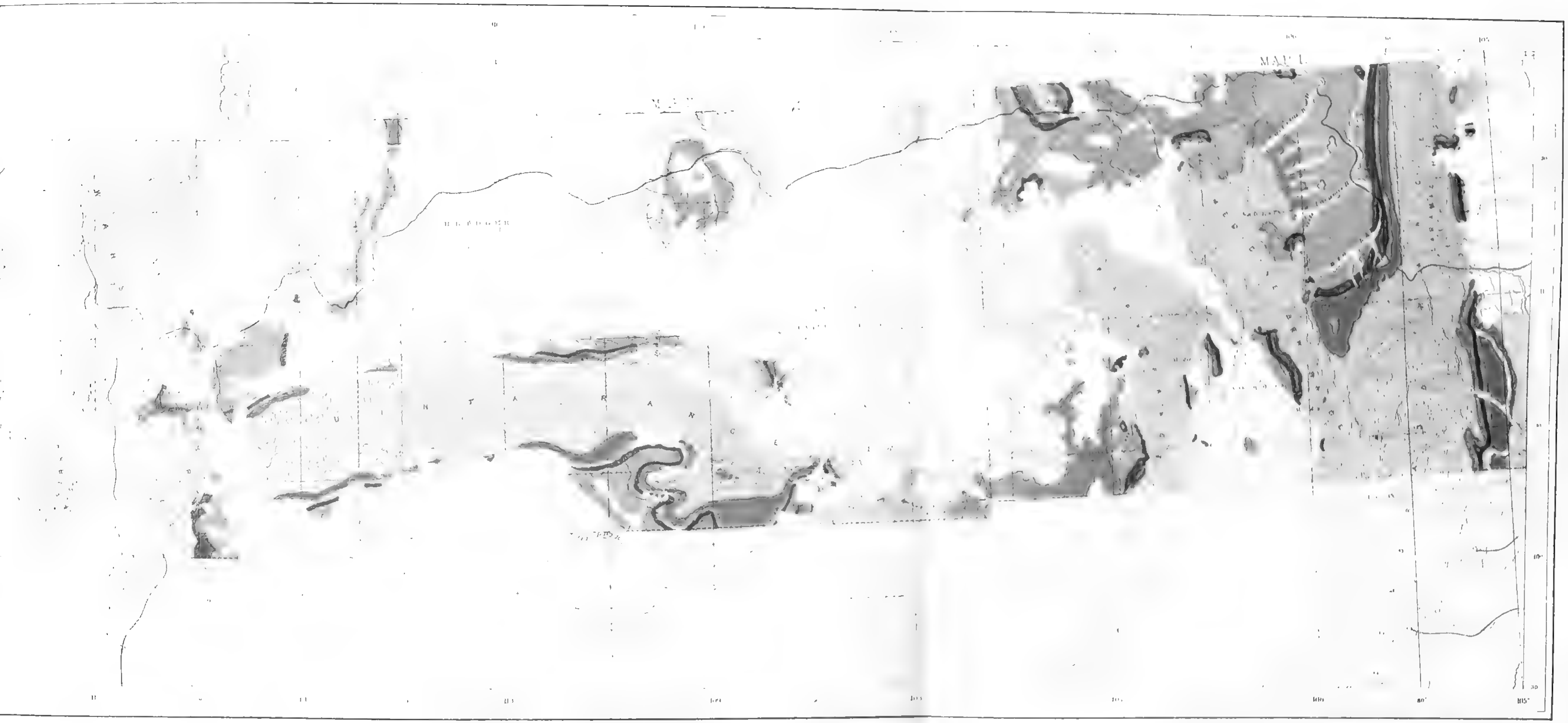

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CHAPTER III.

PALÆOZOIC.

SECTION I.

PALÆOZOIC EXPOSURES.

PROVINCE OF THE ROCKY MOUNTAINS.—In Colorado Range, between Colorado Springs and latitude 41°, the lowest sedimentary rocks found in contact with the metamorphic Archæan series are sandstones of the Triassic age. The appearance of the Palæozoic series near Colorado Springs has been described by Hayden. Directly south of the 41st parallel, on the eastern foot-hills of the range, in the neighborhood of the head waters of Box Elder Creek, limestones of the Palæozoic begin to appear, and from there northward to the northern limits of our map they are found in contact with the Archæan series, save in a few places where horizontal strata of the Niobrara and Wyoming conglomerate Tertiaries advance eastward and cover the entire upturned sedimentary series. Conspicuous instances of this overlap of the Tertiaries masking the Palæozoic are noticeable directly north of Granite Cañon Station on the railway, at the head waters of the Chugwater, and again at Sybille and Bush creeks. With these exceptions there is a continuous chain of Palæozoic outcrops from the head waters of Box Elder Creek for seventy miles northward. As shown upon Map I., the strike of this exposure is exceedingly sinuous and follows the protrusions and reëntrant curves of the Archæan. East-and-west it varies in width from a quarter of a mile to four miles, and in dip from the low angle of 15° or 16°, at the head of Box Elder Creek, up to the vertical, and in some instances at the extreme north to a reverse dip. On the west side of the range the first appearance of the Palæozoic coming out from beneath the overlap of the conformable Trias may be seen directly north of Harney Station. Thence to the northernmost limit of the map it is a broad, continuous belt from six to ten miles wide, dipping gently to the west. The Palæozoic series upon the east side of the range dip invariably to the east. South of the Union Pacific Railroad on the west side of the range, and south of the head waters of Box Elder Creek on the east side of the range, red Triassic sandstones lie directly in contact with the Archæan series. In consideration of the opposing dips of the sedimentary rocks on both sides of the range, it is at once evident that the whole northern part of the range has been simply a broad anticlinal thrown into a steep dip on the eastern side, and that erosion has carried off nearly the entire sedimentary series, leaving only margins of upturned beds, all the axial portion having been removed. North of the 41st parallel, undoubtedly the entire series, down to the Cambrian, extended quite across. South of that latitude it is evident, from the overlap of the Triassic, that the Palæozoic series were not deposited over the whole present area of the range In other words, the southern Archæan region was formerly, as now, much higher than the Laramie Hills, and while the Palæozoic was deposited conformably over the top of the Laramie Hills the southern edges of its members abutted against the elevated slopes of a lofty Archæan island. Even the Laramie Hills were undoubtedly a ridge prior to the deposition of the Palæozoic series; and it is therefore natural that over a submerged ridge having a plateau-summit the superficial currents of the ocean should have made themselves felt, and the consequent deposition be slight. As a result, the entire Palæozoic series is limited to a total thickness of 850 feet. Upon Map I. of the Atlas, as well as upon Analytical Map II., at the close of this chapter, it will be seen that the Palæozoic series at this locality is designated by but one color, without the subdivisions which appear to the west, and that this color is the same as is elsewhere given to the Upper Coal Measures; the reason being that this horizon is the only one which has been definitely determined by palæontological evidence. Certainly the upper 700 of the 850 feet are found to contain fossils directly referable to the Upper Coal Measure series, and in the scanty exposure below that horizon, within the limits of our work, we have failed to detect any organic remains. The lower 150 feet consist of red limestones and a reddish sandstone of varying fineness. Farther north, in the Black Hills, Dr. Hayden, Prof. N. H. Winchell, and the late Mr. Newton obtained a large number of Primordial types from a zone corresponding precisely with the red limestone and red sandstone which underlie our Coal Measure limestone. The equivalence of section is carried out by the constant finding in the Black Hills of Coal Measure fossils close above the Primordial zone. These two members of the Palæozoic series may be traced southward into the region of our map, and so far as stratigraphical and lithological proofs are worth anything they tend to show that the red siliceous zone underlying the limestones of the Laramie Hills is simply a continuation of the Primordial sandstone of the Black Hills. Although we have actually found no fossils in this horizon, we feel the greatest confidence in asserting that the whole Palæozoic series, from the Primordial to the Triassic, is here compressed within the 850 feet. The following local section from the base upward, from examinations at the table between Horse and Lodge Pole creeks, presents a characteristic average result:

	Feet.
1. Compact, fine, gray sandstone, almost a quartzite, with thin sheets of conglomerate	100
2. Reddish-white sandstone	50
3. Red arenaceous limestone	50
4. Gray and blue arenaceous limestone, 5. Thin bed of conglomerate, 6. Bluish limestone, highly siliceous, 7. Pink and cream-colored limestone, alternating with thin sandy beds,	650
Total	850

At Granite Cañon, just north of the Union Pacific Railroad, the following section, also counted from the base upward, was obtained:

1. Compact, reddish-gray sandstones with fine pebbles.
2. Brilliant red arenaceous limestones.
3. Massive blue limestones.
4. Light-gray limestone, with arenaceous beds.

East of Signal Peak, three or four miles south of the railroad, the section gave:

	Feet.
1. Red sandstone, with considerable variety of texture, calcareous near the top	100
2. Bluish-gray limestone	400
3. Red arenaceous limestone, 4. Thin bed of fine conglomerate, 5. Blue limestone,	300
Total	800

Throughout the series there is a noticeable absence of slates, clays, marls, and mud rocks. The sandstones are all more or less calcareous, and throughout the limestone strata there are passages which are gritty, or more or less finely siliceous. Within the heavily bedded limestones are frequently intercalated narrow zones of pure sandstone, with or without the addition of fine conglomerates. The lower and presumably Cambrian sandstones are subject to great local variations of color and texture. They are sometimes so hard and compact as closely to approach quartzite, and again produce coarse and friable conglomerates made up of more or less rolled Archæan pebbles and a fine, gritty, siliceous matrix. They are almost everywhere of a prevailing reddish color, and are always calcareous toward the top, passing by a variety of gradations—in some places abrupt, in others by gradual intercalation—into a red arenaceous limestone which itself presents a close superficial resemblance to certain red quartzites. In the finer siliceous material and in the red arenaceous limestones there is not infrequently a fine banding of color, indicating a variation of sediment; but the rock shows no disposition to split upon the color bands. The body of Palæozoic limestone varies greatly, both in purity and in physical condition. Toward the bottom, and indeed through by far the greater part of its thickness, it is a dull, dark limestone, interrupted by coarsely arenaceous beds. The general colors are dark bluish-gray, with pink and white saccharoidal and granular beds near the upper limits of the series. Between given horizons, with their gentle westerly dip on the west side of the range, and in a nearly vertical position along the eastern foot-hills, there is the greatest physical difference, the nearly horizontal beds showing but little alteration, the more highly inclined being variably altered into hard, compact strata, the beds of exceptional pureness becoming a coarse white marble. The darker and lower beds of the series are largely dolomitic. A fragment from this locality, submitted to chemical analysis by Mr. B. E. Brewster, is recorded in the table of limestone analyses given in the general résumé of sedimentary geology.

The very uppermost beds directly underlying the red Triassic sandstone at Horse Creek are of very fine-grained limestone of a deep flesh-red color, with small sparkling crystals of calcite disseminated through it. It is in general characteristic of the whole upper zone of limestone, and under analysis proves to be nearly a pure dolomite, containing—

Carbonate of lime	60.09
Carbonate of magnesia	39.20
Total	99.29

The impurities are small grains of silica. Under the microscope the fine red zone of limestone which serves to divide the Cambrian sandstones from the dark-gray limestone is seen to be a mixture of red, siliceous grains, which are usually quite sharply angular, and minute crystals of calcite. The only fossils obtained from this series are characteristic of the Coal Measures, namely:

Productus semireticulatus.
Productus cora.
Productus prattenianus.
Athyris subtilita.

Mr. G. B. Grinnell* mentions the discovery of a *Spirifera centronata* in the Black Hill beds, but he does not say in what part of the limestone it occurred. Farther westward, in the belt of the Fortieth Parallel Exploration, this fossil is found to be characteristic of the Waverly group in what we have denominated the Wahsatch limestone, occurring in numerous localities in Wahsatch and Oquirrh ranges. If, as is probably the case, this fossil occurs in the lowermost beds in the Black Hills, it will be interesting as marking another of the horizons which have developed in great thickness to the west, but are here compressed into such narrow limits. It may be predicted that sooner or later the missing horizons between the Trias and the Cambrian are likely to be in large part discovered, for in an ocean in which undisturbed deposition took place from the beginning of the Cambrian to the close of the Mesozoic age no great period of time would be likely to elapse without sedimentation, and it is to be predicted that one after another the now missing main horizons will be identified, even if reduced to extreme thinness.

After this general statement, a few local details will serve to fix the main phenomena of the Palæozoic occurrence in this region. South of the head of Richaud Creek, on the east side of the range, the limestones of the Palæozoic series strike about north-and-south, dipping 70° to 75° to the east. North of Richaud Creek their strike is north 40° east, with a dip of about 60° to the southeast. In other words, the upturned edge of the Palæozoic exposure follows the topography of the massive Archæan spurs. This is especially noticeable near the head of the Chugwater, where the Palæozoic and with it the conformable Mesozoic series, from the supposed Cambrian to the top of the Colorado group of the Cretaceous, wraps around a southwardly projecting Archæan spur and sweeps northward, following the curve of a reëntrant angle, and then strikes south again along the flanks of Iron Mountain, describing between the head of Richaud Creek and the head of the south fork of the Chugwater a complete letter S. As a result of this extreme sinuosity of strike, the limestones are considerably altered, and on the tops of the ridges frequently develop a fair variety of white marble. From a short distance south of Iron Mountain a sheet of Pliocene con-

* Black Hills of Dakota, Ludlow, 1874.

glomerates overlaps the whole upturned stratified series, and abuts against the Archæan; but south of Shelter Bluffs the bold limestones of the Palæozoic again come to the surface, and thence southward to the south fork of Crow Creek they form the dominant feature of the foot-hills. From the north fork of Horse Creek to Wahlbach Springs the Palæozoic limestones rise above the top of the overlying Triassic beds to a height of 500 or 600 feet, exposing sheer cliffs of Carboniferous limestones standing at an angle of 70°. This ridge is intersected by three streams, which divide it into sharp, wave-like blocks trending a little west of north. The limestone here contains numerous fossils, of which *Productus semireticulatus* was the only determinable species. Just north of Wahlbach Springs the Palæozoic declines to an easterly dip of 15° or 20°. South of that point, between the Cheyenne Pass road and the north branch of Crow Creek, it extends out from the main Archæan range some distance eastward, and falls off to the east in a nearly perpendicular, precipitous front of 700 or 800 feet. It is also abrupt to the west, where it is separated from the main Archæan region by a sharp cañon. The Palæozoic series here forms a nearly horizontal table. From its position it seems to suggest a connection with the gently dipping limestones of the west side of the range. It is, indeed, evident that over the entire plateau-like summit of this region the western dipping members of the anticlinal once extended in a nearly horizontal position. In that view it would be more correct to describe the orographical structure as a sharp monoclinal break with a scarcely perceptible dip to the west and a very deep plunge to the east. The rocks of this Table Mountain are really in the position of a shallow synclinal, the western edge dipping slightly to the east and the eastern edge slightly to the west. It is interesting as the sole instance where any but Archæan rocks appear between the two foot-hill belts of Palæozoic rocks. West of Wahlbach Springs the Palæozoic has an exceedingly gentle dip, approaching the horizontal position which once obtained over the whole plateau-summit of the ridge. Sharp, wave-like ridges recur just south of the north branch of Crow Creek, and form interesting outlines, showing the grayish-white limestone, which is nearly always the upper member of the Palæozoic series here. On the north side of the south branch of Crow Creek a nearly vertical position is maintained by the Palæozoic series, which is here quite thin. The lower members are probably entirely wanting; the upper ones overlap into unconformable contact with the Archæan, the lowest exposed beds consisting of a compact conglomerate, not unlike one which is interstratified far up in the limestone, as seen at various points on the western slope. Directly north of the Union Pacific Railroad the Carboniferous again forms an outlying ridge composed in its upper members of the gray limestones underlaid by the characteristic red sandstone. The whole strike is a few degrees west of north, with an eastward dip of from 30° to 35°. The basal red sandstone, capped by red arenaceous limestone, is very well developed, and is overlaid by massive blue limestones, which are again succeeded by the lighter and more fossiliferous series. South of the railway line the Palæozoic declines to a dip of only 30° to the east, and in the very middle of the belt are obtained abundant *Productus cora* and *Athyris subtilita*. Still farther southward the rocks decline to 8° and 10° easterly dip, and continue in an unbroken outcrop as far as the old Denver and Laramie stage-road. It will thus be seen that an extremely high general dip, only locally varied by shallow angles, and great sinuosities of strike, dominated by the rigid spurs and reëntrant curves of the Archæan, are the characteristics of the chain of Palæozoic outcrops on the east side of Colorado Range.

Along the west flank, as already mentioned, the series makes a continuous outcrop from the northern limit of the map to a point two miles north of the Pacific Railroad, where it is overlapped by the conformable red Trias. Throughout this distance the Palæozoic series rests unconformably upon the Archæan and maintains a comparatively uniform position, free from all noticeable local flexures, varying in dip from 5° to 6° west, and reaching an extreme inclination of 12°. Always next to the Archæan series occur the red sandstones, which we correlate with the Black Hills Primordial, presenting toward the east a rather abrupt, but low, mural outcrop. Lithologically, the Primordial coincides with that already described upon the east side, appearing chiefly as a coarse red sandstone, more or less compact, made up of a matrix of fine quartz-grains containing angular pebbles, and in places passing into an indurated conglomerate. None of the beds display the quartzitic tendency seen in the steeply dipping basal beds of the east flank of the range. So, too, the marbleized passages of limestone are wanting in this gently dipping western series. The lower sandstones pass up into granular, variably arenaceous, reddish-yellow limestones. Either from originally greater thickness, or from less compression, the series here is developed about 1,200 feet thick. On the western side no fossils were obtained from the uppermost members, but distinct Coal Measure types were obtained within 200 feet of the base. Where the road which traverses the range from the Sybille descends the west flank and crosses the zone of Palæozoic, which here dips from 5° to 7° to the west, the bluish-gray limestones, forming a zone of 250 or 300 feet, and reaching down to within 200 feet of the base of the series, yield the following determinable species:

Productus prattenianus.
Productus costatus.
Athyris subtilita.

Near the top of Cheyenne Pass, also, in a very similar limestone, doubtless indicating the same horizon, were found—

Productus semireticulatus.
Productus cora.
Athyris subtilita.
Bellerophon, sp.?
Orthoceras, sp.?

Northwest of Sherman are seen excellent exposures of the base of the series. Here the lower red sandstone is characteristically, though thinly, developed, and is seen to be succeeded above by a grayish limestone with a red tinge, the whole striking north 20° east, and dipping 7° to 9° west. Near the base of the limestone, and but slightly removed from the so-called Cambrian sandstone, were obtained—

Productus prattenianus.
Productus cora.

In Medicine Bow Range a locally exposed fragment of the Palæozoic makes its appearance where Laramie River leaves the mountains.

Directly resting upon the Archæan is a body of light-blue Carboniferous limestone standing nearly vertical, and covered to the north and south by the overlapping sandstones of the Trias. Nine or ten miles to the north, into the Cretaceous basin, projects a powerful promontory of Archæan rocks, culminating in Bellevue Peak. Around the northern end of this promontory, about 1,000 feet above the plain, is wrapped a semicircular outcrop of Palæozoic rocks, dipping from 20° to 25° to the north. Although predominantly of limestone, the exposure is saccharoidal in texture and highly arenaceous throughout.

On the west side of Medicine Bow Range, and immediately north of the 40th parallel, in North Park, the Triassic sandstones, which generally form the lowest exposed member of the stratified series, resting directly and unconformably upon the Archæan, are eroded off, uncovering a local exposure of Carboniferous limestones, for the most part bluish-gray, locally varied by arenaceous zones. They yielded no fossils, but clearly belong to the upper portion of the Coal Measure series.

At Elk Mountain, the extreme northwest point of Medicine Bow Range, the conditions described at Bellevue Peak and at the head of the Chugwater are repeated. Around a bold Archæan boss, which rises above the Tertiary and Cretaceous of the plains, is wrapped a belt of the Palæozoic limestones, which extend up to within 1,200 or 1,500 feet of the summit of the peak. As usual where the lower sedimentary series is bent around an Archæan body, the overlying conformable rocks, up as far as the Colorado group, partake of the flexure. Here the limestones possess a coarsely crystalline texture, and many of the beds are highly arenaceous. At the same time they are not so characteristically bedded as the limestones of the same horizon on the Laramie Hills. At Sheep Butte, where the beds dip 80°, the arenaceous condition of the limestone may be clearly seen, and among the beds are pure bluish-gray sandstones.

At Rawlings Peak a mass of Archæan has been thrust up, carrying with it a full section of the Palæozoic and Mesozoic series, and erosion has cut into the heart of this local dome, displaying admirable sections from the Laramie group of the Cretaceous down through the whole series to the Archæan. Immediately overlying the gneisses appeared the siliceous strata already noted as underlying the Carboniferous limestones. The greatest thickness exposed cannot be less than 700 feet of gray and white quartzites and sandstones, which have something of a reddish tinge upon their weathered surfaces, the individual beds usually not exceeding one or two feet in thickness. At the bottom is a fine-grained conglomerate about seventy feet thick, consisting of small white quartz pebbles in a finely siliceous matrix. The uppermost bed is a ferruginous sandstone fifteen feet thick. No fossils were obtained, except indistinct fucoidal remains. Conformably over this series is a deposit of almost chemically normal red hematite. Where seen, it is about twenty feet thick. It is already of considerable commercial value, having been mined as a paint and flux. Directly overlying the ferruginous zone is a bed of limestone about fifty feet thick, so compact and fine-grained as to resemble some of the lithographic limestones of our Jurassic series. South of the railroad at Rawlings Gap, the same lithographic limestone is seen, overlaid by darker, heavier limestone beds, the whole dipping 10° southward. Farther north, about two miles from the railroad, the best sections are obtained. Here, however, a thickness of only about 150 feet of quartzitic series is exposed in the valley. This is directly overlaid by the ferruginous sandstones, and above that the fifty feet of drab lithographic limestones, darker toward the base, followed above by about thirty feet of white siliceous limestone, and this by beds of varying thickness of dark-blue earthy limestone, from which were obtained *Pleurophorus oblongus* and some fragments of a strongly curved *Productus.* Above the blue fossiliferous limestone is a dark earthy bluish limestone, sometimes shaded with red, followed by forty feet more of grayish granular limestone, making thus far 200 feet of lime series, which are here succeeded by fifty feet of arenaceous shales, beyond which is a gap of 500 feet, through whose earthy surface outcrop occasional edges of thin arenaceous shales. From the character of the soil, this gap is assumed to be largely made up of unseen calcareous and argillaceous beds. Above this is another gap, without outcrop, of 400 feet, limited above by the distinct and characteristic Triassic beds Directly under the latter is a fine-grained, semicrystalline drab limestone, in which was found *Natica lelia*, a new species occurring also along the East Fork of the Du Chesne, on the south side of the Uinta

Mountains, where it is associated with distinctly Permo-Carboniferous fossils, and, as here, its horizon is directly succeeded by the lower members of the Trias. In view of the occurrences in the Wahsatch and Uinta, the evidence that this *Natica* bed represents the top of the Permian is considered clear. Therefore the upper portion of the 1,150 feet of beds included between the Primordial quartzites and the Triassic sandstone is colored and considered as Permo-Carboniferous.

From a reference to Analytical Map II., exhibiting the Palæozoic exposures, it will be seen that in the country already treated in this chapter—namely, the region of the Rocky Mountains proper, shown in Map I. of the Atlas—the Palæozoic exposures, though an important link in the geological history of the region, form but an insignificant portion of the total area. They are altogether confined to immediate contact with the Archæan masses, and in all cases dip directly from them. The maximum thickness of the whole Palæozoic series, as exposed along Colorado Range, is 1,200 feet. At the Rawlings uplift the series is expanded both at the top and bottom—upward, by the appearance of Permo-Carboniferous strata between the Upper Coal Measure horizon and the Trias sandstones, downward by the expansion of the Primordial or Cambrian member of the series, which here reaches 700 feet in thickness. The only fossils obtained belong to the horizon of the Coal Measures, with the exception of the single *Natica* which marks the Permo-Carboniferous. Although they are barren of fossils, from the downward sequence of beds, we have no doubt whatever that the red sandstones, conglomerates, and quartzites underlying the Carboniferous limestones belong, as we have correlated them, with the Primordial of the Black Hills and Colorado Range. On the east side of Laramie Hills the Palæozoic series reaches its greatest compression, namely, to 800 feet in thickness. There is absolutely no unconformity from the base to the summit. Therefore in this thin deposit is represented all the time from the Cambrian to the Trias, and yet organic life is only represented by types of the Coal Measure epoch and the Permian. This is perhaps natural, as fully three fifths of the whole series carries these fossils, for here, as farther to the west, the Coal Measure age furnished by far the greater amount of sediment. Yet it is not a little peculiar that representatives of the sub-

Carboniferous, Devonian, Silurian, and Cambrian ages should not be even hinted at. The stratigraphical correlation with fossiliferous horizons a few miles north of our area is so evidently natural that our assignment of horizon may, I think, be safely relied on.

UINTA RANGE.—In leaving the Rocky Mountains and passing into the basin of Green River, the Palæozoic series manifest themselves in much greater thickness and far greater individualization of horizons. Another characteristic difference is to be noted between the region already described and that of the Uinta. In the former, the Palæozoic outcrops are simply bands of upturned strata edges bordering massive ranges of Archæan rock. In the region of the Uinta they are absolute folded uplifts of Palæozoic material, laid bare by the removal of the entire Mesozoic series which were upheaved with and formerly overarched them. In the Rocky Mountains the thin Palæozoic was deposited around Archæan islands and over Archæan plateaus. When the two came to be uplifted together, erosion easily removed parts of the Palæozoic covering, laying bare the older series. In the Uinta region the vast scale of Palæozoic deposits, with proportionally great conformable Mesozoic beds, makes the later folds of such great thickness that erosion has been powerless to remove material farther down than the Middle Carboniferous. There is only a single instance where the Archæan is reached, and that is the case of a great isolated schist peak around which the Upper Carboniferous was deposited.

Uinta Range is a broad, plateau-like anticlinal, whose summit region has scarcely a perceptible dip, while the flanks, both by curvature and dislocation, are thrown into every variety of contorted and highly inclined position. The other Palæozoic exposures of this region are two isolated masses of Carboniferous which form really the eastern extension of the Uinta and represent the dying out of the mountain building action in that direction. Aside from these, which belong to the system of the Uinta, there is a considerable exposure of Upper Coal Measure limestones bordering Bear River near the northern extremity of Map III. of the geological series, and this is essentially a part of the Wahsatch system. The Palæozoic exposures of the Green River Basin, considered as a province, or in comparison with those of the Rocky Mountain region, would never have been altogether intelligible or clearly correlated with those to the west but for the key-section which unravels the relations of the whole series, a section exposed and repeated upon three lines in Wahsatch Range; and since, in these middle longitudes of our work, the series as a whole has reached such a great thickness and such remarkable stratigraphical individualization, hereafter it will be best later to treat the various divisions of the Palæozoic, both stratigraphic and historic, by themselves.

The Uinta system forms one of the exceedingly limited number of exceptions in the parts of the Cordillera system to a general northerly trend, the average strike of topographical axes being within 30° or 40° of the meridian. There is a considerable number of ranges having an accurately meridional trend; others north 40° east; others north 50° west; but of ranges following a parallel of latitude there are very few. The Siskiyou, near the northern boundary of California, the eruptive outbursts of Arizona and western New Mexico, and the system of the Uinta, form the chief examples of direct east-and-west lines of upheaval. The range is formed of an anticlinal having a broad plateau-summit often twenty miles from north to south, the strata of this upland region resting in a nearly horizontal position. At the north and south, along two distinctly marked lines of sudden flexure, the rocks dip away from this central plateau of level strata. The region of abrupt change from the approximately horizontal position to the steep northern and southern dips, is marked by tremendous local faults and every variety of lateral and longitudinal compression. The Palæozoic rocks of the range consist prominently of three members:

1. An immense body of quartzites and indurated sandstones intercalated with groups of sheets of argillaceous shale, the whole forming the lowest of the Uinta Palæozoic series, and referred by us (not, however, without some questioning) to the Weber quartzite or middle member of the Coal Measures. The general thickness is 12,000 feet.

2. Directly overlying this throughout the whole range is observed a series of sandstones and limestones, more or less variable, and having a thickness of 2,000 to 2,500 feet. From the base to the summit of this series Coal Measure fossils are obtained.

3. Overlying the uppermost member of the Coal Measure limestones, but exposed at only a few localities, is a body of calcareous and argillaceous shales and mud rocks, bearing typical Permo-Carboniferous fossils.

These features obtain throughout the length of the Uinta as far east as the meridian of 109° 20′. I will now note certain characteristic exposures of the Upper Coal Measures.

Overlying the quartzites of O-wi-yu-kuts plateau, east of the head of Willow Creek, were found hills of drab Upper Coal Measure limestone, which dip about 50° to the north. We are unable to detect any nonconformity between this series and the quartzites below at this point. Southeast of Diamond Mountain extends a sharp ridge, forming the eastern edge of O-wi-yu-kuts, in which is exposed the whole series of the Upper Coal Measure sandstones and limestones, having a strike of 17° north of west and a dip of 31° to the northeast. Between the Coal Measure limestone and the underlying sandstones was again observed a true conformity.

East of that the simple structure is complicated by a series of broad crumplings on the south-and-east terminus of the range, where evidence of a north-and-south folding is observed, and the two outlying masses of Palæozoic which rise above the Tertiary are local quaquaversal uplifts, having their longer axis drawn north-and-south. These two outlying bodies, Yampa Peak and Junction Peak, are each chiefly made up of the mixed arenaceous limestones and calcareous sand rocks, which, taken together, form the group of Upper Coal Measure strata; and in the summits of both masses, owing chiefly to faults, a portion of the underlying quartzite is brought to light. The local structure of these outlying bodies will be found fully described in Volume II.

The outcrops of the Upper Coal Measure limestones along the northern flank of the Uinta trace an irregular line, as may be seen by Map II. of the Atlas, or by Analytical Map II. at the end of this chapter. They produce a series of wave-like ridges, either continuous or separated by the narrow cañons of streams, forming a distinct noticeable ridge traced parallel to the strike of the range. As is the case with all these outlying Coal Measure limestone ridges, both here and along the Rocky Mountains, they present an escarped face toward the range, while the backs of the strata dip outwardly toward the valleys. At the head of Black's Fork, beneath the red Trias, are good exposures of the soft Permo-Carboniferous and Upper Coal Measure beds. In the region of Gilbert's Meadows the Tertiaries overlap the Upper Coal Measure series and come directly in contact with the lower quartzitic mass. Farther west, however, at Lime Pass, the Tertiary beds are eroded away, exposing the limestones of the Coal Measures, which dip 45° to the northeast and strike 15° north of east. The strata best exposed are gray and blue limestones, which rise in bold, wave-like ridges, the overlying clayey beds having been largely worn away in low saddles and ravines or covered up by débris. Still farther to the west, opposite Lime Pass, the softer Permian beds are seen to consist of mud rocks and slates closely corresponding to the similar series of rocks between the Upper Coal Measure and Trias sandstones in Weber Cañon of the Wahsatch. From the Carboniferous limestones here were obtained a few fossils, *Productus prattenianus* being the chief recognizable form. The upper member of the Coal Measure series here consists of conglomerates which are very coarse west of Lime Pass. To the east, however, the lowest member seems to be a coarse-grained gray sandstone, a gritty siliceous matrix containing grains of limpid quartz, somewhat tinged with iron oxyd. At the head of Burnt Fork the characteristic steep wave-ridges, geologically below the red Triassic sandstones, are of the limestones of the Coal Measures, still preserving a strike of about 15° south of east and a dip of from 35° to 45° to the north.

This series again outcrops in Vermilion Creek Cañon, a cut 1,500 feet deep, yielding an excellent section of the Upper Coal Measure series, dipping 27° to the northeast. Beginning at the top of this section, from 100 to 150 feet of variable cherty limestone are exposed, from which were obtained—

Fusilina sp.?
Nucula parva.
Nucula sp.? (minute forms in limestone).
Pleurotomaria (casts in limestone).
Bellerophon carbonaria (very abundant).

Beneath these is a thickness of about 900 feet of light buff and gray sandstones, thinly bedded and variably calcareous. Farther west this sandstone member becomes altogether calcareous, and, indeed, throughout the region of the Uinta it may be considered either a calciferous sandstone or a siliceous limestone, according to its local variations. More essentially limy toward the base, it finally gives way to a soft series of mixed buff and gray sandstones intercalated with limestones. Below the buff intercalated sandstones and limestones, which may possibly be 1,100 feet in thickness, is a bed about 100 feet thick of very noticeable pinkish sandstone, and below this 500 to 600 feet of mixed drab sandstones and limestones. In the upper mixed sandstones and limestones are several noticeable cherty seams, none, however, to be compared with the thick cherty limestone which caps the series; and in the intercalated zone below the upper cherty limestone are also seen several black seams three or four inches thick, highly ferruginous. One of the fine-grained cherts of the lower group, subjected to analysis, yielded—

Silica	96.5
Carbonate of lime	2.0
Carbonate of magnesia	0.7
Iron and alumina	0.6
Water	0.4

The prominent capping cherty limestone is quite constant wherever in the Uinta a good section of the whole Coal Measure series is obtained, and it is to be considered as the dividing line between this group and the Permo-Carboniferous. It is curious to observe that where the Upper Carboniferous series is exposed in a cañon section like this, the siliceous members seem to predominate. If, on the other hand, the section is exposed upon a ridge, calcareous members predominate in the outcrop and in the débris. This is evidently due to the greater brittleness and easy fracture of the sandstones. But careful sections of this series display remarkable variations over very small geographical areas.

Directly and conformably above the cherty *Bellerophon*-bearing beds at Vermilion Creek there is a series of several hundred feet of greenish clays and mud rocks, giving evidence of moderately shallow water deposit, and clearly representing the Permo-Carboniferous

Overlying the heavy red sandstones of the Weber series, as displayed upon the summit of the Escalante Hills, is a great development of the Upper Carboniferous rocks, extending southward until it passes under the Mesozoic beds which form the divide between Yampa and White rivers. Here is an extent of country about sixteen miles from north to south by thirty-five miles from east to west—with the slight exception of overlying masses of Triassic, mere fragments left in the general erosion—composed of intercalated sandstones and limestones of the Upper Coal Measure series. The interesting orographic phenomena of this region will be found detailed in their proper chapter. Yampa Cañon itself is cut through the members of this series, the abrupt walls of the gorge showing a fine section of the mixed sandstones and limestones which belong directly under the cherty *Bellerophon* limestones and extend down into the drab limestones and sandstones that overlie the red Weber sandstones. Toward the western limits of Yampa Plateau several interesting sections are displayed. That of Section Ridge presents a sharp anticlinal, with axis northeast-and-southwest, sinking abruptly to the southwest. The ridge is capped by limestones which belong to the horizon of the cherty *Bellerophon* series, though the strata here are less siliceous than at Vermilion Creek. They dip 20° to the northwest, approximately with the slope of the hill, forming an abrupt escarpment to the southeast. The upper members contain —

Nuculana bellistriata.
Schizodus curtus.
Orthis carbonaria.
Orthoceras crebrosum.
Naiadites.

Fossils representing the upper part of the drab limestone and sandstone group which constitutes the lower members of the Upper Carboniferous series are found about twelve miles southeast of Zenobia Peak:

Spirifer lineatus.
Spirifer opimus.

A considerable number of undeterminable forms are also found. These fossils seem to correspond with the horizon in the region of the pink sandstones of Vermilion Creek. The exposures of Yampa Cañon show very heavily bedded rocks, as indeed do almost all exposures of horizontal rocks in vertical cañons. The lower part of the cañon section shows a prevailing red color not unlike the deep-pink beds of Vermilion Creek Cañon.

West of the great cañon of Lodore the Upper Coal Measure series exposes a line of bluffs which form the southern wall of Summit Valley, culminating in Ute Peak. Here the upper beds of the Weber sandstones are coarse-grained red rocks of glistening surface and loose texture, broken by frosts into large massive blocks with rounded edges. Conformably overlying this sandstone is a bed of reddish, decomposed limestone, containing many partially decomposed calc-spar forms, some of which are circular, as if they had been the casts of corals. The limestone is exceedingly siliceous, containing 28 per cent. of quartz sand and 70 per cent. of carbonate of lime. Above this are about fifty feet of coarse white sandstone, over which lie limestone shales and a dense, compact, heavily bedded blue limestone, with conchoidal fracture, rich in fossils. The following forms were identified:

Spiriferina Kentuckensis.
Athyris subtilita.
Meekella striocostata.

These are the lowest forms obtained from the Upper Coal Measure system in the Uinta, and are collected within sixty feet of heavy beds of the Weber. The beds at this point dip about 15° a little west of south. To the west of Ute Peak, in limestones occupying a higher position and intercalated in sandy shales, were found fragments of *Syringopora.*

Geode Cañon offers in its deep, picturesque gorge a section of the Upper Coal Measure and Lower Mesozoic series 2,000 feet deep. The upper portion is cut through nearly horizontal beds of the Upper Coal Measures, while near the mouth of the cañon the beds round over to a dip of 29° to the south. The *Bellerophon* cherts are easily recognized, and contain the usual casts of *Orthoceras* and two species of *Bellerophon*, besides *Bellerophon carbonaria*, together with a specifically unrecognizable *Discina.*

This bed is here about fifty feet thick, underlaid by fifty feet more of yellow, compact, cherty limestone, abounding in geodes lined with calc-spar crystals and concretions of flint. Beneath it is a seam of thin, compact sand and clay, rich in oxyd of iron. Below are massive beds of compact white sandstone, variably calciferous, and passing downward into intercalated sandstones and limestones.

Directly under the red Triassic sandstones of the foot-hills of the East Fork of the Du Chesne, for a considerable distance, the formation is composed of thinly bedded mud rocks, fine shaly limestones, and calcareous, argillaceous shales, yielding the following species:

Myalina (resembling *sub-quadratica.*)
Myalina n. sp.
Bakevellia parva.
Pleurophorus sp.?
Macrodon sp.?

These are the only fossils obtained in Uinta Range from the soft, easily eroded beds that separate the lower sandstones of the Trias from the *Bellerophon* cherts which mark the uppermost horizon of the Coal Measures, and are interesting since the forms as well as the physical condition of the beds are closely allied to the Permo-Carboniferous of Weber Cañon.

Along Rhodes's Spur, which rises west of the Du Chesne Cañon, the drab limestones near the base of the Upper Coal Measure series appear with the shallow dip of the upper plateau. From the base of the formation, not far above the Weber beds, were obtained—

Chonetes granulifera.
Martinia lineata.
Syringopora multattenuata.
Zaphrentis.
Lithostrotion.
Euomphalus.

Half-way from Kamas Prairie down to Provo Valley, the trachytes are sufficiently eroded to display a limited outcrop of grayish-blue limestones having a dip to the south and west. These extend for half a mile along the bank of the stream, overlaid by a red sandstone, probably Triassic, none of which, however, was found in place. It was identified by débris protruding through the soil. This is interesting as indicating the wrapping of the Upper Coal Measures around the western end of the Uinta uplift. Where the upper Weber Cañon emerges from the Uinta Mountains a body of drab limestone is seen, forming the southern wall of the cañon, and having a dip of 25° to the northwest. From the foot-hills of the range, near Kamas Prairie, were obtained, at a point evidently not far removed from the contact with the Weber formation—

Productus semireticulatus.
Spiriferina pulchra.
Martinia lineata.

So far as we have observed, there is no nonconformity here between the limestones and the underlying quartzites.

Along the northern flanks of the Uinta Mountains, over their western extent, indeed west of Lime Pass, the exposures of the Upper Coal Measures are usually covered either with Tertiary or modern débris, and owing to the dense growth of forest, outcrops are obscure and rare. Enough is seen, however, to trace the continuity and arrive at the structural outline of the series, but not enough to throw light upon the lithological variation or to add to the fauna.

As may be seen from a glance at the map, the Upper Coal Measure series, whose features have just been treated, remain in the form of a band of variable thickness, surrounding the central anticlinal plateau, but never arching continuously across, except at the extreme eastern and western ends. In other words, from the entire central portion of the uplift erosion has removed not only the overlying Mesozoic but the Upper Carboniferous, exposing the sandstone and quartzite formation of the Weber for a width north-and-south varying from twelve to twenty-five miles, with an extreme length from east to west of about 150 miles, the trend showing a slight convex curve to the north. The main central mass rises in a comparatively horizontal position, showing a slight anticlinal curvature in transverse direction, which is complicated by faultings at the north and south extremities, and sags which appear in transverse section at various points of the arch; and when viewed longitudinally the axis itself is seen not to represent an even line, but a series of shallow sags and arches. The result is a complicated system of undulations, whose dips rarely exceed 5° to 8°, while along the northern edge the immense series of strata is flexed sharply over to the north in positions which vary from a slight dip to 55°, the flexure being accompanied and followed by extensive dislocations. There is thus displayed a thickness which we estimate at 12,000 feet, although the cañon section, as determined by Major Powell,* exceeds that amount. The best and deepest exposures are those offered by the O-wi-yu-kuts Plateau, the Cañon of Lodore, the head of Black's Fork, and the head of Bear River. Plate V. shows the walls of the Cañon of Lodore, where the steep precipices of horizontal Weber beds are about 3,000 feet high.

The axial region of Weber sandstones in the region of Brown's Park has been both dislocated and deeply eroded, permitting the Tertiary Valley of Brown's Park to occupy the interval between two elevated mountainous plateaus of the Weber sandstone. On O-wi-yu-kuts itself the Weber formation is seen to rest unconformably against the eroded surface of the Red Creek Archæan body. Along its northern edge it dips with apparent conformity under the Upper Coal Measure series Southward and through the main body of O-wi-yu-kuts Plateau the sandstones approach a nearly horizontal position. On the cliffs overlooking Brown's Park, at the cañon of Beaver Creek, for instance, they dip 5° to the north. These cliffs bordering the northern side of Brown's Park rise rapidly about 1,800 feet, displaying the edges of the series. They are usually formed of a red, indurated sandstone tending to quartzite, and along their southern margin, especially toward the eastern opening of Brown's Park, the lower beds bend over into a southern inclination, the extreme examples dipping 8° to the south. Following northward, the beds curve over into a position of from 50° to 60° to the north. The relation of the less steeply dipping but geologically superior Upper Coal Measure series of Diamond Creek is considered to be explained by the downthrow of the gently inclined limestone strata into contact with the underlying sandstones. An appar-

* Geology of the Uinta Mountains, 1876.

ent nonconformity here, in a region of evident dislocation, has no bearing upon the actual conformity of the two series. Minor dislocations in the O-wi-yu-kuts sandstones themselves suggest caution in estimating the thickness of the beds. As estimated by us, there are exposed here about 10,000 feet of the Weber series, for the most part of heavily bedded, rusty yellow or red, sometimes grayish, compact sandstones, with limited passages of actual quartzite. The general color of the exposure, either in the cañons or upon the bold walls fronting Brown's Park, is a dark, earthy, purplish red. The surface of the eastern end of O-wi-yu-kuts Plateau is seen to be ribbed by the edges of the gently inclined sandstone strata, which have a strike much more east-and-west than the overlying Carboniferous series to the east. These parallel ribbed outcrops of the sandstone series extend up close under the limestone cliffs, whose beds at first glance would seem to have been deposited unconformably over their edges. But this apparent nonconformity is explained by a curved fault of the overlying series. West of the west end of the Archæan mass of Red Creek, the sandstones of the Weber group have a dip generally from 10° to 15° to the north. North of Ashley Park, however, the beds are seen to have been deposited unconformably upon the Archæan body. The planes of contact are shown on the hills west of Garnet Cañon, in a little stream which is indicated on Map II. by a dotted line near the western edge of the Archæan body, and also eastward in Willow Creek, where a distinct nonconformity is seen between the two series. Several prominent conglomerate sheets start from what was formerly the Archæan shore; and as displayed by the heights east of Willow Creek, it is evident that the deposition of the Weber series not only extended to the summit of the Red Creek body, but actually overtopped it by a considerable thickness. Plate VI. shows the deeply eroded cañons of Green and Yampa rivers at their junction, one of the most interesting instances of cañon-cutting.

Beneath the Coal Measures which are exposed near Lime Pass, on the narrow ridge at the head of Black's Fork and Bear River, a great thickness of the Weber group is exposed. From Lime Point southward into the range, the dip increases from 45° to 52°, without displaying the slightest nonconformity, while up near the summit of the ridge it bends over to nearly 16°, beyond which, in the axes of the flexure, there is a sudden break, involving dislocation, the rocks at the head of the cañon in the Bear River region dipping 4° to 5° to the south, and showing a slight dip also to the east and west, which indicates that that region is one of the longitudinal axial arches. As here displayed, the upper beds are chiefly of a coarse, gritty, red sandstone, not infrequently banded like the colored jaspers. Below this is an immense mass of red and purplish quartzitic sandstones, sometimes so coarse as to constitute a conglomerate, and containing a varying admixture of but slightly decomposed, shattered crystals of orthoclase and plagioclase. Greenish clay shale beds from 50 to 100 feet thick, sometimes hardened into green argillaceous slates, which in extreme cases of alteration contain a little mica, alternate with the quartzitic sandstones. In descending the series, the rocks become more compact, with frequent white opaque beds, to which the name sandstone is no longer applicable; they are essentially rough quartzites. Not less than 10,000 feet of conformable members of the Weber series, from the highest beds displayed at Lime Point to the lowest white quartzites, are here exposed, and to these must be added an unknown amount extending indefinitely under the horizontal central region.

At Tokewanna Peak the beds have a dip of 16° to the north. There is an exposure of a great amount of red quartzites on the ridge to the south of the peak. Here the northern axis of the range is well defined in a break beyond the second point south of this peak, above which the beds have a dip of 6° to the south.

Above the morainal material of Gilbert's Meadows the first exposures are Weber quartzite beds dipping 42° to the north. This angle holds in ascending the creek to the forks, where it flattens out on the sides to a dip of 20° for about two miles, and then near a side ravine changes suddenly to horizontal, and farther up dips 5° to the south. An evident fault has taken place here, separating the horizontal interior summit region from the northern inclined beds. On the northern side of Gilbert's Peak the quartzites dip 42° to the north, while the beds which form the peak itself are of sandstone, with a slight southern dip, and include several strata of bluish clay beds about 100 feet in thickness. These are entirely wanting in the upper 1,000 feet of the peak. South of this the quartzites have a dip of 3° to 5° to the south, and the axis of flexure is seen to have here a northeast direction from Tokewanna Ridge to this point, bending still more to the north at Smith's Fork, while to the east it curves into an east-and-west trend. The northern shoulders of the main ridge to the east of Gilbert's Peak have a dip of from 3° to 5° to the north. Northward it rapidly curves over into the steep dip of the limestone, which it conformably underlies.

An important point, as showing the relations between the Weber and the overlying Upper Carboniferous, is at the eastern apex of the Uinta fold, near Little Snake River, where in a small conical hill northeast of the gap the heavy beds of the Weber are found, conformably overlaid by the lower drab limestones of the Upper Carboniferous series dipping 45° northeast, with a strike of north 50° west. So, too, at East Mountain the north face is composed of the southerly dipping beds of the Weber formation, conformably overlaid by the Upper Carboniferous drab limestones.

The geological conditions of the southern slope of the Uinta differ from the northern edge simply in the greater gradualness of the flexure and the comparative absence of considerable faults. At Mount Lena the glistening red sandstones which form the uppermost member of the Weber dip 7° to 10° to the south, and pass conformably under the drab limestones of the Upper Coal Measures. West of the Three Lakes, and near the head of Ute Fork, are seen heavy exposures of the striped red quartzite, which is one of the upper members of the Weber group. It here dips to the south from 7° to 9°, and carries some of the thick clay beds which were mentioned at Gilbert's Peak. Above the mouth of a creek which descends the southern slope from Emmons' Peak the uppermost members of the Weber quartzite are again exposed. They are here of heavily bedded sandstone, striped purple and red, while in ascending the range or descending the geological series the rocks become more quartzitic and of lighter color. In both the upper cañons of the Du Chesne is well shown the quartzite series which here have a gentle dip to the south, exposing walls, more or less obscured by débris and forest, 2,000 or 3,000 feet in height.

In general, the summit region, although formed of approximately horizontal strata, is deeply carved by glacial action into the characteristic amphitheatres formerly occupied by the *névés*—amphitheatres which deliver their drainage into deep U cañons formerly occupied by trunk glaciers, whose walls are from 2,000 to 3,000 feet in height. Plate VII., a view in the lower valley of the Middle Fork of Bear River, shows the broad glacier cañon with glimpses of the quartzitic mountains, although not of summit peaks. The horizontality of these beds gives to the precipitous faces of the spurs and amphitheatre walls the look of a gigantic masonry laid up in even courses. A typical summit region is that of Mount Agassiz. The peak itself is formed of coarse quartzitic sandstone containing rounded pebbles, beneath which is a zone of rough grits 800 or 900 feet thick, carrying quartz pebbles up to the size of a hazel-nut. The general color of the zone is pale green. Under this is a reddish-brown rock containing pebbles and beds of slate and shaly sandstone. The intercalated mud and shale beds are scarcely altered; they closely resemble the soft mud strata of the Connecticut River sandstone. Interstratified with the white quartzites in the bottom of the Agassiz amphitheatre, are a few sheets, never over three or four feet in thickness, which contain a little finely comminuted white mica, which was probably developed here, not preserved as original sedimentary particles.

Upon the slopes of Mount Agassiz, about 1,000 or 1,500 feet below the summit, in a piece of quartzitic débris which could not be distinguished from the rock *in situ* immediately above it, was obtained half of a ribbed *brachiopod*, referred with some doubt by Hall and Whitfield to *Spirifer imbrex.* The material of the fossil itself is precisely that of the enclosing quartzite, and there is a strong probability that the fragment represents a horizon about 700 feet down from the summit of Mount Agassiz, and the fossil, which is a Carboniferous one, offers very fair evidence of the age of the series. It is altogether impossible that a fragment of the limestones which once arched over this region could have withstood the long period of erosion which has degraded the range since the close of the Cretaceous age. I therefore conclude that this cannot be a relic of the fossiliferous Upper Coal Measures which were once vertically above the spot. It seems equally improbable that a traveller, Indian or otherwise, should have acci-

dentally dropped on this débris pile a foreign fragment identical with the neighboring rock in place.

From another portion of the upper Bear River Valley, and on another débris pile, was also obtained a quartz pebble containing the impression of a crinoid column. While I admit the possibility of these being accidentally imported fragments, the presumption is decidedly in favor of their belonging to the quartzites of the region; and until better evidence to the contrary is adduced, I consider that they must be held to have indicated a Coal Measure age for the series. How well this coincides with the evidence of the Wahsatch section, will be shown hereafter.

Plate VIII. shows Mount Agassiz at the head of Bear River, as seen over a lake which occupies a deep glacial basin excavated in the horizontal Weber beds.

In the bottom of the basin, directly under Mount Agassiz, are heavy beds of white feldspar-bearing quartzite, deeply intersected by a variety of planes, jointing the rock into rough blocks. Plate IX. is a near, detailed view of the level tabular quartzite of Mount Agassiz. In these white quartzites are sheets of conglomerates consisting of rounded pebbles of pure white quartz and of a red jaspery material, with one or two evidently of crystalline schist containing the material of a dioritoid gneiss. Intercalated in these beds of quartzite is a series of muddy shales which easily weather out, leaving deep chambers between the strata of quartzite. The summit rocks dip about 8° to the south. Those to the north incline from 5° to 7° northward. A specimen of the whiter quartzite gave upon analysis 98.5 of silica, the remaining constituents being lime and alumina.

Northward the cañon of Bear River descends more rapidly than the inclination of the strata for five or six miles, when the beds are suddenly broken and flexed over into a dip of 45° to the north. In the comparatively horizontal summit series are exposed from 4,000 to 5,000 feet of southerly dipping beds, about an equal amount dipping to the north.

In conclusion, the Uinta Palæozoic series consists of—

1. A series of siliceous beds 12,000+ feet thick, impure sandstones at the east end of the uplift, but gradually compacted into quartzite in the western portion of the range; these beds are intercalated with groups of clay shales

and occasional conglomerate sheets which contain round rolled Archæan pebbles.

2. Conformably, as we believe, over No. 1 is a series 2,000 to 2,500 feet thick of mixed limestone, calciferous sandstones, and cherty limestones, showing great variability in the thickness of bedding, but prevailingly of heavy limestone near the base, with varying thin-bedded intercalations of lime and sand near the top, always capped with a zone of highly cherty *Bellerophon*-bearing limestones. From bottom to top the series is rich in Upper Coal Measure fossils.

3. From 200 to 500 feet of calcareous shales and argillaceous rocks and clays, intervening between the Coal Measures and Trias, conformable to both, and carrying Permo-Carboniferous fossils.

WAHSATCH RANGE.—This, far the most remarkable geological occurrence of stratified rocks in the American Cordilleras, derives its chief interest from the continuous exposure of a conformable Palæozoic series, 30,600 feet in thickness, extending from the top of the Permo-Carboniferous down through the whole series consecutively, and ending 12,000 feet below the uppermost horizon of the Primordial. Not the least remarkable of the features of this Palæozoic display is the manner in which these enormously thick series are wrapped around nucleal bodies of Archæan which represent the mountain slopes of a pre-Cambrian ridge.

The range within the limits of our Exploration, as shown upon Atlas-Map III., is naturally divided into three portions: First, the great semicircular sweep of strata around the Archæan and granitic centre of Lone Peak. Second, a similar mass curving around the Archæan body which occupies the summit of the range from a few miles north of Salt Lake City to the region of Ogden. Third, the northward projection of the strata from that point, which is depressed beneath the horizontal Tertiaries in latitude 41° 45′. The dip of all these exposures is to the east, north, and south—never to the west. An immense axial fault has cleft down the centre of the range from north to south, and the western half has been depressed and its rocks buried beneath the Pliocene and Quaternary exposures of Salt Lake Valley. The range therefore represents half of a great fold which has suffered much longitudinal compression and been faulted down

LAKE LAL AND MT AGASSIZ, UINTA RANGE, UTAH

the axis. The interesting orographic details of this structure will be found fully described in Chapter III., of Volume II., and their essential features again treated in Chapter VIII. of this volume.

A full description of the Palæozoic outcrops of this range would occupy more space than has been allotted to the whole of this volume, and I must content myself with a sufficient number of the great characteristic exposures to constitute a proof of their correlation into a generalized section. In order that these sections may be better understood, I offer here a mere outlined statement of the chief beds, in the order of their superposition. Beginning at the top, we have:

	Feet.
1. *Permo-Carboniferous*, composed partly of calcareous, partly of argillaceous, and partly of arenaceous materials, the whole giving evidence of shallow-water origin, and characterized from bottom to top by fossils of Permo-Carboniferous age..	650
2. *Upper Coal Measure*, essentially made up of limestones, interspersed with a variable amount of siliceous beds, the equivalent of the Upper Coal Measure series already described in the Uinta region, characterized by numerous well defined Coal Measure fossils..................................	1,700 to 2,100
3. *Weber quartzite*, a heavy body of quartzitic strata, slightly interspersed with greenish-gray slates, and containing, at both limits, unimportant intercalations of limestone.......	5,000 to 6,000
4. *Wahsatch limestone*, blue and gray rocks, in the upper part frequently rather thinly bedded and interstratified with a few persistent light-colored siliceous beds and quartzites. For the most part the limestones forming this series are compact and heavily bedded, and toward the base very dark-colored and more thinly bedded, with a few siliceous intercalations. Coal Measure fossils are numerous down to 1,600 feet from the base, where occur sub-Carboniferous types, which occupy but a narrow horizon, immediately followed by fossils of the Waverly group, these underlaid by beds containing Devonian forms, the whole making a continuous single body of limestone..................................	7,000

	Feet.
5. *Ogden quartzite*, generally white, shading off into pale green, often saccharoidal, more or less associated with greenish clay slates and rare conglomerates	1,000 to 1,500
6. *Ute limestone*, a dark-blue, compact, fine-grained rock, containing, a short distance below the top, Quebec fossils, which continue nearly to the base of the series. Toward the base the limestone becomes shaly for several hundred feet	1,000 to 2,000
7. *Cambrian shales*, a bed of variable calcareous and argillaceous slates of varying thickness, containing Primordial fossils	75 to 600
8. *Cambrian quartzite*, an immense series of siliceous and arkose rocks	12,000
9. *Lower Cambrian slates*, dark argillites, and intercalated siliceous schists	800

I purpose briefly to describe two separate sections in Wahsatch Range, which will serve to illustrate the succession of strata and life from the lowest of the Cambrian series to the close of the Palæozoic. The most excellently displayed of these, so far as continuity of outcrop goes, is that shown in the cañon of Weber River, from near the mouth of Lost Creek down to Morgan Valley. This section shows only the upper edge of the Cambrian series, never exposing the deepest members. The second section will be that from the mouth of Big Cottonwood Cañon directly across the range to Parley's Park. As much of this section is on mountain sides and ridges, the absolute continuity of outcrop is often lost under unimportant masses of débris and accumulations of soil; but the lower portion, namely, the Cambrian, is observed in deep continuous exposures in the cañon cut. Besides these two sections, details of the general scheme will be filled up by such additional partial sections as are considered essential to the rounding out of our knowledge of the region.

The base of the Weber Cañon Palæozoic section is seen in Morgan Valley, a depression parallel with Wahsatch Range at the east base of the Archæan mass which forms the main ridge from the region of Ogden nearly down to Salt Lake. Upon the eastern flank of the Archæan to the north and south are seen resting the members of the Palæozoic, but directly

east of Farmington the Palæozoic series is eroded away very deeply, and its former place is overlaid by the nearly horizontal members of the Vermilion Creek Tertiary, which rests directly, in evident unconformity, upon the Archæan. On the eastern side of the valley, however, the Tertiary is chiefly eroded away, and the bold heights of Morgan Peak are entirely made up, from summit to base, of the Palæozoic series. The lower foothills, all along the eastern edge of Morgan Valley, are partially composed of the horizontal strata of a very late Pliocene series, and are still further covered up by débris which rolls down from the height to the east.

The section observed, from the base upward, is as follows:

1. The lowest visible outcrops of the older rocks are composed of the peculiar cream-colored and pinkish quartzites, overlaid by thin greenish siliceous argillites, very compact and having a splintery fracture. No great thickness of these rocks is exposed, certainly not over 200 or 300 feet, but it is the unmistakable summit of the Cambrian, as will be seen by future comparison.

2. Conformably overlying this is a body of limestone about 1,100 feet thick, the lower part composed altogether of calcareous shales, very black, and splintery in fracture, while the upper members are of dark and continuous beds of limestone. This zone, too, is much obscured by overlying débris and soil. The outcrops are never continuous for any considerable length, and the extremely limited exposures yield no fossils. But, as will be seen hereafter, it is clearly in the position of the Ute limestone, the great body of the Quebec Silurian horizon.

3. Overlying the limestone and conformable with it, as is seen at one exposure, is a body of white quartzite, containing more or less restricted zones of conglomerate, the average grain of the quartzite being very fine, and the color varying between pure white and grayish green. Like the two previous members of the section, it is chiefly covered by débris and rubbish, with only occasional outcrops here and there along a line of five or six miles. These have the character of the low lines of cliffs, for the most part buried in soil, the base rarely appearing, while the backs of the strata slope eastward at an angle of 30° or 40° into the hills, rapidly covered by débris. The thickness is estimated, by the space occupied by these scattering outcrops,

at 1,200 feet. Up to this point, these three members would be of little value taken by themselves, but their general thickness, lithological character, and sequence are important when hereafter compared with sections of better exposure. They occupy the low foot-hills, and their total amount of outcrop is rather small. The strike, as shown at several points, varies a little both to the east and to the west of north; the dip is eastward at an angle of about 40°.

4. Directly and conformably overlying the Ogden quartzite comes the great Wahsatch limestone, which shows continuous outcrops for several miles and is thoroughly exposed from summit to base, making a total single series of limestone of 6,500 to 7,000 feet. The most valuable part of the whole Weber section begins with the bottom of this limestone, which rests on a few thin sheets of olive-colored argillites separating it from the Ogden quartzite below. There seems to be no intercalation whatever of limy material at this point. The quartzite comes up sharply to the argillites, which are here not over ten or fifteen feet thick, and give way immediately to impure earthy limestones of a very dark color. Thus far, on this section, the lower 1,200 feet of the Wahsatch have not yielded any fossils, but at the height of from 1,200 to 1,400 feet from the bottom of the limestone, in the neighborhood of Weber Station, the hills directly north of the dépôt are rich in Coal Measure forms. This point constitutes the entrance to Weber Cañon, which is cut in a nearly east-and-west direction transversely to the strike of the strata. The hills on the north side of the river rise to 2,000 and 2,500 feet above the cañon bottom, and the Palæozoic strata edges are seen dipping eastwardly at angles from 28° to 45°, the outcrops slanting up the hills and sinking beneath the bed of the cañon. At Weber Station the beds, which are about 1,300 feet stratigraphically above the base of the limestone, present their edges clearly to view, and show a varying dip of from 30° to 40°. They are here usually of quite pure limestone, and the strata vary in width from extremely thin sheets to heavy tables. So, too, they vary in their lithological condition, some being highly crystalline, others merely granular, and some even very roughly granular. The following forms were collected here:

Zaphrentis Stansburyi.
Chonetes granulifera.

Productus symmetricus.
Martinia lineata.
Spirifer opimus.
Spiriferina Kentuckensis.
Athyris subtilita.

Passing up the cañon, the series of limestones continues consecutively, without any interruption, for five or six miles, exposing 5,000 to 6,000 feet in thickness above the dépôt. The dip varies from 35°, in extreme cases, to 55°, but the steep dips are extremely local, and are enclosed both above and below by beds of the normal inclination of 40°.

About 1,100 feet from the summit of the group, in very pure grayish-blue limestone of dark hue, the following fossils were obtained:

Spirifer opimus.
Athyris subtilita.
Terebratula bovidens.
Productus prattenianus.
Aulopora sp.?

Nearly 800 feet from the top were collected—

Terebratula bovidens.
Productus prattenianus.
Aulopora sp.?

Also 500 feet from the top are *Terebratula bovidens* and *Athyris subtilita.*

About 300 feet from the summit of the series are some extremely dark beds, which emit a fœtid odor upon being struck with a hammer, and are intercalated with very impure arenaceous limestones. These contain numerous *Spirifer opimus* and *Athyris subtilita.*

The limestones at 1,000 feet from the top enclose a series of thinly bedded but heavily blocked quartzites, which contain two or three sheets of small pebbles. These, however, are very thin and localized. The quartzite is more properly indurated sandstone and occupies a belt 150 feet thick. In general, the upper 1,000 or 1,500 feet of this limestone series are made up of thinly bedded rocks, less pure than the strata below, and more or less intercalated with siliceous zones. Some of the beds are also considerably argillaceous. It is noticeable that while the massive limestones below are quite uniform in dip, the intercalated region is subject to great local disturbances. It would seem that the limestone beds are able to undergo compression with less contortion than the more siliceous beds. As a consequence, the included siliceous zones are wavy, and exhibit extreme irregularity of dip, while the limestones enclosing them on both sides maintain an even inclination. Below this upper thousand feet the materials are much more uniformly calcareous, and the siliceous zones are never pure enough to show any distinct sandstone strata. As a whole, the color of the series is dark. From the Weber dépôt to the summit of the series, therefore, the whole of this immense limestone is characterized by distinct Coal Measure forms, while the lower 1,200 or 1,300 feet have here yielded no fossils. This is no doubt due to the fact that it touches the edges of the foot-hills, and, like the three series described below, is largely covered with débris. Particular attention should be paid to the fact of the contortions and disturbances in the region of sand and quartzitic beds in the upper 1,200 or 1,000 feet of the series, as those phenomena are persistent over considerable areas of the Wahsatch, and will hereafter be described more particularly in some of the partial sections, where their recurrence is marked by most interesting internal plication. The closing members of the Wahsatch group are arenaceous limestones, with a brilliant brick-red color.

5. The passage from the Wahsatch limestone into the Weber quartzite is made in perfect conformity, and, as the beds clearly evidence, with undisturbed consecutive deposition. Above the reddened and arenaceous summit of the Wahsatch limestone are a few intercalations of siliceous limestone. The Weber beds at this point dip about 40° to the east. In this lower zone are sheets of conglomerate, the pebbles of which are usually small and composed of white quartz. The general appearance of the quartzite zone is here that of a coarse, rather gritty sandstone, unevenly compressed into quartzite. The bottom of the series is prevailingly red for about 250 feet, and averages coarser than the material above. Over the red is a very finely laminated white and grayish quartzite, quite uniform in texture, and with only the most sparing enclosures of pebbles. Above this

point the series rapidly decline in dip to an inclination of only 16° to 20° to the east, accompanied by slight undulations. The curve from the steeper to the gentler dip is very gradual, and is unaccompanied by dislocations. There seems to be also a very small amount of local cracking of the strata. This low dip is held for about two miles up the cañon, the strata becoming thicker and more heavily bedded, the texture of the quartzites more and more dense, and the conglomerates occurring at less frequent intervals. A mile and a half east from the base of the series there is scarcely any conglomerate at all, and the rock is a true quartzite of whitish or greenish hue, developing on many of its weathered surfaces a peculiar dark brown stain which looks like the oxydation of manganese. At the lower railway tunnel an interesting sharp double curvature is described by the strata. From the easterly dip of 16° they pass under a short shallow synclinal, rising on the reverse dip of about 20° for 100 feet or so, then, curving over an anticlinal, dip again to the east, from which point the easterly dip is maintained at an angle of 50° to 57°. There is a small development of limestones here, quite black, and sufficiently siliceous to scratch glass, though effervescing under acids. This singular black rock is found to contain 83 per cent. of silica, 5 of organic matter, and 12 of carbonate of lime and magnesia. Above the tunnel are about 1,500 feet of massive quartzites of greenish-white hue, closely resembling the similar rocks at Mount Agassiz. The strike here deviates more and more to the north in ascending the cañon. Throughout the whole 5,000 feet of this series no fossils are found. Toward the top are numerous peculiar holes in the rock, which seem like the cavities left by decomposing fossils, but the evidence is too slight to be of value. It is from the characteristic occurrence of this remarkable bed of quartzite at this locality that the name Weber quartzite has been given to the body. It is here essentially a quartzite, although toward the base rather more truly an indurated sandstone. The thickness, which we estimate in this exposure at 5,000 feet, represents the minimum observed section of this series, where both its lower and upper limit can be observed. It likewise represents the most extreme lithological result in the direction of the quartzite; and I am convinced that those two conditions are expressions of a common cause—that rocks made up of siliceous detritus may be compressed to half the thickness of the original deposit in passing from an incoherent sand rock to the strictly crystalline condition of quartzite.

6. Conformably overlying the quartzite is a very heavy bed of much altered gray limestone from 600 to 700 feet thick. The bedding-planes are often entirely obliterated, and the material extremely crystalline, showing traces of great interior disturbance. The lower beds show a true conformity with the underlying quartzite. One or two hundred feet up in the series the alteration of the limestones reaches its maximum, and on the heights to the north of the cañon it approaches a white marble. It is riven with cracks in every direction, but shows no trace of the intrusion of foreign chemical agents. South of the cañon a few fossils were collected in a badly preserved condition, but sufficiently distinct to be referred by Prof. Meek without hesitation to the Upper Coal Measure forms. One of these is a *Spiriferina Kentuckensis;* the other *S. pratteniana*s. The gradual deviation of the strike from true north-and-south to a little east of north, already mentioned in the Weber quartzites, here reaches a direction of north 15° east. The average colors of these limestones are creamy grays, inclining often to white in the more crystalline portions. A deep ravine which enters the cañon from the north cuts diagonally across the upper part of the Upper Coal Measure limestones down into the Weber quartzite, and displays their conformable contact very well. Here the limestones are still more altered, and may be called a crude marble. The quartzites are also more disturbed, and show the effects of intense compression. This region of maximum disturbance and metamorphism is directly in the axis of the change of dip already mentioned as shown below the lower railroad tunnel. Passing over this curve to the west of the head of the ravine, the limestones are again seen conformable to the diminished dip of the quartzite, inclining at about 16°. On the heights south of the river, where the whole formation passes under the horizontal beds of Eocene conglomerate, this great bed of limestone is less altered, and shows many strata of pale yellow and drab color, resembling their equivalents, the lower drab limestones of the Upper Coal Measure series of the Uinta. Overlying this main body of 700 feet of limestone is a series of yellow shaly limestones 175 feet thick. This rock is extremely brittle, and, owing to the

uneven strain to which it has been subjected, is shivered into peculiar splinters, so that the surface of each stratum, instead of being the natural smooth plane of deposition, is a series of minute waves and troughs, like broken wave-marks. This shaly structure is obviously due to uneven pressure. The surfaces of the fragments are not infrequently stained a pale, sulphur yellow. Overlying these calcareous shales, as heretofore quite conformable, is a series of sand and mud rocks, all more or less calcareous, varying in color from chocolate to olive, with red argillaceous sandstones, the whole about 225 feet thick. It has the appearance of a comparatively shallow-water deposit, made of argillaceous material, limestone, and sand, the thickness of individual beds being unusually limited. There are very many beds not over an inch thick On the upper surface of the strata, at several horizons, ripple-marks are preserved with unusual distinctness, and on a scale of fineness not often seen, the distance between the wave and trough being frequently not over an inch or an inch and a half. Alternating dark chocolate and olive-colored shales form the lower 200 feet of this group, while the upper 25 or 30 feet are pretty solid sandstone. Over these, still conformable, are 100 feet of yellow and olive calcareous shales, which are so earthy as usually to decompose, yielding a bad outcrop. Above this is a bed of bluish-gray limestone, rather compact, about 150 feet in thickness. Next come 20 feet of reddish-brown clayey sand, hardly compacted into rock, containing thin stony seams intercalated at intervals in the soft, easily eroded matter. This is immediately followed by 75 feet of a yellowish-gray, brittle, easily decomposed limestone Next above are 100 feet of light-colored, very thinly bedded limestones, that give way to 100 feet more of dark, siliceous, tough limestone, which breaks under the hammer with great difficulty, yielding an exceedingly rough, ragged fracture. In this were obtained a few fragments of fossils, made out by Professor Meek to be of the genus *Bellerophon;* and the highly siliceous character of the bed, closing as it does the Upper Coal Measure series, leads me to correlate it with the siliceous *Bellerophon* limestones already described in the Uinta.

7. Next above in sequence, and apparently with entire conformity of dip angle, although there are slight indications of erosion upon the surface

of the siliceous limestone prior to the deposition of the overlying shales, follows a body of variable shales, thin seams of limestone and mud and sand rocks, the whole being of shallow-water origin and displaying ripple-marks, comprising 620 feet of conformable beds. At three localities in this series were obtained fossils of Permo-Carboniferous facies, including—

Aviculopecten McCoyi.
Aviculopecten oxidaneus.
Aviculopecten n. sp.
Schizodus ovata.
Myascites Weberensis.

Directly above the siliceous limestone, which I consider to be the equivalent of the *Bellerophon* limestone, are shales carrying beds of argillaceous sandstone three or four feet in thickness, which vary in color from chocolate to olive, the whole being about 100 feet thick. The olive-colored shales carry the same remarkably preserved ripple-marks as were observed below the *Bellerophon* limestone, but they are far larger than those above described. Above this series of chocolate and olive shales are 200 feet of soft muddy shales, containing thin beds of argillaceous limestone, also ripple-marked, and limited layers of mixed arenaceous and impure limestones. Still above these are 250 feet of buff and gray sandstone, usually made of extremely fine material held together by more or less argillite, and alternating with fine beds of earthy argillaceous shales, the whole capped by a thin siliceous series, almost a quartzite, 70 or 80 feet in thickness. The series of Permo-Carboniferous shales varies in dip from 48° to 60°, rising in some local cases as high as 70°. The capping bed of quartzitic sandstone is directly and conformably succeeded by the red beds of the Trias, which will be found described in the chapter on Mesozoic formations.

Leaving out of consideration the thickness of beds which at the base are but very obscurely exposed, below the bottom of the Ute limestone (No. 2 of the described series), and counting from the bottom of that limestone, we have in this single section to the top of the Permian 16,000 feet of conformable strata, characterized by Permo-Carboniferous fossils in the upper 620 feet; and in the next 1,600 feet, Coal Measure fossils related to the forms of the Upper Coal Measures, though very scarce and very fragmentary, owing to the physical condition of the rocks, which are highly altered. Then comes the Weber group, made up of 5,000 feet of quartzite, occupying the position of the Middle Coal Measures, underlaid by more than 5,000 feet of Coal Measure limestones, comprising the upper five sevenths of the Wahsatch limestone. From this section we obtained, first, a clear expression of the stratigraphical sequence of the series; secondly, the upper and lower limits of the Coal Measure series, which give for that member here a thickness of about 12,000 feet. Of the 16,000 feet, about 9,100 feet are limestone, 6,200 are of purely siliceous material in the form of sandstones and quartzites, and 700 to 800 feet of argillaceous and arenaceous mud rocks, characterized by more or less calcareous material. It is also noticeable that, with the slight exception of the thin bed of slate which underlies the Wahsatch limestone and separates it from the Ogden quartzite, and a few slightly argillaceous limestones in the upper 1,000 feet of the Wahsatch body, all the shales and argillaceous material are confined to the upper region of the Coal Measures directly under the *Bellerophon* limestone, and to the Permo-Carboniferous which immediately succeeds it.

I will now give a section observed between the mouth of Cottonwood Cañon and Parley's Park, the most extended and instructive stratigraphical exhibition of the Palæozoic series in the Fortieth Parallel area.

1. A glance at Map III. of the geological series will discover a considerable body of Cambrian occupying the lower half of Big Cottonwood Cañon. The same formation is seen to recur upon the south side of the granite ridge which separates the two Cottonwood cañons, extending part-way down to the bed of the cañon, and again recurring upon the heights northwest of Alta. The deepest section of this body is offered on the lower course of Big Cottonwood Cañon, which lies wholly in the Cambrian for five miles. The strike of the rocks is diagonal to the cañon, so that the exposures on the cañon walls and in the lateral ravines display both the edges and the backs of the beds, giving an excellent idea of their physical condition. The cañon in its zigzags often follows the strike of the rocks for a short distance, and then cuts either perpendicularly or

obliquely across them. The estimate of the general thickness of the body as exposed here is made by laying down a great number of local observations on the map, and deducing an average dip and strike, to which is applied the transverse distance of the outcrop, and the result gives about 12,000 feet. While an accurate, detailed measurement is probably impossible, this estimate is a sufficient approximation to truth for all our purposes.

Near the mouth of the cañon, to the south of which the Cambrian series overlie the granite and Archæan body unconformably, are seen the lowermost members of the series, here formed of a body of dark blue and purple, and dark olive-green, often almost black slates, largely made up of fine-grained and thinly laminated argillites which alternate with zones more or less siliceous, the whole measuring from 800 to 900 feet in thickness These constitute our Lower Cambrian slates. Conformably above them are 8,000 to 9,000 feet of mixed siliceous schists and argillaceous schists, in beds varying from a few inches in thickness to heavy strata eight or ten feet thick. They are prevailingly siliceous, but over a great thickness the alumina proportion is high. One of these intermediate forms gave on analysis 60 per cent. of silica, the other constituents being mostly alumina, with a little iron, lime, and alkalies. Above these varying schists are about 3,000 feet of true quartzite, capped by 200 feet of schistose rocks, quite micaceous toward the bottom. Among the beds near the top of Twin Peaks, a high summit south of the cañon, is a series of the strata of micaceous quartzite, in which the mica occurs rather sparingly in fine brilliant specks, apparently muscovite. It imparts a decidedly fissile structure to the rock. On the peak next east is found a dark-blue, argillaceous slate, in which there is a considerable development of phlogopite in dark bronze crystals. Throughout the region of Twin Peak schists which directly underlie the highest quartzites of the Cambrian, are numerous zones that closely approach mica schist. In the ravines that lead down the northeast side of Twin Peaks these mica-bearing schists, which are not sufficiently charged with the mineral to be called a mica-schist, are observed underlying the upper quartzites.

An excellent section of the Cambrian schists is obtained from the mouth of Big Cottonwood Cañon, in a northeasterly direction across the spur which divides the waters of Cottonwood Creek from those of Mill Creek. About the same estimate of thickness is formed from an examination of this ridge, namely, that from the dark bottom slates to the top of the argillaceous slates which cap the body, there is an exposure of about 12,000 feet.

Although search was made throughout these schists as carefully as our time would permit, no fossils were obtained, and the reference to Cambrian will be explained later in the chapter.

The series consists essentially of four members: the bottom slates, 800 feet; varying siliceous and argillaceous schists containing some mica-bearing zones, 8,000 or 9,000 feet; salmon-colored and white quartzites intercalated with dark schists, 2,500 to 3,000 feet; and the capping schists of 200 feet, which are partly argillaceous and calcareous and partly mica-bearing argillites. The dip as shown in Cottonwood Cañon is very high, in the region of 60° near the mouth of the cañon, declining eastward, so that the higher members of the groups directly under the Silurian limestone in Big Cottonwood Cañon slope to the east about 45°, while across the ridge just below Alta, in Little Cottonwood Cañon, they preserve the steep dip of 60°. The contact between this series and the underlying unconformable mass of granite and Archæan schists is extremely interesting, and from its situation offers remarkable opportunities of studying the early contours of the older rocks. From the mouth of Cottonwood Cañon the line of contact rises upon the ridge to the south, forming the divide between the two Cottonwood cañons, and circles across the divide around the base of Twin Peaks, leaving the upper 2,000 feet of the mountain mass Cambrian, and the lower 3,000 feet on the Little Cottonwood side granite. The line of contact is nearly horizontal, and extends back six miles to a little below the town of Alta, successively higher members of the Cambrian series resting against the granite, until at last the ancient series rises into contact with the Silurian limestone, which conformably overlies the Cambrian. This is well shown in the lower section at the bottom of Map III.

2. Next above the Cambrian lie 1,000 feet of Ute limestone, which for the most part is very light-colored, highly crystalline, and characterized by peculiar cloudings of color that extend across the beds. Near the bottom of the series, and at one or two horizons near the top, it is noticeable for containing a large proportion of tremolite, and under the microscope it is seen to

be highly siliceous, the silica appearing as rounded glassy grains of pellucid quartz. The outcrop extends up the hills on both sides of the cañons, and to the south is conspicuous upon the divide, from which it descends into Little Cottonwood and in the valley a little way below Alta exposes a fine precipitous cliff, the result of a fault. Here again are seen the same highly crystalline, almost marble-like condition and the same prevalence of tremolite and silica. Under these circumstances it is not at all remarkable that the bed contains no fossils; but it is unquestionably Silurian, as will be seen later.

3. Above this Ute limestone occurs the white granular body of Ogden quartzite, which is here reduced in thickness to about 800 feet. It may be traced up the hills to the south, and forms an interesting saddle on the ridge-top between the Ute limestone and the bold masses of Wahsatch limestone which directly overlie it. Here are but limited traces of the thin body of greenish argillites that farther south, in the region of Rock Creek, were found on both sides as bounding-beds of the Ogden body.

4. Immediately above this is Wahsatch limestone, which forms the high ridge north of the cañon, and is traceable south against the granitic slopes of Mount Clayton. In the whole semicircular sweep which the Wahsatch limestone here describes around the Archæan body are the most interesting changes of molecular condition. The ridge to the north of Big Cottonwood shows a scarcely altered dark limestone, in which the fossils are preserved, while toward the south it becomes white marble, and near Mount Clayton is intersected by numerous dikes of granite-porphyry. The lower beds are pretty sharply defined from the Ogden quartzite, but themselves contain a little granular quartz, which remains upon dissolving the limestone in acids, and is partially rolled, though in general angular.

The lower Wahsatch beds in Big Cottonwood Cañon are heavy, and owing to the high state of alteration contain no fossils. On the ridge to the south, at the Reed & Benson Mine, about 1,300 feet from the base of the series, were found the following species characteristic of the Waverly:

Spirifer Albapinensis.
Spirifer centronatus.

Athyris planosulcatus.
Athyris Claytoni.
Euomphalus Utahensis.
Terebratula Utahensis.
Cryptonella sp.?

On a horizon a little above that of the Reed & Benson Mine were obtained the following distinctive Coal Measure forms:

Spirifer cameratus.
Spirifer planoconvexus.
Spirifer sp.? (like *disjunctus*).
Syringopora sp.?
Diphyphyllum.

And still higher up, about 2,500 feet from the base of the series—

Spirifer lineatus.
Spirifer sp.? (like *disjunctus*).
Athyris subtilita.
Euomphalus sp.?
Zaphrentis sp.? (like *centralis*).

On the summit of the ridge above the Flagstaff Mine, a bed of white calcareous quartzite in Wahsatch limestone is full of indistinct cylindrical cavities, the casts of fossils, and frequent *Spirifer cameratus.*

On the heights to the south of the cañon are some Z-shaped folds in the upper part of the Wahsatch beds, similar to occurrences which will be described in the Ogden Cañon section.

On the north side of the cañon bottom, in the less altered limestones about 2,000 feet from the top of the series, were obtained—

Chonetes granulifera.
Productus Nebrascensis.
Productus pertenuis.
Productus symmetricus.

Farther west on the strike, at about the same horizon, were obtained —

Productus semireticulatus
Spirifer ?
Zaphrentis ?
Crinoids.

From the very uppermost beds directly under the lower members of the Weber quartzite, on the hill-top north of the Big Bend of Cottonwood, were obtained —

Productus prattenianus.
Productus semireticulatus.

5. Conformably over the Wahsatch limestone is the enormous body of Weber quartzites with slight intercalations of conglomerate, and near the upper limits of the series a few thin, argillaceous schists. In the region of the schists, which cannot be less than 4,000 feet up in the series of quartzites, the siliceous beds themselves are interestingly banded like ribbon jasper, a feature which is worth noticing as occurring farther east in the Uinta, but as not observable in the Weber quartzites to the north or west of this point. The area occupied by the Weber at the head of Cottonwood Cañon is cumbered with an immense amount of glacial and modern débris obscured by growths of coniferous timber, and in general it is impossible to measure the thickness accurately. Where observed, the dip, like that of the underlying series, approximated to 45°, but occasionally was somewhat higher. Judging by the average dip and the area in which only quartzitic strata outcrop, there cannot be here less than 6,000 feet of the Weber formation. This body may be traced to the northwest until its steep edge appears against the foot-hills of Jordan plain. By a general examination of the ridge it becomes clear that it is pure quartzite without important intercalations, except at the bottom, where for several hundred feet the passage from Wahsatch limestone into quartzite is made by thick intercalations of seven or eight beds of limestone. This feature, unnoticeable to the north, recurs to the south, and is characteristic of the junction of the two formations in this longitude.

6. Continuing from the Big Bend of Cottonwood Cañon in a northwest

direction toward Parley's Park, the contact of the upper limit of the Weber quartzite with the heavy beds of drab limestone which form the lower portion of the Upper Coal Measures, is distinctly observed; but owing to the forest and débris, only a few fossil forms were obtained, and those in a much-weathered, unsatisfactory condition. Yet the character of the limestone, and its conformable position directly over the Weber, clearly refer it to the base of the Upper Coal Measure series. A continuous belt of limestone, about 1,200 feet thick, is here exposed, of which the upper portion is rather finely stratified and shaly, and bears *Bellerophon carbonarius.*

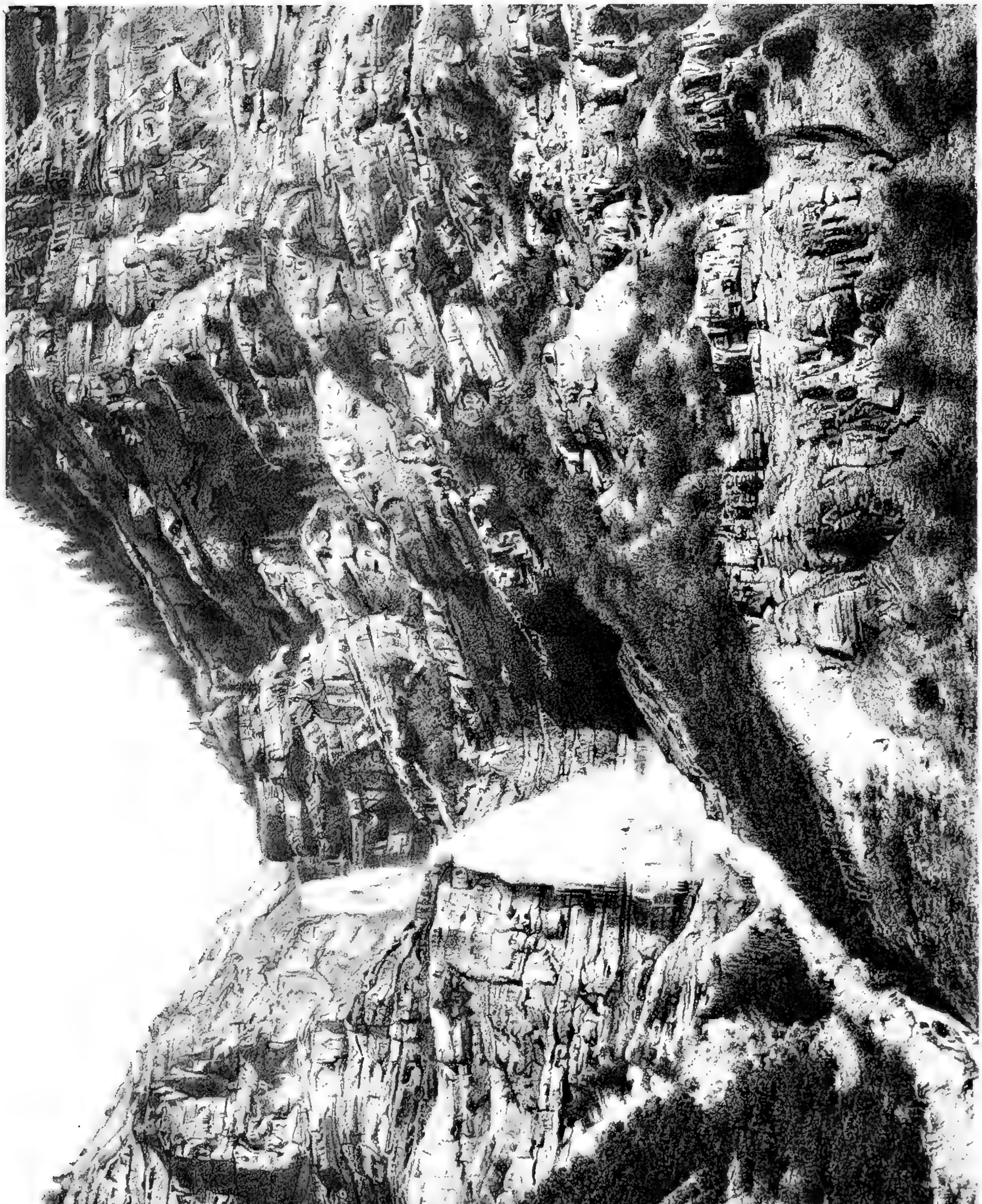
7. Directly over this is a series of calcareous shales and ripple-marked argillites with yellow shale rocks, and at the summit of the series a considerable body of quartzitic sandstone which directly underlies the red Trias. In the mud rocks and in the calcareous shales on the extreme foot-hills of Parley's Park, in a position about three hundred feet below the Trias, were obtained a *Bakevellia*, probably *parva;* a *Eumicrotis*, probably *Hawni;* and an *Aviculopecten*, like *parvula.* Owing to the amount of forest and débris, it is impossible to be sure that these upper series, which correspond with the Permo-Carboniferous shales of the Weber section, have not been reduplicated by a fault, for there seem to be, as nearly as can be estimated, about 900 feet.

The principal points of interest of this section are, first, the deep exposure of rocks which we have referred to the Cambrian, lying conformably below the Ute Silurian limestone, affording us the deepest view of the Palæozoic beds that we get anywhere upon the Fortieth Parallel; secondly, the absolute stratigraphical parallelism between this and the Weber section; thirdly, the fact that we obtained, as in the Weber section, Coal Measure fossils down to within about 1,300 feet of the base of the Wahsatch limestone, and at that horizon was established by ample evidence the existence of the Waverly group; fourthly, the lithological and faunal identity of the Permo-Carboniferous shales with those of the Weber. As a whole, the section is not so continuously exposed and the opportunities for measurements of the thickness of beds are less favorable than in Weber Cañon The Wahsatch limestone seems to be thicker than in the Weber, while the Ogden quartzite has diminished from 1,000 to 800 feet Otherwise a comparison of the sections will show an approximate identity. As in the Weber section, there is absolutely no nonconformity from the base, 30,000 feet up to the very summit.

South of Lone Peak the great body of Wahsatch limestone already described in the Cottonwood region completes a semicircle about the granite mass, and then abruptly trends in a southeasterly direction, forming the whole range from base to summit. The region is here complicated by faults parallel to the strike, as well as transverse, so that an accurate measurement of the thickness of the series is impossible. As at the north, Coal Measure fossils characterize the beds to within 1,200 or 1,300 feet of the base of the series. That base is exposed very clearly north of the town of Provo; and along the whole eastern flank of the range back of Provo Peak the limestone is seen to pass by a series of intercalations into Weber quartzite. A remarkably good instance of these intercalations is shown on Tim-pan-o-gos Peak. The peak itself is a narrow ridge trending parallel to the strike of the body, namely, a little west of north, and reaches an elevation of 11,937 feet. It falls abruptly down to the east and west from 3,000 to 5,000 feet, and is composed of approximately horizontal strata of the Wahsatch series. The beds forming the upper part of the ridge consist of repeated alternations of layers of limestone and limestone shales, with light-colored quartzites and siliceous shales. This intercalated passage into the Weber is clearly recognizable along all this region south of Clayton's Peak, and represents a much more gradual transition than in the Weber section, where the change from Wahsatch limestone up into Weber quartzite is characterized by a sudden break and a few unimportant intercalations. The interbedded zone carries numerous fossils in the limestone members, which in general have been changed into a white calcitic material. Among the species recognized were—

Spirifer cameratus.
Athyris subtilita.
Productus semireticulatus.
Discena sp.?

The mixed zone, varying from 400 to 550 feet, includes about forty intercalations. The well known layer of white vitreous quartzite in the



upper part of the Wahsatch limestone and a little below the transition-zone is constant here.

Plate X. represents the front face of the Wahsatch at Provo Fall; the cascade is here about 600 feet high, tumbling over escarped edges of the Wahsatch limestone group.

The following few other illustrations are selected from Wahsatch localities, to add data to the general section.

On the foot-hills a short distance to the north of Camp Douglas, directly underlying the red Trias limestone, are seen the series of the Permo-Carboniferous and Upper Coal Measures. Here was obtained *Aviculopecten Weberensis.* Farther south, on the spur between Parley's and Emigration cañons, is a local anticlinal, a minor contortion in the great series of the northerly dipping strata which extend thence to the mouth of Cottonwood Cañon. Conformably included within the anticlinal fold of the red Trias sandstones is a small body of the characteristic red beds and clay shales of the Permo-Carboniferous, containing the following:

Aviculopecten Weberensis.
Aviculopecten curtocardinalis.
Aviculopecten McCoyi.
Aviculopecten parvula.
Sedgwickia concava.
Eumicrotis Hawni.
Myalina permiana.
Myalina aviculoides.

North of Clayton's Peak, and directly surrounding the eastern side of the body of granite, are seen the heavy beds of the Weber quartzite, here very much iron-stained and showing evidences of severe alteration. The general strike describes a complete curve around the granitic mass of Clayton's Peak, with its convexity toward the east. The rocks east of the peak dip directly east under the Provo trachytes, and make with the westerly dipping quartzites of the Uinta an unquestionable synclinal, through whose faulted axis bodies of trachyte have appeared.

About four miles up City Creek Cañon, Ute Silurian limestone is seen between Cambrian schists and Ogden quartzite. It is here from 1,000 to 1,100 feet in thickness, and at a horizon about 600 feet from the bottom yielded specimens of *Dikellocephalus Wahsatchensis*, a fossil characteristic in this region of the Quebec age.

Upon the high summit of the Wahsatch, east of Centreville, unconformably overlying the Archæan gneisses, is a body of salmon-colored quartzite, containing large gritty grains of pellucid quartz, and underlaid by a dark, heavy bed of purple quartzite. The salmon-colored quartzite is about 600 feet thick, and is overlaid by a few calcareous shales, which are immediately succeeded by Ute limestone 1,000 feet thick, showing the conformable transition from Cambrian to Silurian.

The Cambrian recurs on Ogden Peak, where heavy quartzitic beds, with an easterly dip of 60°, lie upon the steep edges of Archæan bodies which stand about 75° to the west. Near the top of Ogden Peak the Cambrian is characterized by a well defined bed of compact conglomerate, containing remarkably smooth pebbles of quartz. From this point north for twelve or fifteen miles, looking at the range from the west, the Archæan gneisses may be seen to be overlaid by an unconformable body of strata dipping to the east, which represent the edges left by the great fault that has depressed the western half of the range. Of these conformable strata, the uppermost, northeast of Ogden, are Wahsatch limestone, while the lowest exposure is of Cambrian of varying thickness. Here, from the study of the contact between the Cambrian and the Archæan, it is clear that the Archæan itself was shaped into rather elevated topographical forms, and that the Cambrian was deposited over them all, submerging the entire ridge. Supposing the uplifted Cambrian back in a horizontal position, the present exposed contacts give an idea of the pre-Cambrian, Archæan topography, and it is evident here that there were Archæan peaks of 3,000 and 4,000 feet, while an examination of the nonconformable contact in the region of Cottonwood Cañon shows a steep mountain face of 30,000 feet; and in the deposition of the Cambrian against these slopes it is evident that there was no tendency on the part of the sediment to conform at all to the ancient surface.

Ogden Cañon offers an admirable partial section of the Palæozoic.

1. Dioritic gneisses, the prominent feature of the Archæan near the mouth of Ogden Cañon, are unconformably overlaid by Cambrian quartzites striking north 30° to 35° west and dipping 60° to 65° eastward. Here are about 1,000 feet of quartzites, overlaid by 100 feet of siliceous and argillaceous shales, which in passing up become decidedly calcareous, showing an evident transition into the overlying Ute limestone. The occurrence of these argillaceous and calcareous shales here is well shown on the south bank of the cañon, and is of importance, since they form the stratum in which the uppermost Primordial forms are found elsewhere. Throughout the lower part of the exposure the quartzite is of uniform lithological habit, and smooth, even bedding. It is exceedingly compact, and the quartz grains which compose it are sometimes visibly rounded. In other words, the original figure of the grains of sediment has not been entirely obliterated and compressed into a uniform crystalline mass, as is the case with nearly all the Archæan quartzites examined by us. The tints are light-gray in the lower horizon, inclining to salmon above, due to oxyd of iron upon the stratum-planes. In the upper part of the series, corresponding to the conglomerate horizon on the top of Ogden Peak, are seen distinct beds of conglomerate, made of evenly worn oval pebbles of gray, red, brown, and white jasper, reaching two or three inches in diameter. Both here and in the conglomerates which are displayed on the east side of the Wahsatch, under the Ute limestone near Centreville, the pebbles are interesting for the evidence they give of the great pressure to which the quartzites have been exposed. They are often flattened and elongated, and in some cases two pebbles are compressed so as to overlap each other. In some instances three or four pebbles are compressed into one solid mass, penetrating each other as if absolutely plastic. Throughout all these distorted and compressed pebbles there is no evidence of cracking. The argillaceous shales, which here, as elsewhere, close the Cambrian series, are exceedingly fine-grained, are of prevailing olive and greenish-gray color, and are identical with the beds from the same horizon which underlie the Ute limestone at Quebec Peak, at the forks of the Muddy.

2. Above these are twenty-five feet of more characteristically calcareous shales that pass up into well defined limestone, which is thicker than to the

south, reaching 1,200 to 1,500 feet. Here, on the hill-sides to the south and north of Ogden River, is an excellent consecutive outcrop of the material forming the Ute limestone. As a whole, it is here, as in the region of Cottonwood, distinctly a siliceous limestone, and although formerly burned for lime was found to yield too siliceous a product. About 300 feet above the base is a well marked zone, twenty or thirty feet thick, of argillites similar to those which mark its separation from the Cambrian. Below these twenty feet of shales the general character of the limestone is more shaly than above. Directly over them is a dark-blue limestone, overlaid by a nearly white series of granular crystalline beds, the upper portion of which is more or less characterized by shales. The only fossils found here were highly altered *Stromatopora*.

3. The Ogden quartzite, which directly overlies the Ute limestone, has here a thickness of from 1,250 to 1,350 feet. It is pale-reddish or yellowish, and conspicuous for a multiplicity of jointing-planes. Subjected to chemical analysis, it yielded 77.79 of silica, the remainder of alumina, lime, and alkalies. About midway in the formation is a thin bed of white marble, above it a thin series of olive-colored, argillaceous shales.

4. From the summit of Ogden Peak to the head of Ogden Cañon extend the massive, continuous beds of the Wahsatch limestone, which are displayed particularly on the north wall of the cañon in precipitous cliffs 2,000 to 2,500 feet above the level of the river. Immense piles of débris, fully 2,000 feet in height, obscure many of the lower strata. As a whole, the beds are coarsely crystalline, often siliceous, sometimes cherty, and here and there characterized by argillaceous, muddy impurities. About 5,000 feet from the base of the series, and near the top of the cañon, we reach the siliceous zone already described in the Weber section, and here occurs a remarkable series of plications. The impure siliceous zones are plicated in the form of the letter Z, the amplitude of the folds being about 500 feet. The beds directly under the siliceous zone, although entirely conformable, show the effect of this crumpling but very slightly, and in the overlying strata this influence gradually dies out, leaving the higher members absolutely conformable with the undisturbed region below the siliceous zone. Twelve hundred feet from the base of the limestone here, or practically at

the identical horizon at which the Waverly fossils were obtained at the Reed & Benson Mine, we collected the following:

Productus sp.?	Waverly.
Spirifer Albapinensis.	
Spirifer centronatus.	
Athyris planosulcata.	
Euomphalus Utahensis.	
Streptorhynchus inequalis.	Devonian.
Proetus peroccidens.	

While this series of fossils, as a whole, has an unmistakable Waverly facies, the occurrence of the last two, which are essentially Devonian forms, marks this horizon as the turning-point between the Devonian and the Waverly. In this connection it should be mentioned that at about the same horizon in Wahsatch limestone at Rock Creek was obtained *Spirifer centronatus*, a well defined Waverly species also occurring in the White Pine District at the base of the Waverly. Farther up, directly above the flexed region of the siliceous zones near the head of the cañon, was found a new species of *Zaphrentis* associated with true Lower Coal Measure forms.

The horizon of the Waverly is again shown in Logan Cañon. Cache Valley is a broad anticlinal formed of the Palæozoic series, from the Cambrian well up into the Wahsatch limestone. The axis of the synclinal is occupied by horizontal beds, which obscure the uppermost members of the Wahsatch. In the low beds which are exposed near the mouth of the cañon, about 1,400 or 1,500 feet above the lowest exposures, at a horizon which must be very closely that of the Waverly, in Ogden Cañon, were obtained the following fossils:

Chonetes Loganensis.
Rhynchonella pustulosa.
Euomphalus latus, var. *laxus.*
Spirifer Albapinensis.
Spirifera centronata.
Proetus peroccidens.
Proetus Loganensis.

Higher in the same limestones, in the horizon of the Lower Coal Measures, were obtained a small species of *Productus*, *Zaphrentis Stansburyi*, and *Lithostrotion*.

From Copenhagen to Call's Fort the Cambrian, with the Ute limestone and overlying Ogden quartzite, is seen outcropping very distinctly. The contact between the Cambrian and the Ute limestone slopes down to the plains, and is depressed under the Quaternary directly at Call's Fort. The quartzite here has a high vitreous lustre, conchoidal fracture, and extremely fine texture; its prevailing colors are decidedly salmon. The strike of the quartzites and limestones is approximately north 20° west, diagonally crossing the range. Here the upper member of the Cambrian directly overlying the quartzites is a fine-grained argillaceous slate, shading up into calcareous shales, of the bottom of the Ute limestone. At the base of the latter were obtained —

Dikellocephalus Wahsatchensis.
Dikellocephalus gothicus.
Crepicephalus (*Loganellus*) *quadrans.*
Lingulepis Ella.

Here the limestones generally are considerably thicker than in the section described in Ogden Cañon. We estimate them at about 2,000 feet. From the upper part of the same series, a few miles south, at the head of Box Elder Cañon, F. H. Bradley, in 1871, obtained *Halysites catenulata.* In this immediate region, therefore, we have obtained Quebec forms near the base of the Ute limestone, and Bradley a form distinguishing the Niagara near the summit of the same member.

East of Cache Valley synclinal lies a broad anticlinal, which diverges from the trend of the Wahsatch and strikes a little east of north. The character of this anticlinal is somewhat peculiar, showing a very gentle slope to the east and a much more considerable one to the west. Throughout the whole axial region of the anticlinal is a gently dipping series of the Cambrian quartzites, overlaid on both flanks by the outwardly dipping Ute limestones. To the east the series above that horizon is entirely covered by the Vermilion Creek Eocene Tertiary, while to the west the

* United States Geological Survey of Montana, Idaho, Wyoming, and Utah, Hayden, 1872.

exposures in Muddy Cañon and Blacksmith's Fork show the full section from deep in the Cambrian quartzite to the middle and higher members of the Wahsatch limestone. About eight miles to the north of Blacksmith's Fork Cañon the Cambrian quartzites appear with a gentle dip to the west, gradually flattening out to the east. Conformably overlying them, and itself conformably overlaid by the Ogden quartzite, is a fine and characteristic exposure of the limestone at Ute Peak, the typical locality from which this body of Silurian limestone has received its name. The peak is on the south side of Muddy Creek, just below the junction of its two important forks, the lofty and abrupt faces of Ute Peak itself forming a wall of the main cañon and of the south fork. From the stream's bed it has an elevation of 2,500 feet of precipitous slope, while toward the west it falls away with the gentler inclination of the higher plateau country. The beds here strike from 15° to 20° west of north, and dip westwardly from 15° to 20°. The relations of the Ute group with the underlying series are well shown. The cañon of the south fork has cut through the base of the Silurian limestone, and also through the thin shales which form the uppermost member of the Cambrian, exposing in the bed of the cañon the Cambrian quartzites, which gently rise to the east toward the axis of the anticlinal. The cañon of the north fork of the Muddy, running at right angles to the strike, cuts through 1,600 to 1,800 feet of the quartzite, forming a narrow, almost impassable gorge, with perpendicular walls. In these quartzites were observed some peculiar markings suggesting imperfect borings or the tracks of worms, such as have been ascribed to the genus *Scolithus.* The shales over the quartzites are indurated argillites, slightly calcareous and interlaminated with brown, earthy-colored sandstone, altogether making a group 100 feet in thickness. A Cambrian rock of interest occurs in Beaver Cañon. It is a peculiar smoky-purple quartzite, which is again seen on the east side of the Wahsatch, opposite Centreville. It is of remarkably vitreous lustre, and is a tough, dense rock. The individual grains of quartz, up to the size of a pea, have a peculiar purple dusky hue, the siliceous matrix being made up of an excessively fine cryptocrystalline, almost amorphous quartz, the beds developing a certain schistose structure from partly foliated quartz. Minute flakes of white mica, and fluid inclusions with moving bubbles, are detected with the microscope. The Ute limestone is shown upon the slopes of Ute Peak to be very nearly 2,000 feet thick. Although there are numerous passages of pure limestone, the average character of the whole mass is siliceous, while the lower third or quarter is varied by a considerable amount of fine argillaceous material. Besides the general siliceous nature of the whole Ute group here, there are also beds of pure sand, and an immense amount of calciferous sand rock is intercalated at intervals throughout the whole mass. Some fine beds toward the middle of the series develop, on weathering, a remarkably banded structure, due to the variable amount of silica and the organic matter connected with the lime. Calcareous schists and sandy beds decidedly predominate over the pure lime beds. This siliceous character seems to be remarkably persistent over wide areas. About twenty-five feet above the top of the Cambrian argillites, in a bed of calcareous shale, enclosed in dark, dense limestones, are found numerous *Entomostracea* containing new species of two genera:

Dikellocephalus quadraceps.
Conocephalites subcoronatus.

Two hundred feet higher in the series is a dark, siliceous limestone, somewhat cherty, which outcrops on the north side of the peak, bearing an undetermined species of the genus *Obolella*, and near the summit of the series, about 200 or 250 feet below the bottom of the Ogden quartzite, were found —

Euomphalus (Raphistoma) rotuliformis.
Euomphalus (Raphistoma) trochiscus.
Maclurea minima.

On the summit of the ridge, but still somewhat below the Ogden quartzite, were found —

Ophileta complanata.
Raphistoma acuta.

These characteristic spaces prove that the greater part of the Ute limestone is Quebec. They leave a small portion of the top of the series unaccounted for, and it seems probable from the *Halycites* which was found near the summit of the series by Bradley, taken together with the Upper Silurian fossils from the upper part of the Silurian limestone in middle Nevada, that the extreme upper portion of the Ute limestone of the Wahsatch, say from 150 to 200 feet, may be, and most probably is, of Upper Silurian age, while the remainder of the 2,000 feet is clearly Quebec.

Box Elder Peak is the culminating point of the promontory-like north end of Wahsatch Range. The limestones that overlie the Ogden quartzite dip to the northeast from 45° to 50°. Well up in the series of limestones were obtained the following:

Zaphrentis excentrica.
Zaphrentis Stansburyi.
Cyathophyllum Nevadensis.
Lithostrotion Whitneyi.
Productus cora.
Productus punctatus.

Here are exposed about 4,000 feet, not far from two thirds of the entire Wahsatch limestone.

Province of the Great Basin.—From the meridian of 112° to that of 120° extends the Great Basin country, which is characterized by broad valleys of Tertiary and Quaternary, interrupted by fragmentary outcrops of meridional ranges, which often reach a considerable height, and culminate in Humboldt Range at a little over 12,000 feet above sea-level. The country immediately bordering the western base of the Wahsatch, whose lowest depression is occupied by Great Salt Lake, is at an elevation of about 4,200 feet. This nearly level basin extends westward about two degrees to the base of Ombe and Gosiute ranges. Thence for about seventy miles westward the average elevation of the Quaternary valleys rises, until at Ruby Valley it is about 6,000 feet. Still westward the valleys gradually decline to the level of Pyramid Lake, 3,900 feet in altitude. This whole region is ribbed with detached mountain ranges, rudely parallel and generally of meridional trend; anticlinals, synclinals, and monoclinal masses which rise suddenly out of the Tertiary and Quaternary plains. They are essentially composed of partial exposures of

Palæozoic rocks, together with unconformable underlying masses of Archæan granite and schist, the whole broken through and often masked by extensive flows of Tertiary volcanic rocks. This briefly characterizes the region as far as the meridian of 117° 15′, beyond which to the west no Palæozoic exposures are seen. From that meridian to the Sierra Nevada the main geological characteristics are frequent masses of Archæan granite and schist and enormously thick developments of rocks of the Alpine Trias and Jurassic ages, together with great outbursts of volcanic rocks. The section of the Great Basin, therefore, which comes within our observation consists of a central mass in the region of Piñon and Humboldt ranges, longitude 115° 45′, where the valleys which skirt the mountain bases are about 6,000 feet high, and depressed regions flanking it to the east and west, one occupied by the basin of Great Salt Lake, and the other by the family of lakes which receive the drainage of Humboldt and Truckee rivers. The entire distance from the base of the Wahsatch, which bounds the basin on the east, to the flanks of the Sierra Nevada, which outline it on the west, is about 425 miles, while the extent of the region characterized by Palæozoic outcrops, namely, from the Wahsatch to the meridian of 117° 15′, is about 275 miles; and this is the province whose geological complexities I am about to attempt unravelling. In this region there are between twenty and thirty considerable mountain masses which rise out of the Quaternary and Tertiary plains, extend a short distance, usually in a north-and-south or northeast-and-southwest trend, and then either abruptly or gradually decline beneath the level of the desert again. In no single one of these ranges is the whole Palæozoic section displayed, and, studied by itself, it would have been excessively difficult to establish a correct sequence for the various members. It is only when compared with the full conditions so splendidly displayed in the Weber section of the Wahsatch that we are at all able to decipher these isolated mountain blocks. With the exception of Humboldt and Piñon ranges, the continuity of the strata is not very great. Since the whole Palæozoic is made up of quartzites and limestones, in the absence of characteristic fossils it is sometimes impossible to refer a body of limestone finally. There are many instances where the whole mountain mass consists of a low exposure of limestones of no very great thickness, characterized by Coal Measure invertebrates; the fossils offering insufficient evidence to warrant a definite reference either to the Upper or the Lower Coal Measure limestones. In general, the Upper Coal Measure limestone, which in the provinces of the Wahsatch and Uinta was distinguished by the constant intercalation of sandy material throughout its upper horizons, in the province of the Basin is chiefly of limestone, and that often dark and heavily bedded, not lithologically distinguishable from certain parts of the Wahsatch body; so that when an isolated body of limestone is met with, whose exposed thickness is not too great to be stratigraphically referred to the Upper Coal Measures, and the fossils likewise do not show distinctly to which horizon it should be assigned, we have sometimes been obliged to make an arbitrary reference simply from the probable connection of the body with neighboring ranges. When we find a body of from 5,000 to 7,000 feet of limestone underlaid by a quartzite and containing Coal Measure fossils in the upper members, we unhesitatingly refer it to the Wahsatch, and this reference has been further strengthened by the discovery, in the lower horizons of the body, of a considerable number of sub-Carboniferous and pure Devonian types, as well as the recurrence of the Waverly horizon, so well developed in the Wahsatch. On the other hand, as will be seen to be not infrequently the case, when a range consists of a body of limestone under 2,000 feet in thickness, resting upon the quartzite and carrying Coal Measure fossils down to the lowest limestone beds, we have felt entirely secure in referring it to the Upper Coal Measure series and Weber sandstone. In the case of a thick body of limestone carrying the well defined Devonian forms in its lowest members, and directly underlaid by a thin quartzite never exceeding 800 feet, we have recognized it as the bottom of the Wahsatch and the Ogden quartzite. Again, a thin quartzite is seen in some localities capping a body of dark siliceous limestone which carries in its summit members lower Helderberg fossils, and in that case the quartzite was considered to be identical with the Ogden Devonian. No forms at all equivalent to the Permo-Carboniferous fossils have been found, and no rocks at all similar to the shales which enclose them in the Wahsatch have been seen anywhere in our section of the Great Basin.

While the Wahsatch section illustrates in its completeness the whole stratigraphical sequence of Palæozoic rocks, palæontological proofs are only furnished in that range from the summit of the Permo-Carboniferous down to the base of the Quebec, at which horizon the fossils collected at Call's Fort, directly above the Cambrian shales, mark the lowest depth from which organic forms were obtained. In the Great Basin the lower rocks—Quebec limestone, and shales and quartzites of the Upper Cambrian—are well developed, and here with a stratigraphical sequence equivalent to that of the Wahsatch we find abundance of Primordial forms. Therefore, in establishing the complete scheme of the Palæozoic series, while the Wahsatch furnishes everything but Cambrian life, that life is furnished in the desert ranges in a series which are the undoubted equivalents of the basal rocks of the Wahsatch. With these two the section is rendered complete, and is based upon evidence which may be considered to give it a final value. Since the great Palæozoic feature of Wahsatch Range is its remarkable display of continuous sections, in treating of that province I have done little more than describe and fortify these sections. The province of the Great Basin, on the other hand, is one in which the individual sections are very slight and too innumerable for re-description here. They will be found in Chapters III. and IV., and part of Chapter V., of Volume II. Since the interesting Palæozoic feature of the Great Basin, so far as it applies to this chapter, is the continuance westward of the series as displayed in the Wahsatch, I conceive that the best method of treatment here is to begin with the lowest strata, and describe the occurrence of each member in ascending. I commence, therefore, with the

CAMBRIAN AND SILURIAN.

Passing over the limited display of quartzites underneath the trachytes of the Traverse Mountains, which from lithological evidence alone have been referred to quartzites of the Cambrian, the first occurrence which merits attention is in Oquirrh Range. By an interesting series of faults near the western edge of this body, in the immediate vicinity of Ophir Cañon, the Cambrian quartzites and the thin bed of argillites so often mentioned as capping the series are displaced and brought up to view amidst masses of Wahsatch limestone which form the quaquaversal uplift of this region. About one eighth of a mile north of Ophir City is a straight, sheer wall of quartzite 300 or 400 feet high. The material of these siliceous rocks is the reddish salmon quartz that forms the uppermost part of the great body of Cambrian quartzites in the Wahsatch. Over these are about 100 feet of greenish-yellow clays, the equivalent of the argillites of Call's Fort and the Cottonwood region, which contain the following forms, equivalent to those collected at Call's Fort and representing the horizon of contact between the Primordial and the Quebec—a horizon in Utah always confined to these shales:

Ogygia producta.
Ogygia parabola.
Ogygia n. sp.
Lingulepis n. sp.
Kutorgina n. sp.
Dikellocephalus sp.?
Dikellocephalus sp.?

The relation of this exposure to the overlying parts of the series is obscure. The next fossils found in the limestones above are of the Waverly horizon, which Mr. Emmons, who has examined the region, believes to have been faulted down into contact with these Quebec shales. The chief value of this locality, aside from its relations with the rock above, is in confirming the reference to the Quebec age of the upper part of these shales and fixing the bottom of the Silurian.

The western slope of Aqui Range, from Skull Valley up to Bonneville Peak, is formed of a continuous exposure of quartzites, making in all a thickness of about 6,000 feet, which have an average dip of 25° to the west, and decline to a much less steep position at Bonneville Peak. The prevailing rock is white and yellowish-white quartzites, with occasional conglomerate beds and limited strata of dark-green argillites containing spangles of muscovite on the surface-planes. There is also a dusky purple quartzite with pellucid pebbles, such as have been described from Blacksmith's Fork and the Wahsatch of the Farmington region. The fact of so extended a series of quartzites underlying

5,000 or 6,000 feet of limestone is strong evidence in favor of assigning this to the Cambrian. The same quartzite stretches northward along the western side of Aqui Range, up to Grantville Peak, which is the crest of an abrupt anticlinal whose western member dips only about 45°, while the eastern approaches a horizontal position. The exposures at both places are very fine. At Bonneville Peak, particularly, the eastern base presents an almost perpendicular wall 2,000 or 3,000 feet in height. The characteristic feature of the beds on the saddle north of Grantville Peak is the occurrence of the flattened and distorted pebbles of the conglomerate already described in Ogden Cañon. In the Schell Creek Mountains, which form the eastern boundary of Steptoe Valley, south of the great flow of rhyolite that overwhelms nearly all the sedimentary rocks in the northern part of the range, at a locality somewhat south of the limits of our map, are seen the heavy quartzites of the Cambrian, and directly over them argillaceous and calcareous shales from which were obtained *Crepicephalus* (*Loganellus*) *amytus* and *Lingulepis Mæra*. This, from its position, capping the great Cambrian quartzite, and containing undoubted Cambrian forms, shows that the dividing-plane between the Cambrian and the Quebec is for this region in the thin shales. Farther westward a great limestone body takes the place of the upper Cambrian quartzite and the shales.

In the high ridge east of Egan Cañon is displayed a section of Cambrian rocks resting unconformably upon the granite and overlaid by heavy bodies of limestone. Between the Cambrian and the continuous outcrops of limestone is a region variably covered with soil and characterized by infrequence of outcrops. There is ample room for Ute limestone and Ogden quartzite, though their presence is not proved. Here, directly over the granite, are several thousand feet of quartzitic schists, capped by about fifty feet of highly laminated fissile argillites. The character of the quartzites is quite similar to that of the quartzitic schists of the Wahsatch. It is compact, often semi-transparent, frequently quite vitreous, and shows occasional traces of granular structure. Certain beds of dark purple quartzite carry coarse quartz pebbles, others contain flakes of muscovite, and still others show a considerable development of bronze-colored phlogopite. All the outcrops noted as coming to the surface through the soil and débris which overlie this Cambrian series show the conformable dip of the limestones to the west.

In White Pine Range, the base of Pogonip Ridge at its northern end, shows certain limited outcrops of granite, upon which are only partially exposed bodies of mica schists and black arenaceous and argillaceous shales, overlaid by an undetermined thickness of compact, vitreous, steel-gray quartzites, identical with the Cambrian quartzites hereafter to be described in the Piñon. Their position shows an eastward dip of from 24° to 30°. Rising a little on the range, they are conformably overlaid, although the contact is débris-covered, by a great thickness of dark limestone. The lower limestone beds are highly siliceous, of a steely-black, with blue shades, and varying a good deal in physical characteristics, passing downward into rather argillaceous, calcareous shales. Higher in the series it develops a dark-blue color, and is seen to be much banded by zones of arenaceous limestone and occasional seams of pure chert several inches thick. The entire limestone zone is about 4,000 feet thick. From these dark heavy beds were obtained the following fossils, determined by Hall and Whitfield:

Crepicephalus (*Loganellus*) *Haguei*, n. sp.
Crepicephalus (*Bathyurus*) *angulatus*, n. sp.
Crepicephalus (*Loganellus*) sp. undeterminable.
Crepicephalus (*Loganellus*) sp. undetermined.
Conocephalites (*Pterocephalus*) *laticeps*, n. sp.
Dikellocephalus flabellifer, n. sp.
Dikellocephalus quadriceps, n. sp.
Ptychaspis pustulosus, n. sp.
Ptychaspis n. sp. undescribed.
Charicocephalus tumifrons, n. sp.
Agnostus communis, n. sp.
Lingulepis Mæra.
Obolella sp. undetermined.

These clearly Primordial forms extend up for 2,000 feet into the body of limestone. This is the first indication of an important change between the lower Palæozoic horizons of the Basin and the Wahsatch. We saw that at Call's Fort, on the western base of the Wahsatch, Quebec forms, although representing the very base of the Quebec and closely allied to the Primordial species, were found at the base, or very near the base, of the Ute limestone, the lowest limestone of the whole series; and again that Quebec fossils were found within twenty-five feet of the base of the Ute limestone at Ute Peak by the forks of the Muddy. The thin calcareous and argillaceous zone which rests upon the top of the quartzites has here given place to calcareous sediment expanded to a thickness of 2,000 feet, and merged itself into the Ute limestone. This limestone from the typical locality at Pogonip Ridge is called the Pogonip limestone, although the upper 2,000 feet are in reality the equivalent of Ute limestone. Near the top of the series, above the horizon from which the foregoing Primordial fossils were obtained, the following Quebec species were collected:

Ptychaspis pustulosus, n. sp.
Bathyurus Pogonipensis, n. sp.
Orthis Pogonipensis, n. sp.
Strophomena Nemia, n. sp.
Porambonites obscurus, n. sp.
Raphistoma acuta, n. sp.
Cyrtolites sinuatus, n. sp.

Above these Quebec members of the limestone series of this locality there is a gap occupied by a valley deeply covered with soil, and neither of the uppermost members of the limestone series is seen, nor their contact with the rocks above. All that this locality develops are the Cambrian quartzites and schists overlaid by a body of at least 2,000 feet of Primordial limestone, which passes up without petrological change into beds of similar limestone characterized by distinct Quebec forms, and the upper continuance of the limetones is unknown.

At the Eureka Mining District, which is in the body of hills that connect Diamond and Piñon ranges, south of Diamond Valley, and a little south of the south line of our map, there is an excellent exposure of the Pogonip limestone with the underlying Cambrian schists and quartzites

The ridge of Prospect Mountain shows the same lithological features as those of Pogonip Ridge, and carries through an enormous thickness of the formation, certainly 2,500 feet, Primordial forms, embracing the following:

Crepicephalus (*Loganellus*) *granulosus.*
Crepicephalus (*Loganellus*) *maculosus.*
Crepicephalus (*Loganellus*) *nitidus.*
Crepicephalus (*Loganellus*) *simulator.*
Crepicephalus (*Loganellus*) *unisulcatus.*
Dikellocephalus bilobatus.
Dikellocephalus multicinctus.
Agnostus Neon.
Agnostus prolongus.
Agnostus tumidosus.
Lingulepis Mæra.
Lingulepis minuta.
Obolella discoida.
Kutorgina minutissima.
Leptæna melita.

Owing to great disturbance and alteration of the limestones, few fossils were obtained from the upper 1,800 feet of the Pogonip belt; but an *Orthis Pogonipensis* and a *Bathyurus*, probably *Pogonipensis*, were collected—enough to prove the occurrence of the Quebec, and thus establish the complete parallelism of horizons with the great Pogonip limestone at White Pine. The Eureka locality, however, is of great geological interest, since conformably over the Pogonip is the Ogden quartzite admirably defined, having a width of about 900 feet, and still conformably over that again the immense Wahsatch limestone. Under the Pogonip are conformable quartzites of the Cambrian, which, however, were not critically studied.

The northern end of that portion of Piñon Range which lies south of Humboldt River culminates at the high point of Raven's Nest Peak. Here is a fine exhibition of the Cambrian quartzites and schists, with a perfect exposure of their passage upward into the Pogonip limestone, although the limestones here have so far failed to yield any fossils. But from evidence of the overlying Ogden quartzite and the Devonian base of the Wahsatch limestones, which are characterized by numerous well defined Upper Helderberg species, the heavy body of limestone colored as Silurian could not be mistaken for Wahsatch limestone, of which only the lower or Devonian portion is here seen. Pinto Peak, a high tabular quartzite mountain, lies in the axis of an anticlinal, the rocks both to the east and west dipping in contrary directions, and the whole curve of the anticlinal being clearly seen to the south, where the Devonian quartzite and limestones arch continuously over and form the summit of the ridge. The Cambrian quartzites, as shown at Pinto Peak and at the base of Raven's Nest Peak, are heavily bedded quartzitic schists, carrying some beds which are highly micaceous, and at the top characterized by occasional thin beds of argillaceous material. The higher quartzites are steel-gray, rather saccharoidal in texture, are slightly calcareous, and superficially resemble the steel-gray limestones above them. For a considerable distance in the upper quartzite zone, say 300 or 400 feet below the contact with the Pogonip, there is not a little calcareous material, the analysis yielding only 76 to 78 per cent of silica, the remainder being carbonate of lime. It is a highly crystalline calcareous quartzite, and passes upward into rather siliceous limestones, which are alternately dark and light. Doubtless if the steep slope of Raven's Nest Peak were given a more careful examination than our time permitted, Primordial and Quebec fossils would be found. The whole limestone cannot be less than 4,000 feet in thickness, and by its volume and position conformably between the Ogden quartzite and the basal quartzites can be nothing but the Pogonip. The strike of the limestones of Raven's Nest Peak is diagonally across the range at about north 25° east, and they dip from 25° to 35° northwest. Directly south of Dixie Pass the ends of the strata are abruptly cut off by a fault and very deep dislocation, and their edges are abrupt and partly masked by an immense overflow of trachyte. The upper members directly under the Ogden quartzite are less siliceous than the beds below, a good deal altered, more highly crystalline than the lower strata, and reticulated with innumerable seams of white calcite. The quartzites and schists underneath this body of limestone are exposed downward for not less than 5,000 feet. The conformity between the deep Cambrian quartzitic schists and the Ute-Pogonip limestone is absolutely perfect, as is the contact between the upper members of the Ute-Pogonip and the overlying Ogden. In reference to the line here separating the Cambrian and the Silurian—which is intended to be so drawn as to include the Primordial in the Cambrian, as fixed by Dana—it should be said that there is an error on the geological map at this point. The line as drawn here represents the junction of the steel-colored limestones with the underlying steel-colored quartzites. It should be carried 1,600 or 1,800 feet higher, which would have the effect of narrowing the Silurian band on the map and widening the Cambrian. Not enough study was given to this region to prove clearly that the lowermost rocks exposed here are not Archæan. There are some gneissoid rocks which differ lithologically from any of the known Cambrian beds, but they were not sufficiently observed to determine their conformity or nonconformity with the quartzites above. Farther south in this range, near Mineral Hill, the Ogden quartzite is well developed about 800 feet in thickness; and conformably underlying it, especially as displayed upon Cave Creek, about three miles south of Mineral Hill, is the top of a body of limestone more or less siliceous, which, from its position under the Ogden, is also referred to the top of the Ute-Pogonip body. The only organic remains found in this development of limestones are some stems of corals, which, however, are of special interest, as Whitfield determines them to be of the Lower Helderberg horizon.

West of Piñon Range and south of Garden Valley, in the Roberts Peak Mountains, appears a high mass of limestone, flanked on both sides by quartzites, which have been referred to the Ogden. About 3,000 feet of conformable limestones are displayed here, which lithologically repeat the features of Pogonip Ridge. These are dark, more or less siliceous, and intercalated with calcareous shales and thin, cherty beds. The strata incline to the east with a varying strike of northwest-southeast. Along the northern slopes the observed dip was 40° or 50°, here striking north 20° west, while the southeasterly foot-hills gave a dip of but 18° to 24° to the east, and a strike more nearly due north. The upper horizons on both the north and south slopes yield fossils ranging from the Upper members of the Quebec to the Lower Helderberg, the collection including the following:

Cladopora sp ? (resembles *C. seriata*)
Orthis sp.? (resembles *O. hybrida*).
Atrypa reticularis.
Atrypa sp.? (resembles *A. nodostriata*).
Rhynchonella sp.?
Illænus sp.?

All of these but the *Rhynchonella* have been ascribed by Hall and Whitfield to the Niagara; while the *Rhynchonella*, which was collected farther up, closely resembles the *Rhynchonella* found at White's Ranch, associated with Lower Helderberg forms.

North of the Humboldt, in Boulder Creek Valley, near the intersection of the 41st parallel with the meridian of 116° 30′, at a place called White's Ranch, is an isolated hill of limestone conformably overlaid by a pure, greenish-white quartzite having all the characteristics of the Ogden. The outcrop, as will be seen upon the map, is limited on all sides by the Quaternary of the valley. It is an absolutely isolated hill. The limestones were rather dark, fine-grained, and decidedly siliceous, the beds, for the most part, thin and intersected with siliceous seams, the latter carrying some branching impressions like rootlets. There is a total thickness of about 600 feet of limestones. From these were obtained, in the neighborhood of the overlying quartzite, the following Lower Helderberg association of forms:

Atrypa reticularis.
Pentamerus galeatus.
Strophodonta sp.? (like *S. punctilifera*).
Orthis sp.?
Trematopora.
Cœlospira.
Rhynchonella.
Favosites (sp. allied to *F. Helderbergia*).
Diphyphyllum n. sp.
Campophyllum.

This establishes the fact that the uppermost horizon of the Ute-Pogonip limestone body is distinctly Lower Helderberg. Roberts Peak, Eureka, and White Pine form a region along a meridional belt extending north-and-south for seventy miles, by a breadth of about thirty miles, exposing the entire development of Silurian and a part of the Cambrian series. The whole 4,000 feet of limestone consists of three distinct members: 1, the lower 2,000 feet of Primordial; 2, a restricted but as yet unknown amount of the middle of the series, being Quebec; 3, a considerable breadth of Niagara overlying that, with the summit members (underlying the Ogden quartzite) of the Lower Helderberg. The line, therefore, which separates the Primordial, or Cambrian, from the Silurian, will in this region come near the middle of the Ute-Pogonip limestone.

OGDEN QUARTZITE.—Humboldt Range, by far the most considerable mountain ridge in central Nevada, consists essentially of a long body of Archæan granitoid gneisses and quartzites, unconformably upon which rest strata of the Wahsatch limestone dipping to the east and west, showing the range to have been an anticlinal which was folded with its axis running approximately in the line of the old Archæan body. The few exposures of the westerly dipping rocks have their plane of contact in the horizon of the Wahsatch limestone, the Ogden being altogether buried; but south of Frémont's Pass the whole body of the ridge is formed of easterly dipping strata, 7,000 feet of the Wahsatch limestone underlaid by the quartzites of the Ogden. From Frémont's Pass to Hastings's Pass the extreme western foot-hills are made up of easterly dipping quartzites, having a close physical resemblance to the Ogden beds of the Piñon. Their horizon is determined by their lying conformably at the base of the Wahsatch group.

Above the Ute-Pogonip limestone of Raven's Nest Peak, Piñon Range, and quite conformable with it, lies a body of quartzite 900 to 1,100 feet in thickness. It is of thin, even lamination toward the lower members, and above of rather heavily bedded quartzites, much stained with iron. The material of the rock is extremely fine. It contains no conglomerate, as far as observed, and no coarse, angular, or gritty grains, and shows throughout an extremely fine subcrystalline texture. It is traversed by many jointing-planes striking northwest-and-southeast, or nearly at right angles to the strike of the rock. From the Raven's Nest region it trends southwest and then curves again to the southeast, skirting the great body of Ute-Pogonip limestone, and about five miles south of Pinto Peak forms the crest of the main anticlinal of the range. Toward the southwest, the western side of the anticlinal is seen dipping under the lower members of the Wahsatch limestone. At Piñon Pass the outcrops are very distinct, and toward the west they pass gradually beneath Devonian limestones. These limestones form here a synclinal whose axis is northwesterly, and rapidly curve up again with an easterly dip, the Ogden quartzite reappearing at the western base of the range In other words, from Pinto Pass it curves under the anticlinal, and reappears between the Silurian limestone of Cave Creek and the overlying Devonian limestone. Here, where it is distinctly outlined by the limestones on both sides, it is about 800 feet thick, while north, in the region of Raven's Nest, it is 900 to 1,100 feet. The exposure in the region of Pony Creek, where the Ogden quartzites arch over and form the cap of the anticlinal, is exceedingly fine, bold hills having been eroded out of the arch. The lithological characteristics of this quartzite throughout the Piñon are similar, except perhaps along the western base, where it has a rather more flinty and vitreous aspect. The quartzite which overlies the Silurian limestone of Roberts Peak is rather obscure, and its contact with the underlying rocks is not shown; so that, while it is probably Ogden, the proof is uncertain.

At the small isolated hill which rises to the surface through the Quaternary of Boulder Creek on the line of the 41st parallel, near the meridian of 116° 30′, a body of quartzites has already been described as conformably overlying the limestones which carry Lower Helderberg fossils. This, from its position directly over the top of the Ute limestone, is assigned to the Ogden.

At White Pine, where are exposed both Pogonip and Wahsatch limestones, there is a gap between the two great bodies—a valley covered with Quaternary débris, in which are seen no outcrops. The whole region, which should be covered by the Ogden quartzite, is masked by detritus and earth, so that its presence or absence at that locality is so far not proven.

From the undoubted equivalence of the two bodies of limestone to those exposed in the Piñon, and from their relative dip here, there is little doubt that the Ogden does occur underneath the valley earth. As already noted, it recurs in Eureka District in its proper place in the series.

Excepting Aqui and Oquirrh ranges, wherever the Ute and the Wahsatch limestone are both exposed, the Ogden is clearly seen. In the Aqui the examination was exceedingly hasty, and the region is complicated by faults, so that its not having been seen is no proof of its absence. On the contrary, we believe it to be there, and have so stated on the map.

In the region of Ophir City, in Oquirrh Range, the Ogden is wanting. At that locality is found a small gap between the fossils which represent the Call's Fort horizon and the Waverly group. In other words, both the Ute limestone and the Ogden quartzite appear to be wanting; but we conceive this to be wholly due to complication resulting from faults. Excepting in these two obscure localities, wherever we have found a section which has exposed both Silurian and Carboniferous beds, the Ute limestone and overlying Ogden quartzite are invariably recognized, and we consider them to be, so far as the Fortieth Parallel region is concerned, of remarkable stratigraphical persistence.

At one place in Frémont's Pass, Humboldt Range, nonconformable contact between the Ogden quartzite and the underlying Archæan may be observed. Otherwise, wherever the Ogden is seen west of the Wahsatch, either the base is not visible or else it is found resting upon the Ute-Pogonip limestone. Limited, then, by the Lower Helderberg fossils below and the Upper Helderberg fossils above, and itself yielding no organic forms, it may be taken, until still further restricted, to represent the Oriskany, Cauda-galli, and Schoharie horizons; and since the Lower Helderberg fossils possess so high a facies, I have considered it right to classify the Ogden quartzite altogether as Devonian. It is not at all impossible that future study may discover sufficient evidence to settle this question finally. Until then, it seems to me, on the whole, most likely to be chiefly Devonian, and it is therefore so placed in our series.

Wahsatch Limestone.—North of Salt Lake is a considerable area of limestones, which begin on the west side of Malade Valley, on the northern limits of our map, and extend south and west, dipping under Hansel Spring Valley, and then extending still farther southward to form the greater part of Promontory Range. This region shows several synclinal and anticlinal folds, with very gentle dips, but exposes no great thickness of limestones except in the higher part of the Promontory itself. Southwest of the railroad are large bodies of limestone, of prevailing gray color, the lower exposures inclined to dark, almost black beds. The rocks dip at an angle of 38° westward. Extending down the range, they are subject to interesting structural disturbances, and in general expose about 3,800 or 4,000 feet of thickness. Somewhere about 1,200 feet below the top of the series is an included zone of yellowish-brown sandstone, decidedly calcareous, intercalated with numerous thin sheets of gray limestone. The lower portion is sharply defined against underlying beds of dark-blue limestone, but on the upper limit, 300 feet up, it passes gradually through shaly beds into the limestone above. The general strike here is north 28° east. From the limestones directly below and directly above this siliceous zone, not far from Antelope Springs, were obtained the following:

Productus prattenianus.
Spirifer opimus.
Athyris subtilita.
Streptorhynchus (fragments).

While farther south in the range, from limestones of the lower horizon, were obtained many *Zaphrentis Stansburyi* and *Productus semireticulatus.* It is assumed that this siliceous zone is equivalent to that described in the Weber section not far from the summit of the series. From the lithological character of the limestones themselves, as well as from the great thickness exposed and the facies of the fossils, this series is referred to the Wahsatch limestone, although neither the underlying nor the overlying quartzite occurs here at all.

Considering this line of upheaval in its southern extension, it is evident that Frémont and Antelope islands are only parts of an Archæan body which bears to this line of upheaval the same relation as does the Archæan of the Wahsatch to that range. Southward on the same line are seen the Palæozoic masses of the Oquirrh and Pelican Hills. Within our map the Pelican Hills present only an unimportant mountain mass, made up of thinly bedded blue limestones with frequently intercalated quartzites, undoubtedly referable to the uppermost region of the Wahsatch limestone as displayed upon the top of Tim-pan-o-gos. A few imperfect spirifers and crinoids were the only fossils found.

The Oquirrh Mountains, on the other hand, offer an important exposure of the Palæozoic series, thrown into complicated structural relations, and about half made up of Wahsatch limestone, the remainder being overlying Uinta quartzite. The peaks rise to a height of 6,000 feet above the plains, and offer splendid exposures. As seen at Dry Cañon, the uppermost fossils of the Wahsatch limestone are of sub-Carboniferous types, and the vertical range through which fossils of this horizon and of the Waverly extend, is apparently greater than at any other point where the Wahsatch limestone is displayed. Since there is a structural obscurity about the bottom of the limestone, the exact height in the series at which the Waverly fossils are found is not known. From the westerly dipping beds near the mouth of Dry Cañon were obtained—

Streptorhynchus inflatus.
Strophomena rhomboidalis
Spirifer Albapinensis.
Spirifer centronatus.
Rhynchonella pustulosa.
Euomphalus Utahensis.
Euomphalus Ophirensis.
Michelina sp.?
Zaphrentis sp.?

In addition to these, from a ridge above and between Dry and East cañons, in a fine-grained, dark limestone, Professor Clayton obtained some of these species, and—

Proëtus peroccidens.
Orthis resupinata.
Euomphalus latus, var. *laxus.*

Twelve hundred feet higher stratigraphically, Professor Clayton found—

Trematopora.
Fenestella.
Polypora.

And still higher geologically—

Productus lævicostus.
Productus elegans.
Productus semireticulatus.
Productus Flemingi, var. *Burlingtonensis.*
Spirifer striatus.
Spirifer setiger.
Spirifer Leidyi.
Athyris subquadrata.

From the head of Ophir cañon, near the divide, were obtained—

Streptorhynchus robusta.
Chonetes granulifera.
Spirifer opimus.
Rhynchonella Osagensis.

The crest of the range, between East Cañon and North Cañon, shows the remarkable intercalations of quartzites and limestones of the Tim-pan-o-gos horizon, abounding in casts of *Productus prattenianus* and *Spirifer opimus.* Although the upper limit of the Wahsatch body is here defined by the Weber quartzite above the Tim-pan-o-gos horizon, the bottom is nowhere definitely shown. It is needless to amplify localities of the sub-Carboniferous or Waverly fossils in the Oquirrh. Suffice it to say that the whole condition described in the Wahsatch—the intercalations of the Tim-pan-o-gos horizon with their characteristic forms, the 5,000 feet of varied Coal Measure forms down to the sub-Carboniferous, and the occurrence of the Waverly level—is here thoroughly displayed. So also are the persistent siliceous zones which are near the upper part of the series, but still below the intercalated Tim-pan-o-gos level. Near Black Rock, enclosed in limestones carrying *Productus semireticulatus*, *Productus prattenianus*, *Streptorhynchus crenistrea*, *Spirifer opimus*, *Fenestella*, *Polypora*, and *Trematopora*, is a peculiar bed of white sandstone made up of rounded grains of limpid quartz differing entirely from the ordinary vitreous beds which are the characteristic intercalations of the Wahsatch. From the very northwestern foot-hills of the range were obtained—

Chonetes granulifera.
Productus Nebrascensis.
Productus longispinus.
Martinea lineata.
Athyris subtilita.

A feature of the Wahsatch limestone not recognized by us in Wahsatch Range is the occurrence of beds of black, waxy shales, which are found at one or two horizons: one a small development just below the Waverly horizon, which may possibly correspond to the Devonian shales of White Pine; another appearing at the horizon of the Mono Mine, higher in the series. These shales are made up of black magnesian clay of excessive fineness, which is also strongly charged with limy material.

Upon Aqui Range is seen a long, continuous outcrop of heavy beds of limestone, extending from the northern extremity of the range to the southern limit of our map. From its thickness and physical character this has been referred to the Wahsatch, although the only recognizable fossil is a *Zaphrentis multilamella.*

Stansbury Island is a sharp, steep anticlinal of dark limestones, dipping about 75° both east and west, with a north-and-south strike. The limestones are rich in *Zaphrentis Stansburyi* and *Euomphalus subplanus.* Along the eastern base of the island are considerable bodies of quartzite, conformably overlying the limestones, but themselves much obscured by soil. They have been referred to the Weber from their extent, but may possibly represent the siliceous beds of the Tim-pan-o-gos horizon. Bordering Great Salt Lake along the western side, and outcropping here and there through the Quaternary and Lower Quaternary beds of the desert, are isolated rocky hills, often rising to a considerable height, and for the most part composed of beds of dark, more or less siliceous limestone, capped in places by bodies of quartzite and somewhat masked by Tertiary volcanic rocks. Carrington, Hat, Dolphin, and Gunnison's islands, Strong's Knob, and the Lakeside Mountains, with four insular masses to the west and two considerable bodies of the Rocky Hills, together with Cedar Mountain and the little limestone buttes to the west, are all referred by us, from such scanty evidence as we could obtain, to the Wahsatch limestone. They are in general dark siliceous limestones, carrying Coal Measure fossils, usually of the species which predominate in the Wahsatch. The evidence on which they are referred will be found in Volume II. For our present purposes they are only of value as indicating the continuity of the sheet to the west. Both the Ibenpah Mountains and the high ridge of Gosiute Range, culminating in Lookout Peak, a summit reaching 9,695 feet, display large masses of Wahsatch limestone. At the latter locality are shown fully 4,000 feet of dark limestone series. Highly altered specimens of *Productus*, not specifically recognizable, associated with crinoid stems, were the only organic remains found.

At the south end of Peoquop Range and its connected body which culminates in Spruce Mountain, is seen a great area of varied limestones, for the most part dark-blue and dark-grayish-blue, and containing several intercalations of siliceous and earthy impurities. Near the summit of Spruce Mountain were obtained —

Productus costatus.
Productus semireticulatus.
Productus Nebrascensis.
Eumetria punctilifera.

From the ridge directly north of the peak and from several other localities were obtained *Productus Nebrascensis* and *Fusilina cylindrica*, together with large crinoid stems, pentangular disks, and the delicate form of an undetermined *Trematopora*. From several localities of the lower Peoquop to the east of Spruce Mountain were collected *Athyris subtilita* and *Fusilina cylindrica*.

Here in the Peoquop are certainly between 3,000 and 4,000 feet of these heavily bedded limestones containing Coal Measure fossils, but the series is nowhere deeply enough exposed to arrive at the Devonian beds, nor high enough to show the overlying Weber quartzites.

North of the Humboldt, in Tucubits Range, Wahsatch limestone is developed on a line extending from Tulasco Peak northwesterly for about twenty-five miles, and in topographical breadth the belt varies from three to four miles. The crest of Tucubits Range is formed of heavy masses of quartzite, referred to the Weber. Beneath these the dark limestones are particularly well exposed in Emigrant Cañon and all along the western base of the range, especially at the South Fork of Forellen Creek. The beds have a gentle dip of 20° to 25° northward, while they strike a little west of the trend of the range, and consequently lower and lower limestones are exposed in passing southward. Near the mouth of Emigrant Cañon the beds stand at a steep angle, in some cases as high as 45° or 50°, and show ample evidence of local faulting. In a little ravine entering Emigrant Cañon from the south is evidence of a northwest-and-southeast fault, of which the upthrow has been upon the eastern side, the eastern beds bending down steeply at the faulting-plane. A short distance above this, and east of the fault, at a point very near the base of the limestone, are exposed beds of calcareous shales several hundred feet thick. Above these are 300 feet of light-gray limestone, overlaid by 100 feet of yellowish calcareous shales, and above these 100 feet of black, thinly laminated, calcareous shales abounding in fossils; above these again 200 feet of dark-gray limestone, followed by the ordinary heavily bedded blue limestone for 1,500 or 1,600 feet. From the black shales above mentioned were obtained the following fossils of the Upper Helderberg horizon:

Orthis multistriata.
Orthis n. sp.
Spirifer Vanuxemi.
Atrypa reticularis.
Cryptonella (fragment).
Crania sp.?

The cañon slopes above this point are in general too much covered with detritus to afford continuous sections, but from the frequent intervals of limestone outcrops, and the absence of all others, it is clear that there are 4,000 or 5,000 feet of consecutive beds showing toward the upper part a high proportion of shales, which are generally of light colors. Near the upper limits of the cañon is an outcrop of 500 feet of calcareous shales, weathering very yellow, and overlaid by light-drab limestones which pass into blue and siliceous limestones, carrying seams of calcite and crystals of pyrites. Conformably above, although the contact is obscured by soil, are seen heavy masses of Weber quartzite, which extend eastward and compose the whole summit and eastern slopes of the range. At the southern edge of the belt, at Tulasco Peak, in a little ravine running northwest from the summit, were obtained several Coal Measure fossils, among which were the following:

Spirifer cameratus.
Spirifer Kentuckensis
Athyris subtilita.
Pseudomonotis radialis.
Pseudomonotis sp.?
Dentalium Meekianum.
Chætetes.
Fenestella.
Trematopora.

These beds are almost in contact with the overlying Weber quartzites, and their peculiar position with regard to the rest of the range is probably solvable by a system of faults, some of which have been clearly observed. Their facies is higher than the usual Coal Measure horizons of the Wahsatch limestone, and represents the very uppermost limit in their longitude. The Waverly horizon was not here observed, but it is clear that the Upper Helderberg fossils occur in a horizon not far from the bottom of the Wahsatch limestone, and are overlaid by 5,000 feet which contain at intervals true Coal Measure forms, although the beds closely overlying the Helderberg, in which we might expect to find both the sub-Carboniferous and the Waverly, are here, so far as our observations go, entirely barren of fossils.

In the little fragment of gray siliceous limestone which rests unconformably upon the granite of the Wachoe Mountains at Castle Peak, were found *Productus sub-horridus* and *Athyris Roissyi*. Southward, in continuation of the same uplift, at the northern extremity of Antelope Hills, two inconsiderable masses of limestone rise above the general field of rhyolite, and show alternation of limestones and siliceous and argillaceous limy shales, characteristic of the upper middle part of the Wahsatch limestone.

From the Egan Mountains north of our southern limit, with the exception of a small body of rhyolite which, in the northern end of the range, north of Mahogany Peak, breaks through the limestones, the range is composed of the Wahsatch body. At Mahogany Peak were obtained—

Productus multistriatus.
Productus sub-horridus.
Athyris subtilita, var. *Roissyi.*

From Gosiute Peak were obtained *Productus punctatus* and a fragment of *Campophyllum*, and still farther down an undeterminable species of *Diphyphyllum*. The facies of the fossils, and the great thickness of the limestone exposed—not less than 4,000 feet—refer this great ridge unquestionably to the Wahsatch; and although the lower members of the series are not reached, the occurrence of Silurian a little farther to the south in the range suggests the desirableness of further search for the Waverly and Helderberg beds by whoever shall explore south of our limit.

The Ruby group, which lies between Egan Range and Ruby Valley, exposes a considerable thickness of heavy drab, cream-colored, and blue limestones, undoubtedly of the same series as Egan Range, although they represent, both lithologically and by their fossil remains, higher members than are seen on that range. Among the collection made were the following Lower Coal Measure forms:

Productus multistriatus.
Productus semireticulatus.
Productus Nevadensis.
Spirifer pulchra.
Athyris subtilita.
Athyris Roissyi.

From Frémont's Pass south to Hastings's Pass the entire Humboldt range is made up of conformable rocks dipping to the east, having about 1,000 feet of quartzite, referred to the Ogden group at the base of the series, and skirting the foot-hills on the western side of the range. Above this, and forming the whole body of the range and its eastern slope, is a superb exposure of Wahsatch limestone, between 6,500 and 7,500 feet in thickness. The average dip of this whole body is from 16° to 20° eastward, increasing to the south to as much as 25°. The eastern slope in the region of Ruby Lake is scored by remarkable narrow, deep cañons, with abrupt walls, nearly perpendicular, reaching 1,400 or 1,800 feet in height. Plate XI. illustrates one of these sharp cuts in the Wahsatch limestone. At the northern end of the exposure the limestones come directly in contact with the granite and gradually rise to a vertical position, tailing out to the north as a mere narrow blade of beds on edge. On the high peak back of Cave Creek the dip is only 16°; farther south it becomes nearly horizontal, but rises rapidly again north of Hastings's and east of Fort Ruby, where it reaches an angle of 16° and 20°, inclined to the northeast. While as a whole the ridge is an easterly dipping mass, it will be seen that it describes a slight curve, with convexity to the west, and the extreme ends of the curve dip slightly toward each other. This is only one of those instances of curved strike so frequent in the Basin ridges The Wahsatch group is unmistakably conformable with the quartzites below, and the transition between the two rocks is made in very short distances, without any noticeable intercalation of beds. As they approach each other, the quartzites become slightly calcareous, and the limestones somewhat siliceous, yet the line of demarkation can be easily observed. The lower limestones, for about 1,500 feet, are of light grays and buffs, interrupted by a few dark-blue strata. Above this the bedding becomes heavier, the limestones darker, and there are more intercalations of shaly material. On the eastern base there is a great deal of unimportant siliceous interstratification, and not a little buff, shaly limestone. As a whole, from bottom to top, the 6,000 or 7,000 feet are essentially a limestone, only varied by small proportions of clay and sand. Midway are some beds which are purely dolomitic. One of these saccharoidal magnesian stones, taken from about the middle of the series, was analyzed, and its result will be found in the tables of analyses of stratified rocks.

Scattered through the higher members are fragments of recognizable Coal Measure fossils; but the lower members have yielded only stems of *Cyathophylloid* corals and a few badly preserved *Spirifers.* The only identifiable fossil species obtained are in the horizons of the Coal Measure forms:

Chonetes granulifera.
Productus Nebrascensis.
Fusilina cylindrica.

Although faithful search was made at several points through the lower members of the series, no fossils were found, owing to the somewhat altered condition of the strata. Where the main South Fork of Humboldt River flows out from its cañon on the western slope of Humboldt Range, north of Frémont's Pass, the Archæan mass projects westward in a bold promontory. Around its western base is wrapped a series, about 4,000 feet thick, of limestone, overlaid to the north, west, and south by the horizontal Pliocene strata. They describe a crescent-curved strike, and dip normally outward at angles of about 25°. Near the bottom is a slight exposure of conformable quartzite, which is assumed to be the top of the Ogden. The first 1,800 feet are of a prevailing light color, with shades of gray and buff, but mostly covered with earth and débris and yielding no fossils. Above these comes a dense, blue-black limestone, containing the following species:

Productus semireticulatus.
Productus longispinus.
Fusilina cylindrica.
Camarophoria.

Farther north, in the region of Sacred Pass, the upper members of the series yield—

Syringopora multattenuata.
Productus costatus.
Athyris subtilita.

White Pine Mountains, a group culminating about thirty miles south of our southern limit, were visited by several members of the Expedition in the prosecution of mining studies. Here is obtained, though not an entire section of the Wahsatch limestone, decidedly the most important one in western Nevada. The base of the series passes under the Quaternary accumulation of a mountain valley, and its lower geological boundary is therefore not determined. Nor is the upper limit of the series obtained, but a body of 5,000 feet is exposed, which near the base has the most interesting lithological sequence of beds, each charged with characteristic fossils illustrating the complete passage from the Devonian through the Waverly and sub-Carboniferous into the Coal Measures. On Treasure Hill are actually exposed about 1,500 feet of blue limestones, all dipping to the east. The upper 800 feet of these offer conclusive evidence of Devonian age. The species obtained from these Devonian strata have been determined by Hall and Whitfield to range from the Upper Helderberg to the summit of the Chemung. Among them are the following:

Cladopora prolifica.
Diphyphyllum fasciculum.
Acervularia pentagona.
Ptychophyllum infundibulum.
Naticopsis sp.?
Orthoceras Kingii.
Strophodonta Canace.
Productus subaculeatus.
Atrypa reticularis.
Rhynchonella Emmonsi.
Pentamerus sp.?
Spirifera argentaria
Cryptonella Rensellaria.
Orthis sp.? (resembles *O. resupinata*).
Spirifera sp.? (resembles *S. striatus*).
Paracyclas peroccidens.
Bellerophon Neleus.
Isoneima sp.?

The section from Babylon Hill included—

Syringopora Maclurii?
Smithia Hennahii.
Favosites sp.?
Atrypa reticularis.
Rhynchonella Emmonsi.
Pentamerus sp.?
Orthoceras sp.?
Pterinea sp.?

The only forms obtained from Mount Argyle belong to corals. Although they are mostly fragments, Professor Meek has identified the following:

Alveolites multiseptatus.
Cladopora prolifica.
Smithia Hennahii.
Dyphyphyllum fasciculum.

From the Blue Ridge, in the top of the series, we have —

Spirifera Engelmanni.
Productus subaculeatus.
Pleurotomaria sp.?

Above these limestones is a series of calcareous shales, which so far have yielded no fossils. But in the siliceous limestone which directly overlies them were found, upon Telegraph Peak, stems of *crinoidæ* and *Spirifer Albapinensis*, new species of Hall and Whitfield. This specimen here underlies a stratum which clearly belongs to the Genesee slates, although in the Wahsatch it ranges up into a higher horizon and is associated with groups of Waverly fossils from Ogden and Logan cañons, which in themselves show certain distinct Devonian forms, yet at the same time present a general Waverly facies. Above this siliceous limestone, in perfect conformity, is a series of 125 feet of black shales which form a well marked geological horizon at this locality, though they have not been distinctly recognized elsewhere in the Great Basin. It is a peculiar outcrop at best, which will bring to the surface and preserve easily weathered shales, and they may well be supposed to exist in the Wahsatch limestone of the neighboring ranges, their narrow outcrops covered with earth or débris. As shown at White Pine, they are divided roughly into two distinct bodies. The lower group is more argillaceous, and the upper more arenaceous; but in general appearance they are strikingly similar, though a sharp division is indicated by the association of species. From the lower were obtained—

Leiorhynchus quadricostatus, Hall.
Aviculopecten catactus, Meek.
Lunulicardium fragosum, Meek.
Nuculites triangulatus, H. & W.
Goniatites Kingii, H. & W.
Orthoceras cessator, H. & W.

From the upper beds we obtained—

Streptorhynchus sp.?
Spirifera sp.? (resembles *S. disjuncta*).
Productus semireticulatus.

The occurrence of *Leiorhynchus quadricostatus*, a form characteristic of the Genesee slates, in the lower member of the black shales, led Hall and Whitfield to regard the horizon as Devonian, while in the upper series the equally marked *Spirifera*, resembling *S. disjuncta*, was believed by them to mark the horizon of the sub-Carboniferous. The sandstones which directly overlie these shales contain only vegetable impressions, leaves and stems of *Lepidodendron* and *Cordaites*, and casts of crinoidal stems similar to those observed in the siliceous limestones below. Next above this the great body of blue limestone is abundantly furnished with distinct Coal Measure forms:

Diphyphyllum subcespitosum.
Zaphrentis sp.?
Streptorhynchus crenistria.
Productus semireticulatus.
Productus prattenianus.

Productus longispinus.
Productus sp.? (resembles *P. Wortheni*).
Productus Nebrascensis.
Productus costatus.
Spirifera camerata.
Spirifera Rockymontana.
Spirifera planoconvexa.
Spiriferina spinosa
Athyris subtilita.
Athyris sinuata.
Eumetria punctulifera.
Terebratula sp.?

The value, therefore, of this White Pine section is in its illustration of the complete passage from Upper Helderberg forms through Genesee into sub-Carboniferous and up into the Coal Measures. It is also seen that the Upper Helderberg has a range of several hundred feet. The same forms that were obtained by Mr. Hague from the Coal Measure limestones of White Pine recur in a cream-colored limestone at Railroad Cañon. It is a mere block of the series, dislocated from any traceable connection with either mountain mass, and surrounded on all sides by deep valley Quaternary, or fields of basalt which overflow it toward the west. It yielded the following forms:

Chætetes sp.?
Streptorhynchus crassus.
Productus semireticulatus.
Productus prattenianus.
Productus costatus.
Spirifera Rockymontana.
Spiriferina spinosa.

South and west of Piñon Pass, in Piñon Range, lies a synclinal, of which the lowest members upon the western side are Silurian limestones. They do not come to the surface on the eastern side; but directly overlying the Ute-Pogonip body at Cave Creek is the Ogden quartzite, as before described, showing an exposure of about 800 feet. This curves under the synclinal and rises again, occupying the summit of Piñon Pass. Held in the curve of the anticlinal are seen the lower 2,000 feet of the Wahsatch limestone. There is little intercalation at the region of contact between the Ogden and the overlying limestone, the latter beds resting sharply upon the laminated quartzites. The lower 1,200 feet of the Wahsatch are formed of gray, drab, and buff beds, with only occasional intercalations of the ordinary blackish-blue limestone. It is a very exact repetition of the same portion of the Wahsatch limestone in the neighboring Humboldt Range. From 800 to 1,200 feet up in the series the beds yield abundant Upper Helderberg forms. These limestones, never exposing over 2,500 feet, extend southward along the range as far as the southern limit of our map, forming, south of Fossil Pass, a singular monoclinal ridge, with a dip to the east. The 2,500 feet is a relic of erosion, all the overlying beds having been carried away. Upper Helderberg fossils recur at several points, although in one place there would seem to be a mingling of Upper and Lower Helderberg, but Hall and Whitfield decide that they might all occur in Devonian beds; and this decision is sustained by the presence of Lower Helderberg below the Ogden quartzite. Near Hot Spring Creek the limestones furnish the following forms:

Dalmania sp.? (closely resembles *D. anchiops* from Schoharie group, New York).
Edmondia Piñonensis (associated on the same block with *Chonetes* and *Spirifer*).
Orthis oblata.
Orthis sp.? (resembles *O. quadrans*).
Strophodonta sp.?
Spirifer Piñonensis.
Spirifer sp.? (resembles *S. arinosa*).
Atrypa reticularis.
Rhynchonella sp.?

Several of these species recur near Fossil Pass, on the summit of the range.

Nearly due east from Chimney Station, on the eastern side of the range, were found a few fossils, among them:

Zaphrentis sp.? (figured by Prof. Meek).
Favosites sp.?
Cladopora sp.?
Spirifera sp.?

Besides these, there were corals not specifically identifiable, but closely related to Upper Helderberg forms.

Mr. Engelmann, geologist of Colonel Simpson's Expedition, obtained from Swallow Cañon, in the same range, though south of our work, a collection of Devonian fossils, which have been described by Professor Meek. They embrace—

Productus subaculeatus.
Spirifer Utahensis.
Spirifer Engelmanni.
Spirifer strigosus.
Atrypa reticularis.

All of these have been found by us in the Wahsatch limestone of White Pine and the northern Piñon.

In the southern part of Seetoya Range, rising out of an immense mass of rhyolite, stands Nannie's Peak, a granitic nucleus, which has a heavy body of Wahsatch limestone dipping from it in every direction; it is a long, oval quaquaversal, with the greatest elongation of granite lying north-and-south. The best section is seen on Coal Creek, where the strike is nearly east-and-west and the rocks dip to the south about 45°, exposing 2,000 feet of limestones, capped by a heavy bed of conglomerate that may possibly represent the base of the Weber. This locality is interesting because, about a mile from the mouth of the creek, and several hundred feet down from the highest exposure of rock, is a bed about fifteen feet in thickness of black carbonaceous material, passing in places into an impure anthracite coal. The section is as follows, beginning at the top:

	Feet.
1. Conglomerate, possibly the base of the Weber	?
2. Blue limestone, with shales	100

		Feet.
3.	Bluish-black, finely divided argillaceous shales	150
4.	Coal seam	15
5.	Bituminous shale	50
6	Gap (no exposure)	100
7.	Black shale	10
8.	Argillaceous limestone	50
9.	Yellowish calcareous shale	200
10.	Drab siliceous limestone, with shale	200
11.	Blue limestone, with seams of white calcite	50
12.	Rusty quartzite	50
13.	Compact blue fossiliferous limestone	100
14.	Blue limestone and shales	200

From below the coal were obtained the following Coal Measure fossils:

Productus semireticulatus.
Syringopora multattenuata.
Cyathophylloid (fragments).

Below the cañon of the Humboldt, which opens into the valley of Carlin, south of the river the Weber quartzites, which at the mouth of the cañon stand nearly vertical, decline to the east, gradually reaching an angle of about 40°. Quite conformably under them lies the Wahsatch limestone, presenting its edges to the valley, which cuts directly across the strike. In rising the hill the limestones quickly pass under overlying volcanic rocks, and the exposure is confined to the foot-hills immediately bordering the river. Here the limestones are seen to be exceedingly impure, varied with both slaty and sandy material, and to show traces of considerable compression and alteration. Not far from the top (the actual distance could not be determined) are beds of black carbonaceous shales, passing at times into the same impure anthracite which has been opened at Coal Creek. Mining here has also been actually begun on the carbonaceous streak. There are stems of *Lepidodendron* and obscure vegetable impressions in these shales. Farther down, the limestones are again pure, and contain the well known association of several species of *Productus* and the ordinary corals of the Coal Measures.

WEBER QUARTZITE.—Wherever in Oquirrh Range its complicated structure exposes the upper limit of Wahsatch limestone, it is seen to pass by a series of intercalations of limestone and quartzite, characteristic of the Tim-pan-o-gos horizon, into Weber quartzite. The latter body is exposed over fully half of the range, and in the north, at Connor's Peak, is again overlaid by the limestones of the Upper Coal Measures. The exact thickness exposed cannot possibly be arrived at, owing to the faulted condition of the country. It is magnificently shown in the region of Bingham Cañon, where is exposed certainly as great a thickness as is seen in the Wahsatch, and probably a much greater one, approximating to the depth of the same series in the Uinta. The Tim-pan-o-gos horizon is finely shown at Soldier Cañon. Far more than the limestones, the quartzites are liable to angular, fragmentary disintegration, and the surface of all the quartzite slopes is much more covered and masked by débris than that of the limestones; hence the structure-lines are much better made out in the underlying and overlying limestones. The greatest quartzite display is in the region of Bingham Cañon and to the south as far as the mouth of North Cañon. The structure throughout this region is subject to extremely sudden changes, involving great complications and fractures. The general section exposed in Bingham Cañon shows a synclinal fold, whose western members are short and abrupt, the axis of the fold being depressed toward the north. Owing to the irregularity of the structure, it is impossible here to arrive at the thickness, but it cannot be less than 6,000 or 7,000 feet.

In these quartzites Professor Clayton, nearly always successful in his search for fossils, obtained the following forms:

Archæocidaris n. sp.
Martinia lineata.
Polypora.
Crinoid columns.

Here is an instance in which distinctly Coal Measure forms are found in Weber quartzite, and where this is seen overlying Wahsatch limestone. The reader will remember, in the Uinta, my mention of the two Coal Measure forms which we found in the débris of the quartzite in the heart of that range. There was an instance in which the fossils were obtained in the quartzite underlying the Upper Coal Measure limestones. The Bingham find, which is free from all doubts, lends probability to the fragmentary data of the Uinta. These two occurrences of organic forms in this wonderful body of quartzite add the final link of proof of its age. In the section of Weber Cañon the quartzites are seen distinctly enclosed between the two great Coal Measure limestone bodies, without a shadow of doubt as to the position; and now in two localities Coal Measure fossils have been found in the quartzite. After this we conceive there can be no dispute as to the age of this member of the Palæozoic.

In the region of Connor's Peak the synclinal already mentioned at Bingham Cañon is again seen, although near the summit of the peak the upper beds only of the Weber quartzite are exposed, overlaid by blue siliceous limestones and soft, earthy lime beds of the Upper Coal Measures, containing poorly preserved specimens of *Spirifer* and *Productus.*

Important masses of Weber quartzite are seen in Stockton Hills, on the eastern base of Aqui Mountains, in Cedar Mountains, among the Lakeside group, and on Stansbury Island. Otherwise the Salt Lake Basin and the hills which skirt it within the limits of our map are composed of no higher members than the middle portion of the Wahsatch limestone.

If the reader will refer to Map IV. of the geological series, he will observe that the southern portion of the lower half is composed of ridges of Wahsatch limestone and rhyolite, surrounded by fields of Quaternary. Northward, however, he will observe that the upper half of the map is characterized by a very small occurrence of Wahsatch limestone, and by the prominence of Weber quartzite and overlying Coal Measures, and that only in Tucubits Range is there any considerable occurrence of Wahsatch limestone along the northern part of the map. The Gosiute, Peoquop, and Little Cedar Mountains, the Toano group, Fountain Head Hills, and much of the Tucubits show considerable bodies of Weber quartzite. Upon the Tucubits it is seen conformably overlying the enormous development of Wahsatch limestone. On the other hand, in all other ranges—Little Cedar, Peoquop, Ombe, Toano, and Gosiute—the quartzite, the lowest rock, is seen to be overlaid by heavy bodies of gray and blue limestone, varied with certain argillaceous and sandy zones, and carrying fossils of the Upper Coal Measure series, to the very base, absolutely in contact with the quartzite. Such is the faulted and disturbed position, and such the irregularity of the quartzite outcrops, that in this section no correct idea of their thickness can be obtained. On the Tucubits and Fountain Head Hills there cannot be less than 6,000 or 7,000 feet. The other exposures display much less. The quartzites so far do not yield any fossil forms in this region. The point of interest to us is the persistence of this vast bed of quartzite, and the fact of the stratigraphical parallelism with the Weber section.

One of the finest exposures of Weber quartzite in this region is that of Pilot Peak, Ombe Range. Directly south of Patterson Pass a body of quartzite is seen to rest nonconformably upon the granites of the pass, and to occupy the entire ridge down to Pilot Peak. This body is composed of beds of white quartzite, having rather a complicated structure, evidently subjected to great lateral compression, and accompanied with frequent local displacements In general, there is evidence of a synclinal and an anticlinal fold, their axes traced diagonally across the range. Pilot Peak itself is upon the anticlinal, the beds striking north 15° to 20° east, with a dip of 15°, the greater part of the rock mass inclining to the southeast. Along the eastern face of the mountain is seen a precipitous section of the quartzite edges, displaying about 7,000 feet. Lithologically it presents no very great variation. It is all rather heavily bedded, with distinctly marked divisional planes. Near the southern end of the body it has a prevailing bluish-gray or brownish-gray color, while on Pilot Peak it is pure snowy white, passing down into a deep bluish tinge, the lower beds being more or less feldspathic and interrupted by sheets of conglomerate, whose pebbles are formed of quartzite and jasper, evincing considerable compression and cracking. Here are interposed also a few thin sheets of silver-gray micaceous schists. There is nowhere a finer instance of the method of disintegration of quartzite bodies than is shown on the eastern slope, which is covered with huge cuboidal blocks of débris, indicating the ease with which it was shattered by frost. The summit region is characterized by open fissures or rents in the quartzite, with walls 200 or 300 feet deep. Subjected to analysis, the quartzite of this peak gave 94.93 per cent. of silica, .17 of water, with the remainder of alumina, lime, and the alkalies. At the southern end of this mountain mass the quartzites are conformably overlaid by gray limestones, from which, in close proximity to the quartzites, were obtained *Productus punctatus* and *Spirifer cameratus;* this relation serving to fix the age of the quartzite.

In Fountain Head Hills is a wide display of quartzitic rocks, which are continuous westward across the saddle connecting that body with Tucubits Range, and sweep up to form the crest of the range and its eastern slope. The quartzite, as displayed in Fountain Head Hills, is a great bed of angular quartzitic conglomerate, a feature which to the west of this point is persistent across northern Nevada as far westward as the Palæozoic is known to continue. It is a medium-grained, sugary rock, made up of angular fragments of flints and cherts of various colors, in which black and red invariably predominate. The matrix is a yellowish-brown, iron-stained, saccharoidal quartz, having to the touch a peculiar earthy feeling. Under the microscope it is seen to contain a considerable proportion of minute crystals of calcite, the matrix being made up of both crypto-crystalline grains and rounded fragments of quartz.

Near its northern end Tucubits Range is formed of beds of quartzite which conformably overlie Wahsatch limestone. Much of the quartzite is curiously banded with a cherty material, showing black and green colors. The whole of this ridge, and the country south of it overlying Tulasco Peak, are much covered with débris and dislocated blocks of quartzite. Continuous outcrops are never found of sufficient extent to permit a measurement of the thickness. South of Tulasco Peak the brecciated quartzites are again seen, full of grains of limpid quartz enclosed in the rough saccharoidal matrix, and singularly resembling certain forms of rhyolite. The brecciated quartzites here again contain an enormous amount of cherty fragments, brown and black, the matrix being more or less yellow-stained by oxyd of iron. The alumina proportion seems to rise in the brecciated region.

At Middle Pass in Gosiute Range the lowest rock displayed is a small mass of granite, which occupies the pass itself. Directly to the north and south it is overlaid by Weber quartzite, which towers into hills 1,500 or

2,000 feet in height. Both north and south the quartzites are overlaid by the limestones of the Upper Coal Measures, carrying characteristic fossils nearly down to the contact between the two series, thereby clearly identifying the Weber body. The quartzite here is mainly pure white, with bands showing bluish and gray sheets, with a few thinly bedded regions of almost jet-black jasper. It appears to be made up of two sizes of grains, metamorphosed and condensed into a compact rock. The microscope detects thin flakes of mica, sometimes aggregated into layers, and the quartz grains which have not lost their original outlines, although much flattened and compressed, show numerous fluid inclusions. Conglomerate beds appear in the Quartzite near Orford Peak, characterized by coarse subrounded pebbles of chert and flint, overlying a heavy mass of yellowish quartzite, the whole having a strike of north 28° to 30° east, dipping at an angle of 30° to the northwest. Overlying the conglomerate is a thin bed of dark, steel-gray quartzite. Upward the series rapidly rises into contact with the conformable limestones, which bear fossils of the Upper Carboniferous.

River Range, north of Humboldt River, is for the most part made up of a long anticlinal of Weber quartzites, flanked on both sides by Pliocene valleys, and more or less interrupted and limited by bodies of rhyolites. At the extreme southern end, and near the north, occur the overlying limestones of the Upper Carboniferous. No very deep exposures of the quartzites were obtained in this region, not over 4,000 feet at the utmost. The deepest are seen at Penn Cañon, where the structure is that of an anticlinal whose eastern member is almost perpendicular, while the main body of the range is formed of westerly dipping beds, with angles at the centre of the range of 10°, steepening to 25° on the western foot-hills. The lowest exposed strata show a considerable thickness of argillaceous schists and quartzites, which are overlaid by conglomerates, generally including a certain proportion of angular cherty fragments, while the most prominent beds of all are the peculiar dark, angular conglomerates already mentioned. In the upper part of the series is an included bed of limestones underlying an upper series of conglomerates, which are apparently always rounded. The conformable overlying Upper Coal Measure limestones carry their characteristic fossils down to the point of contact, as will be seen when treating of that limestone. In close connection with the group of rhyolites which bounds River Range, are some finely angular conglomerate quartzites, containing a great number of grains and cryptocrystalline fragments of limpid quartz and angular chips of black and green chalcedony. Associated with these are peculiar striped felsitic rocks, interbedded with the quartzites, and having the appearance of felsitic tufas, contemporaneous with the Weber quartzite.

In Osino Cañon, where Humboldt River and the Pacific Railroad cross the end of Elko Range, is exposed a good section of steeply dipping quartzites and conglomerates, the latter of the angular chert-bearing member. The general structure is that of an anticlinal fold having a north-and-south strike, the beds being upturned at high angles. Here again the quartzites contain black carbonaceous seams.

At Moleen Cañon, a mile and a half below the upper mouth, may be seen the contact between the Upper Coal Measure limestones and the Weber quartzites. There is here an apparent nonconformity, the beds of limestone having a slighter dip than the quartzites; but this is probably due to a fault which is evidenced on the hills to the north and south. The uppermost observed beds of the Weber are formed of angular cherty conglomerates, with saccharoidal siliceous cement, which is more or less mixed with feldspar fragments, and, as the microscope shows, with carbonate of lime. These angular conglomerates do not form the uppermost members of the series, and that is an additional argument in favor of an explanation of the discrepancy of angle at the contact by a fault, since the lower or angular conglomerates are brought into contact with the limestones. A further proof that the angular conglomerates are not the uppermost beds is shown at Moleen Peak, where the lower and northern foot-hills of the group are formed of Weber quartzite for 1,000 feet up the foot-hill slopes. Here the quartzites are of broad, heavy bedding, and of yellow, green, and purple colors, with a coarse texture, resembling that of the upper part of the Weber group on Mount Agassiz, Uinta Range. The quartzites enclose numerous beds of conglomerate of purple and green siliceous pebbles, which are never so angular as those of the lower members. The quartzitic conglomerates are here conformably overlaid by the gray limestones of the Upper Coal Measures, which carry numerous fossils down to within a few feet of the contact with the Weber.

As displayed in the upper portion of Seetoya Range, the Weber quartzite, which there conformably overlies about 4,000 feet of Wahsatch limestones, is interesting as illustrating the recurrence here of the Tim-pan-o-gos horizon, namely, the intercalation of upper limestone beds of the Wahsatch with the lower members of the Weber. At this horizon are numerous calcareous slates. Although between the upper limits of the quartzite, as displayed northwest of Seetoya Peak, and the body of rhyolites that forms the eastern base of the range, there are a few exposures of a limestone which overlies the Weber, no fossils were obtained, and there is uncertainty whether this is the Upper Coal Measure or the Wahsatch again faulted to the surface. An estimate of the thickness in this region would therefore be liable to serious error.

The southern part of the Seetoya group shows an immense mass of Weber quartzites extending as far up as Mount Neva. It is of crystalline texture, containing more or less siliceous argillites, with cherty seams. One particular bed was noticeable for its wavy structure, accompanied with a plentiful inclusion of graphite.

At Agate Pass, in Cortez Range, occurs a large body of quartzites with characteristic included angular chert conglomerates, which are only of interest as showing the remarkable persistence and thickness of this peculiar development of the Weber. There is not less than 3,000 feet of coarse, saccharoidal rock, of which the matrix is made up partly of quartz and partly of feldspar grains, with a considerable proportion of microscopical carbonate of lime. A singular feature of the rocks is the constant occurrence of small vugs lined with crystals of quartz and calcite. The siliceous pebbles here reach five or six inches in diameter and are partly well worn, rounded, littoral pebbles, and partly sharply angular fragments of similar cherts.

The great mass of Shoshone Peak and the western foot-hills of the northern prolongation of Shoshone Range up to the Union Pacific Railroad, are formed of a great body of quartzites, schists, and quartzitic argillites. Their prevailing strike is a little west of true north, with a dip of 35°

to the east. They are frequently finely laminated, and at the lower horizon, at the base of the quartzitic series, they pass into blue calcareous bands, with a little pure limestone, supposed to represent the Tim-pan-o-gos horizon. Within the lower limestones, near Argenta, in a limy schist, is a bed of carbonaceous shale which in places inclines to anthracite and has been actually mined for coal. The Shoshone mass itself shows an expansion of quartzites of sixteen miles, at right angles to the trend, and extending for twenty miles on the strike-direction, the eastern foot-hills being covered with belts of rhyolite from two to five miles broad. These quartzites have a southerly and easterly, though chiefly easterly, dip The uppermost layers of the quartzite are compact and dark, interbedded with thin sheets of fine, fissile, argillaceous slates, which, after a gradual calcareous transition, are capped with beds of quite pure limestone. These beds yielded no fossils, and the whole series of argillaceous and calcareous rocks nowhere exceeds an exposure of 200 feet in thickness. As there is some uncertainty about the age of these rocks, and as the only clews are given by the bed of impure anthracite near Argenta, and, further, since the actual connection between the coal-bearing rocks of the northern foot-hills and the immense quartzitic exposure near Shoshone Peak cannot be proved to be free from faulting, we content ourselves with referring this to the Weber, on a basis of simple probability. In general, the great Shoshone body cannot be less than 10,000 feet thick, composed for the most part of dark quartzitic schists, with some beds of almost jetty-black chert, a few argillaceous seams, and a rather limited amount of conglomerate carrying the angular pebbles of chert, the whole dipping eastwardly, or from Reese River Valley.

On the opposite or western side of the valley rises the isolated mass of Battle Mountain, which, with the exception of a few masses of limestone (one on the summit of Antler Peak, and another bordering the western side of the body), is composed of a similar series of quartzitic schists, which, although much disturbed and of varying angle, has a pretty general dip to the west. These two similar bodies face each other on the two sides of Reese River Valley, standing in the position of a broad anticlinal. On the Shoshone side the overlying limestones amount to nothing stratigraphically, and yield no fossils. In Battle Mountain the upper limestones, as exposed at the mouth of Willow Creek, yield Coal Measure forms down very close to their contact with the quartzite, and forms which are more allied to the Upper Coal Measures than to the Wahsatch limestones. For that reason the underlying quartzites, although of prodigious thickness, certainly not less than 10,000 feet, allowing then, even, for considerable reduplication of fault, are, with some doubt, referred to the Weber. This is the most westerly exposure of the series, and also the most western point of Palæozoic outcrop. Beyond this meridian, quite to the Sierra Nevada, the oldest fossiliferous rocks are Trias, which are seen to rest directly, without underlying conformable rocks, upon the Archæan.

Upper Coal Measures.—In the region of Great Salt Lake, as displayed upon the western half of Map III., there are no known outcrops of the Upper Carboniferous except in the single locality of Connor's Peak, in the northern part of Oquirrh Range, where have been obtained a few Upper Coal Measure species in beds of gray limestone overlying the enormous thickness of Weber quartzite. Northwest of Salt Lake, and north of the map, is a large province chiefly made up of Weber quartzite, overlaid by limestones of the Upper Coal Measure series They make their appearance at the southern end of the Ombe Mountains, south of Pilot Peak, and at the town of Buel So far as could be observed, they are quite conformable with the Weber quartzites. Among the most important localities, as illustrating the relation of the two series, are the hills both to the north and south of Toano Pass. Directly north of Fairview Peak the quartzites are seen to be conformably overlaid by limestones which dip to the northwest. From a cherty band near the top of the ridge the following *Brachiopoda* have been recognized—

Productus Rogersi.
Spirifer pulchra.

From the limestones adjoining the cherty band were also obtained—

Productus Nebrascensis.
Spirifer crassus n. sp.
Cascinium.

Northwest of Montello Station, where the limestones directly overlie the quartzites —

Spirifer pulchra and
Productus Nebrascensis

were collected, thus proving the limestones to belong to the upper series, and not to the Wahsatch. The rocks are largely of calcareous shales, gray and yellow, intercalated with beds of solid blue limestone. Higher in the series they seem to be more uniformly of the bluish-gray rock. Here and there appear a few beds which are exceedingly dark, almost black, the color being due, as the microscope shows, to the presence of carbon. In the group of hills northwest of Toano the limestones are altogether similar, though no fossils were discovered here. The upper limestone members are in general quite heavily bedded, and more or less seamed with white calcite. There is an intercalated bed of black siliceous limestone, hard enough to scratch glass, but effervescing freely with acids. The microscope shows it to be made up of fragments of angular and sub-rounded quartz, calcite, and opaque carbonaceous particles. Low in the series is quite a development of calcareous shales. South of Toano Pass the rocks in the region of Owl Valley and along the western half of the range are formed of easterly dipping Weber quartzite, conformably overlaid by a body of limestone showing not less than 1,500 or 1,600 feet in thickness. Near the base of the series, intercalated in the limestone, is a body of quartzite about 250 feet thick. The overlying limestones contain indistinct impressions of *Spirifer* and *Productus.* South of Middle Pass, at Pine Mountain, the quartzites are again overlaid by a westerly dipping body of limestone, which yielded *Spirifer opimus* and *Athyris subtilita,* both forms common to the two bodies of Coal Measure limestones.

In Peoquop Range, directly south of Peoquop Pass, is a fine exposure of Upper Coal Measure limestones, conformably overlying the Weber. On the western side of the range, they have a dip in general to the west, though directly to the south of the pass they describe a broad curve and reach a northeasterly dip. Immediately above the quartzites the lower beds of limestone yield —

Productus semireticulatus.
Spirifer cameratus.
Discina sp.?

Orford Peak, the high summit southeast of this pass, which reaches an elevation of 7,556 feet, carries upon its crest a body of limestone isolated from the main mass, and probably thrown up by dislocation and not altogether eroded off. It is only 150 to 200 feet in thickness, and directly and conformably overlies the Weber quartzite. It contains—

Athyris carbonaria.
Productus semireticulatus.
Productus punctatus.
Productus Nebrascensis.
Productus longispinus.
Spirifer cameratus.
Athyris subtilita.
Athyris Roissyi.

Associated with these were corals of the genus *Campophyllum.* Throughout the limestones of the northern end of the Peoquop are frequent interstratifications of cherty material, often carrying nodular concretions of flint and banded strata of exceedingly fine-grained cherts, with narrow bands of chalcedony. When treated with acids, the most siliceous specimens give a slight reaction for carbonate of lime.

North of Independence Spring the limestones which extend south from the high mass of Euclid Peak conformably overlie the Weber quartzites and carry in their very lowest beds *Productus semireticulatus,* and *bryozoa* belonging to the genus *Trematopora.*

South of Cedar Pass the Little Cedar Mountains are for the most part made up of heavy exposures of Weber quartzite, overlaid on the east by limestones of the Upper Coal Measure series, dipping to the east at angles varying from 10° to 22°, and passing under the shallow Quaternary deposit of the valley to form, with the westerly dipping limestones of the Peoquop, a synclinal. In this limestone were obtained several *bryozoa,* together with *Productus sub-horridus.* In similar but westerly dipping limestones on the western side of the range, still conformably overlying the quartzite, were found—

Productus prattenianus.
Athyris subtilita.
Syringopora multattenuata.
Chætetes sp.?

On the summit of the ridge, a little north of Albion Peak, a fragment of the lowest beds of the limestone has been spared from the general erosion of the region. The limestone, when subjected to analysis, besides a small proportion of white quartz sand, showed the theoretical composition of dolomite.

West of this point the region throwing most light on the Upper Coal Measure series is the neighborhood of Moleen Cañon. The southern end of River Range, for a distance of twelve or thirteen miles northwest from Moleen Cañon, shows the Upper Coal Measure limestones conformably overlying the Weber quartzite. They are composed here of a highly varied series of limestones, often earthy and marly, containing many zones of gray and yellow shales and some hard, heavy beds of black carbonaceous limestone emitting a fœtid odor when struck with the hammer. About four miles north of Moleen Cañon were found, in close proximity to the contact-plane between the limestones and underlying Weber quartzites, *Productus sub-horridus* and *Athyris subtilita.* The *Athyris* was also obtained from the very uppermost members of the limestone, where they pass under the Quaternary of Humboldt Valley, showing a vertical range of about 1,000 feet. South of the river, at Moleen Peak, is a display of limestones overlying the Weber quartzite. The whole series has an inclination to the southeast of 5° to 8°. These two masses, the Moleen mass and the southern part of River Range, directly across the valley, have a similar dip, and between them there seems to be insufficient room for the other member of a fold. They are therefore regarded as parallel monoclinal uplifts, the result of dislocation. The conformable contact-plane between the limestones and the Weber quartzite is very distinct, and there are only the slightest intercalations. On the other hand, the upper members of the quartzite, especially the matrix of the conglomerate, contain a great deal of carbonate of lime, and the lower members of the lime series are highly siliceous and more or less argillaceous. From 150 to 200 feet from the bottom were obtained—

Productus sub-horridus.
Productus symmetricus.

About 300 feet higher in horizon—

Productus sub-horridus.
Athyris subtilita.
Spirifer cameratus.
Zaphrentis Stansburyi.

And from a third horizon a little below the summit of the peak, say 1,200 feet above the quartzite, were obtained—

Productus sub-horridus.
Productus semireticulatus.
Productus prattenianus.
Productus symmetricus.
Streptorhynchus crassus.
Orthis carbonaria.
Eumetria punctilifera.

The extreme western point to which the Palæozoic series extends in our belt, as already mentioned under the head of "Weber Quartzite," is the group of Battle Mountain. There, with apparent conformity, upon the summit of the great quartzite body on Antler Peak, is a mass of isolated limestones; but a little to the west and south the same strata recur inclined to the westward at dips of about 20°, well displayed upon Willow Creek, where they form a precipitous wall of 1,200 to 1,500 feet of dark-gray limestones, in places somewhat shaly. In the lowest exposures in Willow Cañon were found the following Carboniferous forms:

Productus semireticulatus.
Productus prattenianus.
Eumetria punctilifera.
Athyris incrassata.

About 100 feet below the summit of the peak, and separated from the last locality by about 1,000 feet of limestone, the following fossils of entirely distinct generic forms were collected:

Fusilina cylindrica.
Spirifer pulchra.
Campophyllum.

The Upper Coal Measures, as a whole, over the Great Basin part of the Fortieth Parallel area, are a single body of limestones varying as to chemical purity and mode of stratification, reaching 1,600 or 1,800 feet in thickness. It rests conformably on the Weber quartzite, and in this region is the uppermost member of the Palæozoic series, the Permian never appearing west of the Wahsatch.

SECTION II.

RECAPITULATION OF THE PALÆOZOIC SERIES.

Analytical Geological Map II. accompanying this chapter shows all the Palæozoic exposures within the Fortieth Parallel area. At a glance it will be seen that the Rocky Mountain region has only a very slight development of Palæozoic rocks, and they appear simply as the bordering foot-hills of the Archæan mountain masses. Between the eastern boundary of the work, in the neighborhood of longitude 104° and Wahsatch Range, the greater part of the surface of the country is so deeply covered with Mesozoic and Tertiary rocks that little is seen of the underlying Palæozoics. It is only in the great Uinta uplift that the low-lying rocks make their appearance. It is quite clear, however, that, with the exception of the lofty insular Archæan bodies at the east, the Palæozoic forms a continuous sheet over the whole area beneath the later rocks. On the map accompanying this chapter the Archæan and granite exposures are shown for the purpose of illustrating their relation to the Palæozoic series. In Wahsatch Range and in the series of desert ranges which lie to the west as far as longitude 117° 30′ there is no considerable mountain body without its exposure of Palæozoic strata. In nearly all, the Archæan rocks also come to the surface, and almost every mountain block is therefore an illustration of the relation of nonconformity subsisting between the two great groups. Within the Palæozoic there are no considerable passages of metamorphism, no tendency to the formation of gneissoid rocks or crystalline schists, such as are described by some authors in the Appalachian system. As already mentioned, the Palæozoic series are strictly conformable, from the lowest Cambrian beds up to the top of the Upper Coal Measure limestones. Between this vast series and the group of shales and argillaceous limestones of Permo-Carboniferous age which close the Palæozoic age, there is little, if any, discrepancy of angle at the localities observed by us, but there is a slight appearance of nonconformity by erosion. In the Wahsatch region the limestone surface seems to have been acted upon either by marine currents or by shore waves, resulting in the production of gentle hollows, over which the fine muddy and shaly sediments of the Permo-Carboniferous were deposited with a slight nonconformity. Our observations are too limited to lay much stress upon this very trifling discordance. Below that horizon there is, however, no doubt of a strict parallelism over the whole area surveyed.

The most remarkable feature of the section opened up by our labors is the very great thickness of the Palæozoic series from longitude 117° eastward to and including Wahsatch and Uinta ranges, and the rapid thinning of the series from that longitude eastward to the Rocky Mountain zone. The entire series is not exposed in the most western longitudes. The deepest members of the Cambrian are not uncovered there, but the recognized members from the bottom of the Primordial limestone to the top of the Upper Coal Measures show a thickness even greater than in the Wahsatch section. Providing the Cambrian holds at the extreme west the same great volume that is displayed in Cottonwood Cañon of the Wahsatch, the western Nevada section could hardly be less than 40,000 feet conformable. In the Wahsatch it is 32,000 feet. The Uinta only shows an imperfect exposure, nowhere reaching the bottom of the Weber quartzite, and the beds of the Rocky Mountain region with us have a maximum of only 1,200 feet. The great accumulations of sediment, therefore, lie between the east end of the Uinta and the western Palæozoic limit in middle Nevada. Between the Wahsatch section and that at the extreme west there are but slight differences either in the character of the individual members of the Palæozoic or in the total thickness. The area of greatest sedimentation seems to have been from longitude 108° 30′ to 117° 30′.

Referring to Analytical Geological Map I. accompanying the Archæan chapter, and observing the ideal section at the bottom of the map, the reader will perceive that the bed on which the Palæozoic series have been imposed was by no means a plain; on the contrary, it was a vast mountain system which had suffered submergence, and over which the Palæozoic sediment settled. One feature of importance is the fact that there is little or no tendency on the part of the sediments of a given horizon to follow the hill-slopes, but in all cases where observed they abut directly against them as if deposited in absolute horizontality. Owing to the very great height of these Archæan ranges, reaching in one instance an abrupt cliff slope of 30,000 feet, the earlier sediments, those of the Cambrian and Silurian, must have been deposited chiefly in what were the valleys of the submerged Archæan mountain system. The base of the Cambrian is never seen. To the full section, as observed, there is therefore an unknown plus quantity to be added.

All the Palæontological lines are drawn in conformity with the New York system, except that under the term Cambrian I include all the rocks from the lowermost Palæozoic exposures up to and including the whole of the Primordial. This is the line as drawn by Dana, the only difference between his system and mine being that, instead of making the Cambrian a part of the Silurian, I follow approximately the English nomenclature, and confine the Silurian to the region above the junction of the Quebec and the Primordial.

Naturally the most imperfectly exposed of all the members of the series is the Cambrian group. Thus far, among the reported occurrences of the rocks of this horizon in the Cordilleras, the locality at the mouth of Big Cottonwood Cañon must remain as the finest example and the stratigraphical type. The lowest member—the Cottonwood slates, a group about 800 feet thick, which here rest upon highly metamorphic Archæan schists—has thus far yielded no organic forms. Though searched by us with considerable care, it presented no indications of life. The rocks are dark blue, dark purple, dark olive green, and blackish argillites, all highly siliceous, and as a group sharply defined from the light colored quartzitic schists which conformably overlie them. This second group, by far the greatest of the whole Cambrian series, is a continuous zone of schists which have a prevailing quartzitic character though varied with a considerable amount of argillaceous matter. It would seem to be the product of a fine-grained arkose formation, simply compressed into dense schists. From 8,000 to 9,000 feet thick, it has a general uniformity of lithological condition from bottom to top, except that in the region of Twin Peaks are some phlogopite schists and siliceous zones, carrying considerable muscovite. The phlogopite members recur in the Egan Cañon region The prevailing colors of this member are gray, greenish gray, drab, and pale brown; never dark colors. Conformably overlying it are 2,500 to 3,000 feet of cream-color and salmon-color and white quartzites, and quartzo-felsites. Occasional sheets of conglomerate are seen in the quartzites not far below the summit of the Cambrian. These as displayed in Ogden Cañon are of extreme interest. All the pebbles are much flattened, and not unfrequently they are welded together, squeezed into one another, having evidently become plastic when under great pressure. There is not a crack or divisional plane in these welded pebbles. The summit member is a thin series of green siliceous argillites, which are usually not more than 75 or 80 feet thick, and which, in different localities, carry in the lower part of the narrow group, fossils of Primordial types, and in the upper strata basal Quebec forms. In the region of the Wahsatch and Oquirrh, this little group of argillaceous and sometimes calcareous shales holds the division-planes between Silurian and Cambrian. No organic forms have been found in the enormous quartzite series. In middle Nevada, where again the Cambrian series is displayed, a decided change is found to have occurred. The little shale zone has disappeared, and its place is taken by a body of dark, steel-gray and ashen-gray siliceous limestone, intercalated with repeated series of calcareous shales, the entire body of limestone being about 4,000 feet thick. The lower 2,000 contain abundant Primordial fossils, and the upper 2,000 Quebec and later Silurian forms to the top of the limestone. This limestone, called from its typical locality, Pogonip, is persistent over a considerable region of western Nevada, and its lower half always carries Primordial fauna. Only the top of the Cambrian quartzite series is exposed in western Nevada. The true Potsdam sandstone, characteristic of the eastern region, and recurring with remarkable persistence through the Black Hills and parts of the eastern Rocky Mountain system, does not, as such, appear in the middle or western Fortieth Parallel area. Conformably underlying the beds of the Carboniferous limestone series of the Rocky Mountains is the same fine, gritty, red sandstone which a little north of our map and in the Black Hills carries the Potsdam fossils. It is unmistakably the same stratum extending southward into the region of our work, but with us is quite devoid of fossils. From the Utah and Nevada Cambrian were obtained the following:

Lingulepis Mæra n. sp.
Lingulepis ? minuta n. sp.
Obolella discoidea n. sp.
Obolella sp.?
Kutorgina minutissima n. sp.
Paradoxides? Nevadensis, Meek.
Conocephalites (*Ptychoparia*) *Kingi*, Meek.
Conocephalites (*Pterocephalus*) *laticeps* n. sp.
Crepicephalus (*Loganellus*) *anytus* n. sp.
Crepicephalus (*Loganellus*) *Haguei* n. sp.
Crepicephalus (*Loganellus*) *granulosus* n. sp.
Crepicephalus (*Loganellus*) *maculosus* n. sp.
Crepicephalus (*Loganellus*) *nitidus* n. sp.
Crepicephalus (*Loganellus*) *simulator* n. sp.
Crepicephalus (*Loganellus*) *unisulcatus* n. sp.
Crepicephalus (*Bathyurus ?*) *angulatus* n. sp.
Chariocephalus tumifrons n. sp.
Ptychaspis pustulosus n. sp.
Dikellocephalus bilobatus n. sp.
Dikellocephalus flabellifer n sp.
Dikellocephalus multicinctus n. sp.
Agnostus communis n. sp.
Agnostus Neon n. sp.
Agnostus prolongus n. sp.
Agnostus tumidosus n. sp.

In the Wahsatch region, overlying the narrow argillite zone, is a body of limestone varying from 1,000 to 2,000 feet thick, carrying Quebec fossils nearly to its summit. This Ute limestone in passing westward evidently merges into the greater Pogonip body, lime sediments having gone farther down into the Cambrian so as to include 2,000 feet of Primordial, which in the Wahsatch is occupied by the salmon-colored and white quartzites.

The Silurian Ute limestone at its characteristic locality, Ute Peak, is a body about 2,000 feet thick, of gray siliceous limestones and calcareous shales, carrying Quebec fossils to within 60 or 75 feet of its base and within 150 feet of the summit At Ute Peak it is never metamorphosed to any considerable degree, and rarely shows even the most rudimentary form of crystallization. It is essentially an unaltered bed of variable lime and sandy sediment, in which the lime so far prevails as to give to the whole a general calcareous character. This group is persistent through the entire length of the Wahsatch, and is exposed at a great number of points. In the region of Cottonwood, where the strata are thrown into an extraordinary semicircular curve around a nucleus of granite, all the members of the Palæozoic are compressed to a very great degree. The Ute limestone is here only 1,000 feet thick and is essentially a bed of much shattered white marble, containing tremolite and fine quartzitic intercalations. In the eighty miles between Ute Peak and the Cottonwood region it is true that there is abundant room for great variation in the actual original volume of sediment. But it is also true that when subjected to extraordinary compression, and in passing into the crystalline form, there is a very great shrinkage in all limestones, and it is not at all improbable that the difference of thickness in the two localities named may be due purely to the effects of compression. A similar instance is observed in the limestone of the Laramie Hills. On the west flank, where it lies nearly horizontal and has never been much disturbed, the series is about 1,200 feet thick, while directly across the range, where the limestones are highly crystalline and thrown into vertical position, the maximum thickness is inside of 800 feet. It is therefore probable that over the area of our map there was no very great original variation in the thickness of the Ute limestone.

In the Wahsatch region no fossils were obtained from the actual summit of the group, but in the Wind River region, not far removed to the north and east, Comstock, while accompanying the Jones Expedition, observed a limestone comprising 200 feet of beds, carrying Quebec fossils, capped by 150 feet with forms characteristic of the Niagara. In the southern Wahsatch the group is too uniformly crystalline to yield fossils. In middle Nevada, however, in the region of White Pine, Eureka, Piñon, and Roberts Peak ranges, the great Pogonip limestone, whose lower half, as already described, is charged with Primordial fossils, contains in its upper 2,000 feet several Silurian horizons. The Quebec probably there occupies 1,500 feet. From Nevada and Ute Peak in the Wahsatch were obtained the following Quebec species:

Lingulepis Ella n. sp.
Lingulepis or *Lingula* sp.?
Obolella sp.?
Kutorgina sp. undet.
Orthis Pogonipensis n. sp.
Leptæna melita n. sp.
Strophomena Nemia n. sp.
Porambonites obscurus n. sp.
Rhynchonella sp.? (fragments only).
Ophileta complanata, var. *nana*, Meek.
Euomphalus (*Raphistoma*) *rotuliformis*, Meek.
Euomphalus (*Raphistoma*) *trochiscus*, Meek.
Raphistoma acuta n. sp.
Maclurea minima n. sp.
Cyrtolites sinuatus n. sp.
Fusispira compacta n. sp.
Conocephalites subcoronatus n. sp.
Crepicephalus (*Loganellus*) *quadrans* n. sp.
Dikellocephalus gothicus n. sp.
Dikellocephalus quadriceps n. sp.
Dikellocephalus Wahsatchensis n. sp.
Bathyurus Pogonipensis n. sp.
Ceraurus? sp.?
Ogygia paraboloidalis n. sp.
Ogygia producta n. sp.

At Roberts Peak, about 300 feet from the top of the Pogonip series, were obtained the following Niagara forms:

Cladopora, sp. (resembles *C. seriata*, Hall).
Orthis (resembling *O. hybrida*, Dal., but larger).
Atrypa reticularis, L.
Atrypa (resembles *A. nodostriata*, Hall).
Illænus sp. undet.

The very top of the Pogonip, almost in contact with the basal strata of the Ogden quartzite at Roberts Peak and White's Ranch, has yielded the following fossils of the Lower Helderberg horizon:

Favosites Helderbergia, Hall.
Diphyphyllum n. sp.?
Campophyllum (impressions only).
Crinoidal columns.
Small branching *Bryozoa*, too indistinct for generic determination.
Crania sp. undet.
Orthis multistriata, Hall.
Orthis n. sp. (resembling young *O. oblata*, Hall).
Strophodonta punctulifera,? Con. (fragments only).
Spirifera Vanuxemi, Hall.
Trematospira?
Collospira n. sp. (allied to *C. imbricata*, Hall).
Atrypa reticularis, L.
Rhynchonella, sp. undet.
Pentamerus galeatus, Dal. (fragments only).
Cryptonella sp.? (fragments only).

The next overlying member of the series, the Ogden quartzite, is a remarkably persistent and singularly pure sheet of siliceous sediment, which has been in general compacted into a quartzite, and which is spread with remarkable evenness over the whole Palæozoic area west of and including the Wahsatch. At its typical locality in Ogden Cañon, Wahsatch Range, it is 1,200 or 1,400 feet in thickness; at Cottonwood Cañon it is compressed to 1,000 feet, and where seen in middle Nevada varies from 800 to 900 feet.

When examined under the microscope the individual grains of sediment can always be detected, and among the siliceous granules are crystals of carbonate of lime, a little uniformly distributed carbon, and particles of feldspar. In Ogden Cañon it is bounded at the top and bottom by thin developments of greenish-gray argillites, and about the middle of the quartzite is a thin bed of white, slightly siliceous marble. No fossils have ever been found by us in this member. It is referred to the Devonian, because directly underlying it in the top of the Pogonip limestone are Lower Helderberg fossils having marked affinities also with the Upper Helderberg, and at the base of the Wahsatch limestone, directly in contact with the upper beds of the Ogden, occur plentiful Upper Helderberg forms. It therefore occupies the interval between the two Helderberg groups, covering the rocks of the Oriskany, Cauda-Galli, and Schoharie epochs. It is hardly possible, from the physical condition of the bed wherever seen, that any considerable organic forms can ever be found, and it is doubtful whether the precise upper limit of the Upper Silurian will ever be definitely arrived at in the Great Basin.

The next member of the series, the great Wahsatch limestone, first appears in the Fortieth Parallel area in the Wahsatch. It is never seen by us east of that range. It is a single body of limestone about 7,000 feet in thickness, and holds its enormous volume with remarkable evenness wherever observed over Utah and Nevada. The passage between the Ogden quartzite and the Wahsatch limestone is very abrupt, without any considerable intercalations of quartzite and lime. The prevailing type of limestones throughout the whole series is dark and heavily bedded strata. Near the base, in western Nevada, are about 1,000 feet of gray and drab, slightly marly strata, and always about 1,000 feet from the top there is an intermixture of silica, amounting in some cases to distinct beds of sandstone or quartzite 100 feet thick. In the region of this siliceous zone, which is never more than 1,200 feet from the top of the series, are also frequent earthy impurities, argillaceous and sandy. In the little quartzite intercalation alluded to is a quite persistent sheet of conglomerate, the pebbles being made of dark jaspers. At the top of the series its passage into the great Wahsatch quartzite is extremely variable. In Weber Cañon the uppermost limestones are brick-red, and there are one or two unimportant intercalations of red sandstone with the lime beds, but the whole transition is made within 100 feet, and above that horizon stretches the enormous thickness of the Weber quartzite. On the other hand, in the Cottonwood region, more especially in the valley of Provo, on the heights of Tim-pan-o-gos Mountain, there is a full 1,000 feet of frequently repeated alternations of reddish-blue limestone and quartzites. The transition, as observed in middle Nevada, is usually abrupt like that of the Ogden region, but north of the Humboldt are seen the Tim-pan-o-gos intercalations. The lower 1,400 feet of this group are distinctly Devonian, yielding fossils of the Upper Helderberg, Chemung, and Genesee. From the Upper Helderberg were obtained —

Alveolites multiseptatus, Meek.
Cladopora prolifica, H. & W.
Acervularia pentagona, Goldf., Meek.
Smithia Hennahii Lourd., Meek.
Diphyphyllum fasciculum, Meek.
Ptychophyllum infundibulum, Meek.
Naticopsis sp. undet.
Orthoceras Kingii, Meek.

From the upper members of the Devonian, ranging from the Upper Helderberg to the Chemung inclusive, were obtained —

Favosites polymorpha, Goldf., Meek.
Syringopora Macluri? Bill.
Smithia Hennahii, Lourd., Meek.
Cyathophyllum Palmeri, Meek.
Strophodonta Canace, H. & W.
Productus subaculeatus, Murch.
Spirifera Albapinensis n. sp.
Spirifera argentaria, Meek (very closely allied to *S. zigzag*, Hall).
Spirifera Engelmanni, Meek.
Atrypa reticularis, L.
Rhynchonella Emmonsi n. sp.
Pentamerus sp.?
Cryptonella sp.? = *Rensellæria* sp.? Meek.

Paracyclas peroccidens n. sp.
Pterinea sp.?
Pleurotomaria sp. undet.
Isoneima, sp.?
Bellerophon Neleus n. sp.
Orthoceras sp.?

In a single instance, at White Pine, the Chemung is overlaid by black shales, the probable equivalent of the Genesee group, from which we collected the following:

Leiorhynchus quadricostatus, Hall = *Rhynch.* (*Leiorhynchus*) *papyraceous*, Meek.
Aviculopecten catactus, Meek.
Nuculites triangulatus n. sp.
Linulicardia fragosa = *Posidonomya fragosa*, Meek.

The Chemung and Genesee beds are immediately followed, at the height of about 1,400 feet from the base of the Wahsatch, by a considerable thickness, probably 300 or 400 feet, of dark, heavy limestones, carrying fossils which have a close resemblance to the Waverly group, but which have perhaps a closer affinity with the Devonian. The list consists of the following species:

Michelina sp.?
Streptorhynchus equivalvis, Hall.
Streptorhynchus inflatus, H. & W.
Strophomena rhomboidalis, Whal.
Chonetes Loganensis n. sp.
Productus sp.? (fragments only).
Spirifera centronata, Winch.
Spirifera Albapinensis n. sp.
Athyris Claytoni n. sp.
Athyris planosulcata? Phillips.
Rhynchonella pustulosa? White.
Terebratula Utah n. sp.
Euomphalus (*Straparollus*) *Utahensis* n. sp.

Euomphalus latus var. *laxus*, White.
Euomphalus (*Straparollus*) *Ophirensis* n. sp.
Proetus peroccidens n. sp.
Proetus Loganensis n. sp.

Directly above the Waverly, and altogether below a horizon 2,200 feet up in the series, are dark beds containing sub-Carboniferous forms, such as —

Zaphrentis excentrica, Meek.
Fenestella sp.?
Polypora sp.?
Glauconome sp.?
Orthis resupinata, Mart.?
Productus lævicostatus, White?
Productus semireticulatus, Mart.
Productus elegans, N. & P.?
Productus Flemingi var. *Burlingtonensis*, Hall.
Spirifera striata, Mart.
Spirifera setigera, Hall.
Spirifera Keokuk, Hall.
Spirifera sp.? (resembles *S. imbrex*, Hall).
Athyris subquadrata, Hall.

Sub-Carboniferous fossils are obtained in Oquirrh, Wahsatch, and White Pine ranges.

From this horizon the upper 4,500 feet of Wahsatch limestone are characterized by abundant Coal Measure fossils. In middle Nevada, at several localities, principally at the Coal Mine Cañon of River Range, in the hills south of Carlin Valley, and in the Pancake Mountains, from 500 to 800 feet down in the Wahsatch limestone, were observed one or two zones of carbonaceous material, almost anthracitic. They have been quite extensively prospected for coal, and the indications of a considerable coal flora are obtained. Stems of *Lepidodendron* and fragments of broad fronds have been collected. Up to this horizon from the bottom of the Cambrian, excepting the conglomerate beds, there are no indications whatever of shallow water, or of those frequent oscillations of level which mark the corresponding horizons in the Appalachian Palæozoic.*

The following Coal Measure forms were obtained from the Wahsatch limestone:

Syringopora multattenuata, McChes.	3 ?
Lithostrotion Whitneyi, Meek	3 ?
Lophophyllum proliferum, McChes.	1
Zaphrentis Stansburyi, Hall	4
Zaphrentis excentrica, Meek	1
Zaphrentis sp. ? (resembles *Z. centralis*, Ed. & Haime)	3
Cyathophyllum (*Campophyllum*) *Nevadensis*, Meek	1
Archiocidaris n. sp.	1
Streptorhynchus robustus, Hall	1
Streptorhynchus crenistrius, Ph.	2
Streptorhynchus crassus, Meek	1
Chonetes granulifera, Owen	4
Productus cora, D'Orb.	1
Productus Nebrascensis, Meek	2
Productus pertenuis ? Meek	1 ?
Productus punctatus, Mart.	2
Productus prattenianus, Norw.	4
Productus symmetricus, McChes.	4 ?
Productus semireticulatus, Mart.	6
Spirifera Rockymontana, Marc. = *S. opimus*, H	13

* The figure placed to the right in the Carboniferous lists indicates the number of localities at which the species is found, where the position of the bed has been positively recognized. The interrogation-point following a number implies that the identification in one or more of these localities is questioned.

It will be noticed that the species peculiar to the particular beds (that is, found in only one of them) occur in but few localities, generally only in one, and when found in two or more the localities have been contiguous, indicating that the species have not a wide geographical range within the territory collected from. On the other hand, the species common to both beds occur in several localities, showing a more extended range or a more general distribution within the territories. This would reduce the stratigraphical value of the species peculiar to each bed in proportion to the number of localities from which they have been obtained.

Spirifera camerata, Mort.	2
Martinia lineata, Mart.	4
Spiriferina Kentuckensis, Shum.	1
Athyris subtilita, Hall	5
Rhynchonella Osagensis	1
Terebratula bovidens, Mort.	2
Cardiomorpha Missouriensis, Swallow	1
Naticopsis sp.?	1
Goniatites Kingii	1
Cyrtoceras? cessator	1

Above the Wahsatch limestone is the equally great Weber quartzite, a body of indurated sandstones and quartzites, carrying occasional sheets of conglomerate, and interposed between the two bodies of Coal Measure limestone. In the Wahsatch it attains a thickness of about 6,000 feet, in the Oquirrh 8,000, and in middle Nevada probably considerably greater thickness. If we are right in assigning the great sandstone series of the Uinta to this member, it would have there its maximum development, reaching, according to our observations, 12,000 feet, or 14,000, as displayed in the cañon section observed by Powell.

In the Uinta body are numerous intercalations of groups of shale, consisting of seven or eight members separated by sandstone strata. Some of these shale and clay beds, notably one at Gilbert's Peak, reach a thickness of 100 feet. Taken as a whole, a variety of chemical studies of the Weber quartzite would indicate that it had an average of 70 or 75 per cent. of silica, the remainder being made up of alumina, lime, and alkalies. Like the great Cambrian series, it is a compressed body of what was originally arkose sediment. In the intercalated clays and in some of the quartzites are slight developments of muscovite. Conglomerates are not uncommon. Toward the summit of the series, and always in the easterly exposures, the included pebbles are rounded, but over a considerable part of Nevada, where the series approaches the western limits of the Palæozoic area, there is, toward the middle of the group, an enormous development of conglomerate, made up partly of rounded pebbles and prominently of sharp, angular fragments of jasper or chert, and occasionally of crystalline schists, held together by a saccharoidal matrix of quartz and feldspar grains intermingled with carbonate of lime. When comparing the thicker body of the Uinta with those of Utah and Nevada, it will be seen that the beds are in a much less compressed condition. In the Uinta, especially throughout the easterly part of the uplift, the series is made up of what would be called indurated sandstone. Toward the west end of the range, especially in the low horizons, the sandstones are compressed into quartzite, while over the greater part of Utah and Nevada the group is consolidated into a dark quartzitic type of rock.

The next conformable member of the series is the Upper Coal Measure limestone, a body about 2,000 feet in thickness, which, over all of the Great Basin country, is prevailingly made up of lime beds of light-gray or drab, mingled with dark-gray and dark-blue beds. In general it is thinly stratified, frequently subject to local impurities, and from bottom to top well charged with fossils of the Coal Measure group. In the region of the Uinta it has about the same thickness, but between it and the Great Basin development there is a wide physical difference. In the Uinta the base of the series is composed of the dark-gray limestones, and the middle and upper portion for not less than 1,200 feet is made up of remarkably variable intercalations of calciferous sand rock and thin shaly and limy beds, the whole capped by a development of cherty limestone from 100 to 150 feet thick, characterized by an abundant presence of the genus *Bellerophon*, from which it was called by Powell the Bellerophon limestone. Between the Weber quartzite and the Upper Coal Measure limestones over the Great Basin and in the Wahsatch there can be no question of an absolute conformity. In the region of the Uinta, between Professor Powell and ourselves there is a difference of opinion as to this relation. Powell holds that, although they are conformable in angle, he has discovered a nonconformity of erosion, meaning by that that the surface of the sandstone series had been eroded into hills and bluffs, over which, with no difference of angle, the limestone beds were deposited. Having frequently examined the Uinta throughout its whole length, we are of opinion that this nonconformity is illusory, and that the apparent discrepancies can be accounted for by the effects of perspective in observing outcrops, and by the wonderful series of faults which accompany the Uinta uplift, often bringing the upper limestones down into contact with quartzites far below the top of the latter series.

Of the limestone body which forms the chief Palæozoic development in the Rocky Mountain region, fully six tenths are charged with Coal Measure fossils. This thousand-foot limestone has only yielded one fossil outside of the range of the Coal Measure species, and that was a Waverly form obtained in the Black Hills near the base of the series. It is therefore probable that the Weber sandstone is entirely wanting in the Rocky Mountain region, or is represented only by the siliceous impurities which have been noted near the middle of the limestone. It is further certain that the greater part of the lime body belongs to the Coal Measures, and that the single Waverly species indicates a horizon corresponding to the lower part of the great Wahsatch group. The Minnelusa sandstone of Winchell, which has not been re-observed by Newton in his more extended study of the Black Hills, seemed to occupy the position of the Weber, but it does not appear in later accounts of the geology of the Black Hills. With the Upper Coal Measure limestones the Palæozoic of the Great Basin comes to a close.

The following list of fossils gives the species collected from the Upper Coal Measure limestones above the Weber quartzite:

Fusilina cylindrica, Fischer	1
Fusilina n. sp. (very large)	1
Fusilina sp.? (minute)	1
Syringopora multattenuata, McChes.	1
Lithostrotion Whitneyi, Meek	1
Zaphrentis Stansburyi, Hall	1
Orthis carbonaria, Swallow	3
Streptorhynchus robusta, H	1?
Streptorhynchus crassus, Meek & W.	4
Meekella striata-costata, Swallow	1
Chonetes granulifera, Owen	1
Productus longispinus, Sow.	1
Productus multistriatus, Meek	2

Productus Nebrascensis, M.	2
Productus prattenianus, Nor.	3
Productus punctatus, Mart.	2
Productus punctatus var. *Rogersi*, N. & P.	2
Productus semireticulatus, Mart.	5
Productus symmetricus, McChes.	1
Spirifera camerata, Mort.	7
Spirifera octoplicata, Hall	1?
Spirifera Rockymontana, Marc., sp. *opimus*, H.	3
Spirifera sp.? (resembles sp. *Forbesi*, H.)	2
Spiriferina Kentuckensis, Shum.	1
Spiriferina pulchra, Meek	4
Martinia lineata, Mart.	3
Eumetria punctulifera, Shum.	1
Athyris subtilita, Hall	7
Athyris Roissyi?	1
Rhynchonella Utah, Marc.	1
Nucula parva, McChes.	1
Nucula sp.?	1
Nuculana bellistriata, Stevens	1
Sedgwickia? concava, Meek?	1
Pleurophorus oblongus, Meek	1
Schizodus curtus, Meek	1
Naiadites sp.?	1
Bellerophon carbonaria, Cox? (broad bands)	2
Bellerophon sp.? (smooth sp.)	2
Orthoceras crebrosum, Geinitz	1

The following is a list of species recognized in the upper beds, but not found below the Weber quartzite:

Fusilina cylindrica, Fischer	1
Fusilina sp. new	1
Fusilina sp.?	1
Orthis carbonaria, Swallow	3

Meekella striata-costata, Swallow	1
Productus sub-horridus, Meek	7
Productus punctatus var. *Rogersi*, N. & P.	2
Productus longispinus, Sow.	1
Spirifera, resembling sp. *Forbesi*, H. (a Lower Carboniferous species)	2
Spirifera octoplicatus, Hall ? (identification doubtful)	1 ?
Spiriferina pulchra, Meek	4
Eumetria punctulifera, Shum.	1
Athyris Roissyi ? (fragments only)	1
Rhynchonella Utah, Marc	1
Nucula parva, McChes.	1
Nucula sp. ?	1
Nuculana bellistriata, Stevens	1
Sedgwickia ? concava, Meek ?	1
Schizodus curtus, Meek	1
Naiadites sp. ?	1
Bellerophon carbonarius, Cox	2
Bellerophon sp. ?	2
Orthoceras crebrosum, Geinitz	1

The Wahsatch limestone yields the following species, not recognized in the Upper Coal Measures:

Zaphrentis excentrica, Meek	1
Zaphrentis sp. ? (resembles *Z. centralis*, Ed. & Haime)	3
Lophophyllum proliferum, McChes.	1
Cyathophyllum (*Campophyllum*) *Nevadensis*, Meek	1
Archiocidaris n. sp.	1
Streptorhynchus crenistria, Phil.	2
Productus cora, D'Orb	1
Productus pertenuis, Meek	1 ?
Rhynchonella Osagensis, Swallow	1
Terebratula bovidens, Morton	2
Cardiomorpha Missouriensis, Swallow	1
Naticopsis sp. ?	1

Goniatites Kingii	1
Cyrtoceras? cessator	1

The following forms are common to both limestones:

	Lower.	Upper.
Syringopora multattenuata, McChes.	3?	1
Zaphrentis Stansburyi, Hall	4	1
Lithostrotion Whitneyi? Meek	3?	1?
Streptorhynchus robustus, Hall	1	1?
Streptorhynchus crassus, Meek	1	4
Chonetes granulifera, Owen	4	1?
Productus Nebrascensis, Meek	2	2
Productus punctatus, Mart.	2	2
Productus prattenianus, Norwood	4	3
Productus semireticulatus, M.	6	5
Productus symmetricus, McChes.	4?	1
Spirifera camerata, Morton	2	7
Spirifera Rockymontana, Marcou	13	3
Martinia lineata, Mart.	4	3
Spiriferina Kentuckensis, Shum.	1	1
Athyris subtilita, Hall	5	7

In the Wahsatch, in the Uinta, and at the little Rawlings Peak exposure was observed a series of argillaceous and calcareous shales with muddy marls overlying the Upper Coal Measure limestones, the whole reaching about 650 feet in thickness, and carrying from summit to base the following characteristic Permo-Carboniferous fossils:

Aviculopecten curtocardinalis n. sp.
Aviculopecten McCoyi, Meek.
Aviculopecten sp.? Meek (Pal. Up. Mo., plate II., fig. 10).
Aviculopecten occidaneus, Meek.
Aviculopecten parvulus n. sp.
Aviculopecten, sp.? resembling *Pecten Clevelandicus*, Swallow.
Aviculopecten Weberensis n. sp.

Eumicrotis Hawni, M. & H.
Eumicrotis sp. undet.
Myalina permiana, Meek.
Myacites Weberensis, Meek.
Myacites aviculoides, Meek.
Myacites inconspicuus, Meek.
Schizodus sp. = *S. ovata*, Meek.

In the region of the Uinta and at Rawlings Peak the shales are compressed to a thickness of about 300 feet, but in the section of Weber Cañon, where most of the fossils were obtained, the full 650 feet is observed. At the Uinta and at Rawlings there is no appreciable nonconformity between the Permian and the Coal Measure rocks; but at the Wahsatch, as already described, there seems to be a slight discrepancy. It is curious to note the difference in the character of the uppermost sediments of the Upper Coal Measures in the Wahsatch and elsewhere. As seen everywhere else, the horizons immediately under the Bellerophon limestone are all intercalations of sand and lime, but in the Wahsatch they are fine argillaceous shales, characterized by wonderfully fine ripple-marks.

The Permian is a shallow-water, ripple-marked, argillaceous deposit, appearing east of the Wahsatch.

In the whole Palæozoic section there are 18,000 feet of siliceous sediment, 13,000 of limestone, and about 1,400 of slates and shales. The general absence throughout the Coal Measure horizons of beds of coal, and the equally conspicuous absence of shallow-water deposits, indicate that the whole great Palæozoic series was from the first received on the bed of a deep ocean. The sole evidences of littoral or shallow-water depositions are in the occasional sheets of conglomerate which are seen in the siliceous members and in the slight development of coaly matter near the top of the Wahsatch limestone in middle Nevada. When it is remembered that the configuration of the ocean bottom was accidented by enormous Archæan ranges whose peaks towered up to the level of and above the highest Palæozoic deposition, it will be seen that the conglomerate beds might easily be formed from the local degradation of the island masses themselves. Doubtless these mountain slopes contributed largely to the fragmentary materials of the Palæozoic series; but, on the other hand, there are greater arguments for supposing that the vast bulk of the detrital sediment entered the ocean from the west.

Considered as a whole, the Palæozoic series thickens to its western limit on longitude 17° 30′. West of that meridian there is a sudden, remarkable change in the whole geology. No more Palæozoic rocks are observed in Nevada, and in California only inconsiderable deposits of Carboniferous. Over the whole basin of Nevada the oldest post-Archæan rock is the Trias, which lies directly upon the old Archæan mountain slopes, without any interposition of Palæozoic beds. It is immediately evident that the Palæozoic never extended over that region; in other words, that western Nevada formed during Palæozoic time a continental mass which bounded the ocean in that direction, and whose continued degradation furnished the greater part of the sediment that was spread out on the sea-bottom. When viewed from our latitude to the south, from the observations of other western explorers, it is evident that the Palæozoic series as a whole greatly diminishes in that direction. Northward, in Montana, the observed thicknesses are quite inconsiderable as compared with those of the region of the Fortieth Parallel. The rocks of the Salmon River Mountains and Blue Mountains of Oregon and Idaho have not been sufficiently studied to indicate definitely whether the Palæozoic series also thins in that direction; but from the scanty data now known it would seem that the area of this Exploration has opened up what was the region of deepest ocean and most extensive sedimentation.

On the next page is a tabular statement of the Palæozoic strata in Utah and Nevada.

PALÆOZOIC SUBDIVISIONS.

WAHSATCH AND MIDDLE NEVADA.

WAHSATCH SECTION, 32,000 feet conformable.

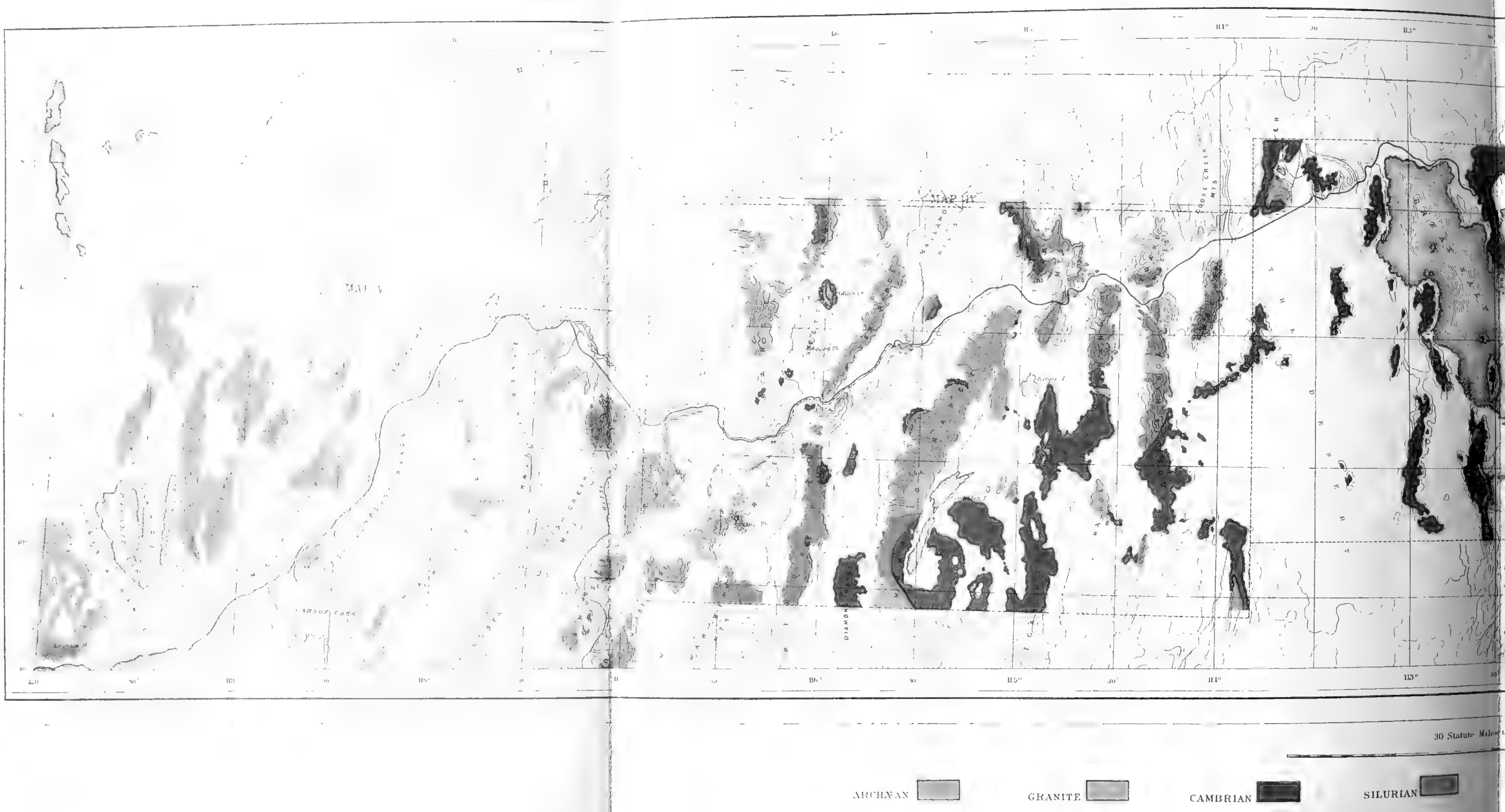
CARBONIFEROUS, 15,000 feet.	*Permian, 650 feet.*	Clays and marls and limestones, shallow.
	Upper Coal Measure Limestone, 2,000 feet.	Blue and drab limestones passing into sandstones.
	Weber Quartzite, 6,000 feet.	Compact sandstone and quartzite, often reddish, intercalations of lime, argillites, and conglomerate.
	Wahsatch Limestone, 7,000 feet.	Heavy-bedded blue and gray limestone, with siliceous admixture, especially near the top.
WAVERLY		
DEVONIAN, 2,400 feet.	*Ogden Quartzite, 1,000 ft.*	Pure quartzite, with conglomerate.
SILURIAN, 1,000 ft.	*Ute Limestone, 1,000 ft.*	Compact or shaly siliceous limestone.
CAMBRIAN, 12,000 feet. +	*Cambrian Siliceous Schists, 11,000 feet.*	
	Cambrian Slates, 800 ft. +	

MIDDLE NEVADA SECTION, conformable.

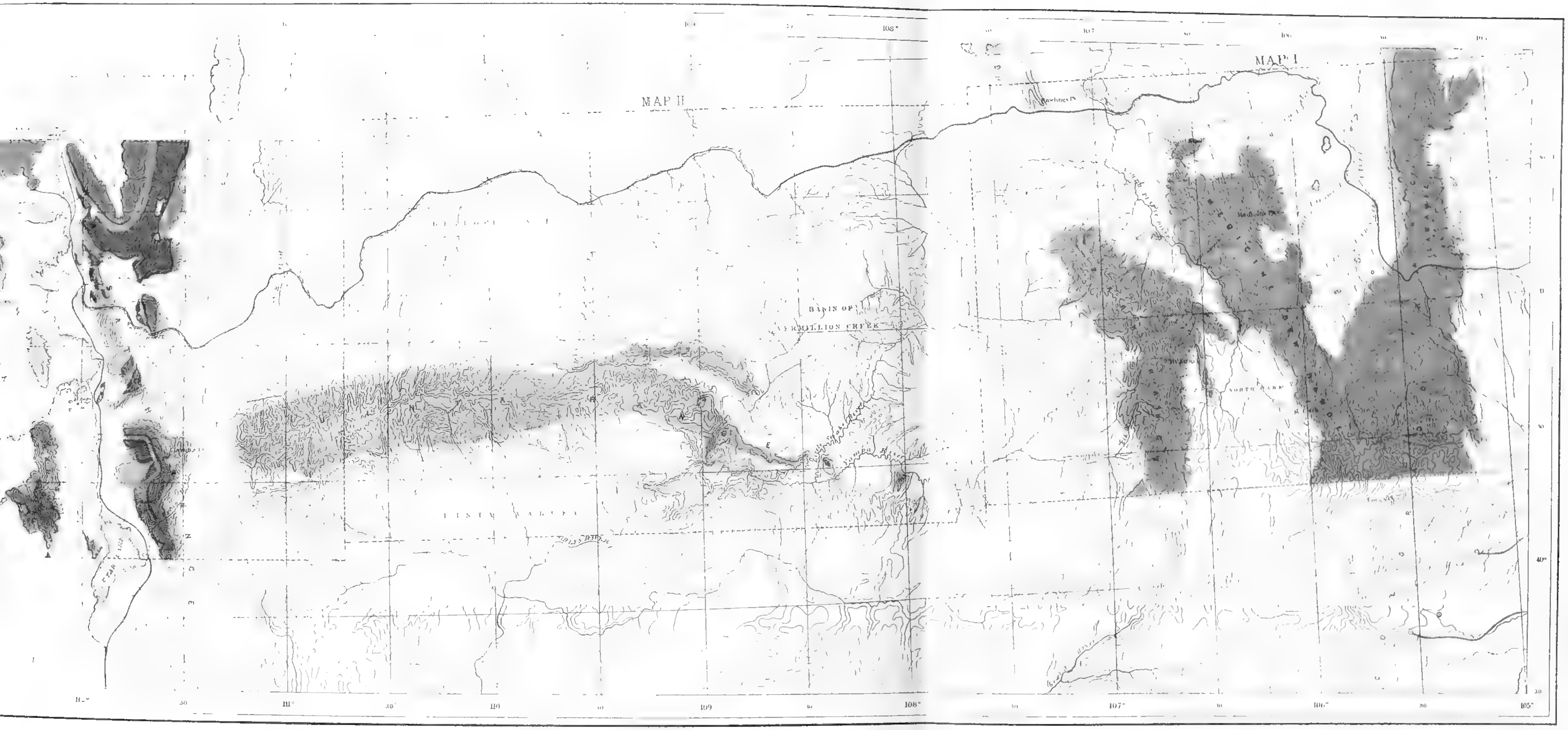
CARBONIFEROUS, 15,000 feet.	*Upper Coal Measure Limestone, 2,000 feet.*	Heavy blue and gray limestones.
	Weber Quartzite, 6,000 feet. +(?)	Quartzite, with, near the middle, angular conglomerates.
	Wahsatch Limestone, 7,000 feet.	Varied gray and blue limestone, often heavily bedded, drab in the Devonian horizon.
WAVERLY.		
DEVONIAN, 2,000 feet.	*Ogden Quartzite, 1,000 ft.*	Pure and fine-grained.
SILURIAN, 2,000 feet.	*Pogonip Limestone, 4,000 feet.*	Saccharoidal blue and gray siliceous, sometimes shaly limestone.
CAMBRIAN.	*Cambrian Quartzite. +*	Compact quartzite.

ANALYTICAL GEOLOGICAL MAP OF THE AREA OF

ARCHÆAN, GRANITIC AND



PALÆOZOIC EXPOSURES



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CARBONIFEROUS

DEVONIAN	WAVERLY / SUB-CARBONIFEROUS / LOWER COAL MEASURES	WEBER QUARTZITE	UPPER COAL MEASURES / PERMO CARBONIFEROUS

SURES

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111

CHAPTER IV.

MESOZOIC.

SECTION I.

TRIASSIC.

ROCKY MOUNTAINS.—Directly overlying the Palæozoic limestones, in conformable superposition, and not infrequently overlapping the Palæozoic and coming directly into nonconformable contact with the Archæan, appear the well known Rocky Mountain Red-beds, which from their position between the Coal Measures below and the well recognized Jurassic beds above, have been generally assigned to the Triassic age. Reserving all discussion of the validity of this assignment to later pages of this chapter, it is proposed here to give simply a brief statement of their physical condition and continuity along the flanks of Colorado Range within the field of this Exploration. From the lower limit of the map, nearly up to the 41st parallel, the Red-beds lie directly upon the Archæan, and form, with their soft, friable strata, a remarkable contrast with the adjoining crystalline rocks, the Red series varying in thickness from 300 to 850 feet.

It is interesting to observe that where they are in direct contact with the Archæan rocks, they have a dip rarely exceeding 15° and often retaining an approximation to the horizontal; while to the north, where erosion has been deep enough to reach and uncover the Palæozoic series, the dip increases to the vertical, with exceptional instances of slightly reversed position. The region of contact between the Trias and the Archæan affords an interesting display of the mode of deposition of the coarse, friable gravel and sandy material of the Trias upon the hard irregularities of the crystalline series.

The beds along the southern limit of the map, bordering the Big Thompson and the Cache-la-Poudre, attain a thickness of 800 to 850 feet, thinning thence northward and reaching a minimum in the region of Horse and Lodge-Pole creeks, where they scarcely attain 300, but thickening again in the region of Chugwater and Bush creeks to nearly 700 feet.

On the western borders of the range, the conditions thus sketched are repeated. North of the Union Pacific Railroad, the soft, easily eroded beds of the Trias, varying from 400 to 800 feet in thickness, rest directly upon the uppermost limestones of the Coal Measures. South of the railroad the Trias overlaps, and, as on the eastern side of the range, comes in contact with the Archæan. Here, within the great bend of the Laramie, is a broad triangular region, fifteen miles on a side, in which the Trias possesses only a very gentle dip from the Archæan, in many places resting truly horizontal. The dip upon the western side of the range is always gentle, from 4° to 10°. South of Red Lake there is an exposure of at least 700 feet, while directly west of Laramie City there cannot be more than 400 feet. At the Chugwater there is about 600 feet, with very heavy red sandstones at the bottom, interrupted by occasional fine conglomerates, these overlaid by finer red sandstones with interstratified beds of red clay; these, again, by red shales, overlaid by compact, arenaceous limestone strata, three or four feet thick, followed by fine red sandstones of rather thick bedding, and a second seam of bluish-white cherty limestone from six to ten feet thick, the whole capped by heavy, reddish-yellow sandstones. At Box Elder Creek, where the section is about 650 feet in thickness, are displayed, counting from the base upward—

		Feet.
1.	Coarse red sandstones with conglomerates, equivalent to the lower members on the Chugwater	100
2.	Massive sandstones	300
3.	Yellowish-red sandstones, with variable bedding and texture	100
4.	Laminated red shales, with some red clay	150
5.	Thin bed of blue limestone	
6.	Fine-grained, earthy, crumbling sandstone, pink and red, with layers of gypsum	
7.	Reddish-yellow sandstone	

In the region of the Big Thompson, where the greatest thickness on the flanks of Colorado Range is exposed, the series consists of heavy beds of coarse and friable pink and brick-red arenaceous material, partly interrupted by conglomerates, partly so coarsely gritty as to conceal the trace of bedding, and partly again thickly accumulated strata of brick-red sandstone, the middle region interrupted by red shales and clays, the whole closed by a series of pinkish, pinkish-gray, and yellowish-gray sandstones, the upper members containing several beds of pink and white gypsum and blue limestone.

Taken as a whole, and with the exception of the gypsum and limestone beds, which nowhere within our field of observation exceed forty feet in thickness, it is essentially a sandstone series, for both clays and shales are exceedingly arenaceous, and the dominant color is a brick-red for the lower half of the series, and variable lighter reds, pinks, and yellowish reds for the upper half. While this division of color holds good in general, it is often varied by extremely brick-red, almost vermilion-colored beds appearing near the top, and light ones intercalated in the region of the heavy red lower strata. The position of the narrow blue limestone beds, as well as that of the gypsums, varies through the upper half of the series. Next to the red color, the most noticeable feature is a remarkably sharp, persistent cross-bedding, developing very fine flow-and-plunge structure with the most remarkable arrow-head sections, which is observed in the upper horizons, where the bedding appears heavy; but never, so far as we have observed, among those beds which come into immediate contact with the Archæan. Zones of conglomerate in general are either confined to the lower members of the series or else to the near neighborhood of the Archæan. The pebbles are rarely very large in this material, and are almost all siliceous. Besides the several well defined limestone beds, a few of the horizons of the upper and impure sandstones appear highly calcareous; rocks which in hand specimens would never be supposed to contain lime, giving a brisk effervescence when treated with dilute acid.

A typical specimen of the red sandstone taken from the upper members of the Trias, near the entrance to Big Thompson Cañon, is a fine-grained, friable rock, deep-red, with a laminated, almost shaly structure. It was subjected to chemical analysis, the results of which will be found in the table of analyses of sedimentary rocks. The analysis shows, besides the siliceous and ferruginous material of the normal sandstones, the presence of an unexpected amount of soluble carbonate, including some dolomite, with an inconsiderable mixture of arenaceous material. It is noteworthy that no sulphates are detected, although the formation immediately in the neighborhood bears beds of quite pure gypsum. Below these shaly beds occur deep-red strata, having a coarser grain and no traces of the lamination characteristic of the last-named specimen, which upon being treated with acids gave no indication of the soluble carbonates.

Laminated red shales, from a horizon near the top of the Trias on Horse Creek, and interstratified between coarse sandstones, were found on examination to contain an amount of calcareous matter equivalent to that of the Big Thompson, together with a similar amount of dolomite. The narrow beds of limestone already noted occur sharply defined from the enclosing siliceous material. Under the microscope they of course do show a considerable percentage of angular quartz grains, but they are almost wholly of dolomitic limestone. In the region of the Chugwater they occupy a horizon very near the top of the Trias, the lower bed consisting of a somewhat cherty material, and the upper of a characteristic bluish-white, siliceous dolomitic limestone. These limestone beds, although outcropping at intervals all the way from the Big Thompson to the Chugwater, do not seem to possess any considerable continuity, but occur at or about the same horizon at irregular intervals. The indications are that there were cessations of deposition of the siliceous material, and that the calcareous deposits were not in continuous sheets, but were gathered by the oceanic currents into limited areas, which in turn were buried by the succeeding sand-strata.

Gypsum deposits characteristic of the red Triassic beds occur chiefly, if not altogether, in the upper half of the series, their irregular, lenticular masses occurring, as do the limestones, at intervals. The gypsum beds vary from two to twenty-five feet in thickness, the heavier masses occurring with a broad bedding, and thinning out from a point of maximum thickness in every direction. The sulphate occurs both massive-granular and highly crystalline, varying in color from a pure, dazzling white to a pinkish shade, according to the amount of ferruginous impurities. In general it appears as a streak of creamy whiteness in the bright red sand-strata, streaked and stained into a variety of pale pinkish and yellowish-pink shades. From the interesting locality at Red Valley, near the northern end of Laramie Hills, a specimen of gypsum gives nearly the characteristic formula, the analysis yielding —

Sulphate of lime	78.11
Water	21.21
Total	99.32

The Red-beds of Colorado Range have thus far yielded to our search no organic remains, saving obscure pieces of half-petrified, half-carbonized wood, which crumbles on exposure to the air, and displays no characteristic structure. The following are some of the more noticeable localities along the eastern base:

Wherever along the eastern base of Colorado Range the strata of the inclined sedimentary series extend for any considerable distance westward toward the heart of the range, they are found to occupy an approximately horizontal position, showing that the rapid change of dip occurs very close to the eastern belt of foot-hill beds. An example of this rule is the recurve around the head of the Chugwater; but at the head of Bush Creek the upper valley, above the region of the Pliocene conglomerates, is occupied by a shallow basin of Trias, which rests, almost horizontally, directly upon the granite. The valley surface is entirely made up of the gypsiferous upper portion of the Trias, a large part of the basin being covered with irregular outcrops of gypsum. The strongest bed observed is about fifteen feet thick, of clear, pure-white sulphate, only stained by the contact with ferruginous enclosing rocks.

Around the Chugwater promontory outcrops a Trias curve, standing at very high angles, with a rapidly varying dip. The beds slope from 61° to 55° on the north-and-south lines, and only 25° where they reach an east-and-west trend.

In the region of Lodge-Pole and Horse creeks, where the beds stand at an extremely high angle, they are more compact, fine-grained, often shaly, with a great appearance of argillaceous material, the colors being deep red and reddish yellow. As with the underlying beds and the overlying Cretaceous in this region of high dip, the whole series is actually thinner than where its inclination-angle is much lower, and this can hardly be due to a local thinning of all the conformable series. It is rather referable to the shrinkage due to unusual disturbance and compression.

Whoever has examined the slightly compacted modern sea-sands made up of the débris of marine Pliocene, especially when placed under the microscope at a low power, cannot fail to remember the large amount of interstitial space between the particles of quartz, sand, and sea-shell. It is evident from such observations that rough sandstones can lose fully forty per cent. of their volume without any compression of the quartzy material. In the more compacted sandstones the interstitial space is either entirely made up of infiltrated argillaceous and ferruginous matter, or obliterated by pressure. In the case of the older quartzites, the Cambrian particularly, the outline of the original granular quartz may often be traced, flattened to a long, lenticular form. In the case of the Archæan quartzites, the figure of the original particle is altogether lost, and the entire mass shows a confused cryptocrystalline structure. It is not strange, then, that a series of beds exposed along a line of 100 miles, as is the Trias east of Granite Ridge, should suffer very great variations of thickness: first, from an irregular depth of original deposit; secondly, from the factor of compression. It is assumed to be a rule that in all cases of extremely high dip the volume of each member of the sedimentary series is distinctly less than in cases of low dip; and the physical condition of the rock is itself an evidence of this compression. Accordingly, when the gently dipping Trias sandstones of the Big Thompson region are compared with those near the head of Horse Creek, the dip, thickness, and actual petrological compactness are found to vary correspondingly.

South of Box Elder Cañon occurs another instance of a westward-extending overlap of Trias resting directly in a depression of the Archæan in a nearly horizontal position, only dipping from 2° to 4° to the southeast. In direct contact with the granite is a considerable bed of reddish-gray conglomerate, overlaid by massively bedded red sandstones. This bed was nowhere recognized to the north, where it is possible that the Carboniferous always lay between it and the Archæan, and the occurrence here is due to the immediate neighborhood of the Archæan mass.

From the Cache-la-Poudre to the southern edge of our map the formation rapidly thickens and becomes correspondingly looser in texture. The series is defined in outcrop at the upper limit by the persistent, trough-like depression which separates the red Trias from the hard Dakota sandstone.

On the Big Thompson the upper part of the Trias is characterized by the presence of several thin sheets of limestone, and in general the transition into the Jura is marked by a calcareous passage-member, mixed with varying sheets of sand, the whole having a thickness of about fifty feet. In this region the gypsum bed is about twenty-five feet thick, of nearly pure white crystalline-granular sulphate, interbedded with dark-red sandstones.

The extremely gentle dip of the sedimentary formations on the western flank of the Archæan mass of the range, renders the final surface, when beveled off by a uniform erosion, remarkably free from bold outcrops, so that the junction between the underlying grayish-blue limestones of the Upper Carboniferous and the Trias is often only discoverable by the change in the color of the earthy deposit which masks the more solid edges of the beds. Here and there at intervals are the limited escarpments of the red sandstone beds, with their bluff faces toward the range. At Red Buttes, near the Pacific Railroad, are the best exposures of the sandstone to be seen on the western slope. For some distance to the east and north of the railway station the sandstones, marls, and clays have been eroded by the local streams, showing cliffs and buttes which reach 100 feet of vertical exposure. The basal sandstones of the series rest directly upon the bluish and yellow Carboniferous limestones. These lowest Triassic beds are here rather pale reddish-yellow, and are characterized by the development of concentric red spots. They are formed of distinctly visible grains of quartz, held together by a calcareous and marly cement. There are several zones of pebbles, and the whole series is prevailingly and characteristically red, up to the very base of the Jurassic.

South of the railroad the Triassic beds still maintain their gentle dip, and in the region of the track overlap the Carboniferous and pass into direct contact with the Archæan. It is a noticeable fact that the Laramie Hills, or northern part of the range, are separated from the more elevated portion to the south by a depression marked by the northern waters of Cache-la-Poudre Creek, the pass extending across the whole range in a northwest-and-southeast direction. This continuous depression terminates on the western side exactly where the Trias overlaps the Carboniferous, while the eastern end of the depression comes at the head of Box Elder Creek, where also the Trias overlaps the Carboniferous and in a similar manner comes in contact with the Archæan. This, to my mind, would suggest a pre-Cambrian displacement here which has depressed the whole northern part of the range, the depression making itself chiefly felt along the eastern base of the northern half.

South of the railroad, on the western side, the contact of the Trias with the Archæan is rather interesting. It is seen gradually to overlap the gentle inclinations in thin beds, and to abut squarely against the steeper slopes of the Archæan. In general, it dips gently away from the Archæan, the Trias ridges being defined by the harder beds which have protected from erosion the softer and more shaly portions below; and wherever there are lines of erosion parallel to the contact-line with the Archæan, the steeper or more escarped faces are turned toward the range.

Gypsum deposits are well shown north of the Willow Creek and North Park road, where they occur through a thickness of at least 80 or 100 feet, and are interstratified with dark, intensely red sandstones.

South of the road are some remarkably eroded forms suggestive of ruined cities.

West of Antelope Creek the Trias extends twelve miles to the south of the Wyoming and Colorado boundary, filling a bay-like depression in the Archæan body. Here are exposed, along the eastern side of Laramie Valley, 1,200 feet of beds having a very slight dip to the north and west, a high, abrupt wall of nearly 1,000 feet presented toward the plains. Upon the front of this escarped precipice may be seen the interstratified marls and limestones of the Jura, overlying the heavier red gypsiferous beds of the Trias. In contact with the Archæan body, the sandstones are of coarse ash-colored materials containing angular fragments and rounded pebbles, with more or less calcareous matter in the cement, followed by a hard, thin, cherty limestone, which passes up into reddish-gray sandstone, and above this the usual beds of coarse red sand, with numerous red clay beds, varyingly shaly, which give a prevailing argillaceous character to a wide zone of the sandstones. Within this red argillaceous series are thin beds of pure clay and white gypsum, the latter varying from two or three inches up to several feet, with one solid body of twenty-two feet enclosed between two series of intensely red, dark, indurated sand-rock. Above this gypsiferous zone occur heavy red sandstones, which pass through yellowish friable beds with marly intercalations into the calcareous beds of the conformable Jura.

The following section illustrates the chief features of the Triassic series, as displayed here, beginning at the summit:

	Feet.
1. Yellowish-red sandstone, passing down into fine, deep-red, evenly bedded, strongly coherent sandstone	375 to 400
2. Argillaceous shales and argillaceous sands, with interstratified layers of fine, pure clay, the whole prevailingly red, with grayish and yellowish-red zones carrying four or five beds of gypsum, one reaching twenty-two feet in thickness; in all	150
3. Red compact sandstones, beds of varying thickness, some coarser and some finer	250
4. Reddish-gray sandstones carrying a bed of cherty limestone four or five feet thick; the whole	175

	Feet.
5. Coarse, friable, ash-colored sandstones of remarkably loose texture, matrix containing more or less calcareous matter, with sheets of pebbles, partly rounded and partly angular cherty masses, together with some fragments of Archæan schists, both hornblendic and granitoid	150 to 200

The Triassic beds are characteristically developed in North Park, especially on the western base of Medicine Bow Range from near the head of Retreat Creek south for sixteen or eighteen miles. The exposure from the base, where they rest unconformably against the Archæan, up to the marls and limestones of the Jurassic, is nearly 1,000 feet. At the base are some light-colored sandstones, carrying pebbles, which are usually small, well rounded, and of a siliceous nature, the cement being extremely fine ferruginous sand, which breaks with a rough fracture, allowing the pebbles to drop out at a blow from the hammer. A similar exposure is seen on the western side of the Park, where again it rests unconformably upon the Archæan. There is only one point in the Park, and that near the head of the eastern of the three forks of the Platte, where are interposed any Palæozoic beds between the Trias and the Archæan. At that point, for a distance of not more than two miles, the conformable underlying Carboniferous limestones are interposed. From the thickness of the overlying Cretaceous which is exposed in this Park it is evident that the basin was very deep, and it is not at all improbable that it is underlaid throughout by the whole series of Palæozoic rocks which are displayed in Colorado Range.

At Elk Mountain and Cherokee Butte the belt of conformable strata wrapped around the Archæan mass contains the Trias, which here presents very generally the characteristics seen on the eastern base of Laramie Hills. The series is distinctly defined here by the Carboniferous limestones below and the soft, Jurassic shales above. At Cherokee Butte, a little to the south of the trail, the Trias is the uppermost member of the inclined series, and passes directly under the North Park Tertiaries which obscure the Jura. There are about 800 feet in all.

The western slope of the Rawlings quaquaversal uplift is marked by concentric monoclinal ridges. The Trias here shows a thickness of about

700 feet, and at the base is formed of pinkish sandstones of rather fine texture and thinly bedded, the upper portion having more of a massive habit and being a deep Indian red. About half-way up in the series is a bed, only about a foot thick, of greenish-drab lithographic limestone, enclosed in soft clays of variable purple and red. This bed is of interest here, since it recurs with great persistence along the flanks of the Uinta Mountains. The base member of the series is here noticeable for extremely thin jointing-planes.

Along the western base of Park Range the Cretaceous is usually the lowest rock exposed, overlapping the rest of the conformable series and coming directly in contact with the Archæan; but east of Hantz Peak, in a shallow recess of the Archæan, and in contact with it, is a limited outcrop of red sandstones which have been referred to the Trias, although without any positive evidence. Farther south, near the southern limit of the map, where Moore's Fork enters the Quaternary valley which lies between the Archæan and the ridge of Dakota sandstone to the west, at the base of the Dakota, are seen the shales and marly limestones of the Jura, underlaid by a long, narrow outcrop of the upper beds of the Trias, which, however, affords no indication of the thickness or general characteristics of the series.

Uinta Range.—The Trias outcrops of Uinta Range consist of the edge of the upturned series displayed at four or five points at the northern base of the range, and a much broader and more intricate and extensive exposure on the south side, particularly in the eastern half of the range in the region of complicated secondary folds connected with Yampa Plateau.

As displayed upon the northern margin of the range, its most eastern development is shown in the region of Vermilion Creek. The section of Triassic beds here laid bare, begins at the top of the series of shales which we have referred to the Permo-Carboniferous, the base portion consisting of red conglomerate-bearing sandstones which carry a seam of drab limestone. Above these is a body of red sandstones of several hundred feet; then beds of massive buff sandstone varying from 600 to 1,000 feet, and corresponding to the cross-bedded sandstones of Flaming Gorge. Above these are fine white and red sandstones, with some intercalations of clay and shaly materials, this member equalling about 100 feet, making a total thickness of Trias of about 2,000 feet. It will be seen that in passing westward from the region of North Park, the Trias has at this point doubled in thickness; moreover, that the prevailing color is no longer a pure brick-red, but the upper half of the series is a massive light-buff sandstone. These rocks continue north from Vermilion Creek Cañon about two miles, and then pass beneath the horizontal series of the Vermilion Creek Tertiary.

The Trias is masked along the northern slopes of the range, until, west of Red Creek and west of the mass of Archæan quartzites and schists, it again makes its appearance, faulted down into contact with the Archæan and with the Weber quartzite. Its outcrops from this point west to the cañon of Burnt Fork are characterized by remarkable sinuosities, of which the most considerable is where Green River cuts its cañon into the Uinta Mountains at Flaming Gorge. Here the Trias bends from its east-and-west course to a northwest course, crossing Flaming Gorge, then turns almost a right angle into a southwest strike for about four miles, after which, at Kingfisher Creek, it resumes the normal strike of approximately east-and-west. In Flaming Gorge Ridge the strike varies from east 50° south to east 50° north. At this point, the Tertiaries having been eroded from the Mesozoic series, the upper limit of the Trias is well marked by the variegated marls of the Jura and beneath by thin shale-beds of the Permian, which are interposed between the base of the sandstone and the summit of the Carboniferous limestone series. As displayed on Flaming Gorge Ridge, the following members are observed, beginning at the top:

	Feet.
1. Massive, cross-bedded, white and buff sandstone	400 to 450
2. Yellow clayey sandstones	50
3. Massive yellow sandstones	400 to 450
4. Red sandstones with white seams, on the whole rather thinly bedded	300 to 350
5. Red, heavy-banded sandstones	400 to 450
6. Greenish and greenish-purple clays	200 to 250

West of Flaming Gorge the valley of Sheep Creek follows the soft shales of the Permo-Carboniferous, leaving on the north high escarped walls of the Trias. At Dead Man's Springs the massive sandstones of this northern wall have a dip of 50° to the north, and they are further characterized by extensive deposits of gypsum. West of Sheep Creek the Trias continues to a little west of the valley of Burnt Fork. In the region of Mount Corson, the overlying Eocene and Pliocene beds, rising high on the slope of the Uinta foot-hills, overlap the Cretaceous and Jura, and come in contact with the Trias. Close to the wooded ridges, far up on Burnt Fork, the upper massive yellowish sandstones of the Trias, locally flecked with red stains of oxyd of iron, are seen conformably underlying the Jura. Here the lower Red-beds, although colored on the map, are obscured by débris. But they are seen underlying the buff sandstones a little farther to the east, at the eastern base of Mount Corson. Still farther west of Burnt Fork they come out from under the Tertiaries in the region of Lime Pass and extend westward for seven or eight miles, showing but imperfect exposures.

On the western side of Junction Peak, Little Snake River has eroded a deep valley through the Tertiary strata, exposing the lower members of the Cretaceous, the shales of the Jura, and underneath them the sandstones of the Trias, which rest conformably upon the soft shales of the summit of the Palæozoic. Thus exposed, the beds strike north 45° west, and dip about 45° to the southwest.

The eastern edges of Escalante and Yampa plateaus are margined by a broad band of Triassic sandstones, which south of the cañon of Yampa River rapidly shallows in dip and broadens in area of outcrop, occupying a large portion of the southern Yampa Plateau. In the remarkable strike from East Mountain to Fox Creek, the upper buff sandstones of the Trias form a conspicuous topographical feature. South of the river the prevailing color of the whole Triassic outcrop is of the usual red.

On the summit of Yampa Plateau, directly south of the junction of Yampa and Green rivers, is a fragment of the Trias which formerly capped the whole plateau and which has been spared by erosion. To the west of Yampa Plateau, around the two anticlinals of Section Ridge and Split Mountain, the Trias winds in a sigmoid curve, bending to the east around Island Park and resuming its normal westward trend along the southern slope of the main body of the Uinta, by Tirakav Plateau. In these wonderfully sharp, complex curves the Trias has developed an amount of flexibility, a power to conform to sharp local bends, which is one of the most surprising orographical features of the region.

A fine exposure of Trias is that laid open on Geode Cañon, one of the upper forks of Ashley Creek. The first prominent ridge overlying the steeply dipping Bellerophon limestones is formed of a body of coarse, massively bedded, deep-red sandstone escarped toward the north, and having numerous intercalations of saline impregnations, of which common salt is the chief ingredient.

To the east of Geode Cañon, between the two forks of Ashley Creek, is an exposure of thirty feet of solid white gypsum enclosed in the Trias sandstones and overlaid by red and white clays. Subjected to analysis, the gypsum is found to contain 76.7 sulphate of lime, 21.5 water. As exposed upon the surface, it has the appearance of a massive statuary marble, varied by pinkish and yellow veins. The red sandstones are here capped by harder, compact, yellowish-gray sandstones, above which are pale pink sandstones 300 or 400 feet thick, and above these a gap of 100 feet or more, representing some soft, easily eroded beds, whose outcrop is lost beneath the surface accumulations. The pinkish sandstones are capped by the beds of flaggy red sandstone, and above that is a line of cliffs composed of 200 feet of yellowish sandstone, above which appear the heavy white cross-bedded sandstones about 600 feet thick. The cross-bedding here develops a remarkable section, in which the flow-and-plunge action are found inclined 30° and 40° to the true planes of stratification. Here are altogether exposed about 2,000 to 2,500 feet of Triassic sandstones. Within the Uinta, gypsum has only been observed in this region, and on Sheep Creek, at the northern base of the range. The failure to observe the sulphates cannot be wondered at, when it is remembered how much of the Trias is obscured by débris, and that the shales which enclose the gypsum are, more than all other parts of the series, liable to rapid degradation.

In the reëntrant synclinal between Split Mountain and the main ridge the Triassic beds range high around the eastward curve, almost to the summit of Yampa Plateau, forming a line of curved bluffs with steep escarpments always toward the hills, while the backs of the dipping beds form approximately the outer surface of the slopes.

At Obelisk Plateau is a portion of the massive cross-bedded sandstone of the Upper Trias, dipping 29° to the southwest and striking north 65° west. Near the mouth of Antero's Cañon, on the west branch of Ute Fork, the upper cross-bedded sandstones appear prominently on the eastern side of the gateway formed by the mouth of the cañon, where are exposed about 1,500 feet of white and brownish sandstones standing at the angle of 70°, with the lower, red strata conformably below them.

From Obelisk Plateau as far west as Heber Mountain on the meridian of 111° 5′, the nearly horizontal Uinta Tertiaries extend far up the flanks of the range, often overlapping the whole Mesozoic series and coming in contact with the Upper Coal Measures, but at intervals eroded away, opening more or less exposures of Mesozoic rocks. At the heads of Lake Fork, especially in the gateway of the western branch, are exposed about 1,500 feet of Triassic sandstones dipping 30° to 35° south, and striking north 65° to 75° east. Here the uppermost exposures are about 600 feet of light-colored, buff, cross-bedded strata, which are capped by shaly clays assumed to be the bottom of the Jura. Under the cross-bedded series are yellowish-white sandstones, gradually becoming redder with increase of depth.

Still farther west, in the cañon of the east branch of the Du Chesne, the following members of the Trias are uncovered: The upper limit is well marked by a limestone carrying *Pentacrinus asteriscus*, which is considered to be the base of the Jura. Beneath this appears the white, cross-bedded sandstone, 600 to 700 feet thick, underlaid by 200 feet of yellowish sandstone; below that, 300 to 500 feet of pinkish-white sandstone, beneath which is the seam of greenish limestone, with some shaly sandstone. This greenish limestone is the one before mentioned, which occurs as far east as the Rawlings uplift, and in future study will doubtless be correlated with a similar limestone sheet observed along the flanks of Colorado Range. Beneath the horizon of the limestones are 500 feet of deep, brick-red sandstone. Between the two bodies, and near the greenish limestone, was found a

Naticopsis, a new species, having somewhat of a Jurassic aspect. The total exposure here is about 1,900 feet.

West of the Du Chesne Fork, along Stanton Creek, are afforded some excellent developments of the massive light buff sandstone, the upper member of the Trias. This exposure extends nearly to the head of Stanton Creek, the whole valley bottom being on the Triassic beds. West of the head of the creek they are masked by the overlying Tertiaries, which here rise to a great height, and further by the floods of trachyte which overpour the region for many miles to the north. Below the trachytes at Heber City, however, the foot-hills are formed of broken outcrops of reddish sandstones striking northwest and dipping at 25° to the southwest. They are undoubtedly the lower red sandstones of the Trias, and are here in the very position which might have been predicted by the known curvature of the underlying strata of the Uinta. North of Kamas Prairie, for many miles up the valley of the Upper Weber, heavy Triassic sandstones are seen dipping to the north. They are well exposed just north of the mouth of the cañon, where it emerges from Uinta Range upon Kamas Prairie, and here consist of heavy reddish beds intercalated with some clays and bearing one or two minor sheets of pebbles. In passing upward they are much covered by débris, and to the west are masked by the overlying trachytes; but enough could be seen of the upper members to recognize the massive cross-bedded sandstone, which is here redder than to the east, although the distinctive structure is as clear as at any place. At Peoria, a little village just north of the remarkable right-angle made by Weber River at the northern margin of Kamas Prairie, the erosion of the trachytes along the river valley displays the Triassic strata on both sides, overlaid by variegated marls and shales of the Jura. The dip is usually 50° to 60° to the north. There are 700 or 800 feet exposed, the lower members appearing under the trachyte. The upper portion, instead of the pale buff or white color characteristic of the cross-bedded series east and south of the Uinta, is here of the same bright pinkish tint which is seen at the quarry farther down Weber River below Echo City. The upper members, however, display the intricate cross-bedding which is characteristic of this horizon.

Wahsatch Range.—In Parley's Park the foot-hills which border the valley on the western side are made of the ordinary Triassic sandstone dipping to the east. A little way below Kimball's they make a sudden right-angle bend, and strike to the east and dip to the north. The trend of this chain of outcrops continues east-and-west until the ends of the strata are sharply cut off upon the line of the western foot-hills of the range. Here, between Parley's and Emigration cañons, the prevalent northern dip is varied by a local anticlinal including a little Permian within its axis. Directly north the characteristic rocks reappear with their normal dip to the north, passing under the synclinal of Emigrant Cañon and reappearing on the spur east of Camp Douglas with a southerly dip. The sandstones as they outcrop on the margin of Salt Lake Valley are pinkish, rather loose-grained rocks, varied in their lower horizons by considerable clay. It is difficult to determine closely the thickness of the Trias here. It seems hardly to exceed 1,200 feet. The rock near Camp Douglas is more compact than south of Emigration Cañon, and splits evenly along the planes of stratification, producing an excellent building-stone.

An important outcrop of the Trias is seen in Weber Cañon, just below the mouth of Lost Creek. Here, at a prominent bend of the river, and at the eastern end of the wonderful exposure of Palæozoic rocks described in the preceding chapter, overlying the 650 feet of Permo-Carboniferous shales, the Triassic series is exposed, about 1,000 feet in thickness, displaying the same general distinction of color seen over this whole country, namely, a division of darker clay-bearing red sandstones below, and a series of lighter, though here pinkish, cross-bedded sandstones above. The distinction of color, however, is far less than in the eastern part of the Uinta, where the sandstones are more loosely coherent and impure. Here the rock is a thoroughly compact sandstone and an admirable building-stone, for which it is extensively quarried by the Union Pacific Railroad Company. When exposed in bridge piers to the action of flowing water, it maintains its coherence very well. It is peculiar here by reason of a great number of jointing-planes and the occurrence of a white gypseous coating of all the joints. Underneath the cross-bedded portion is a thick bed of finely stratified sandstone, the colors varying from Venetian red to cream-color and pure white. A specimen of the compact rock submitted to analysis gave

94 silica, alumina being the principal impurity, with scarcely a trace of lime. The average dip is from 70° to 75° eastward. So far as observed, all the Triassic outcrops found along the base of the Wahsatch and in the country to the east are conformable with the underlying Palæozoic series.

Province of Western Nevada.—It is important to note that in passing westward of Wahsatch Range the Trias never reappears until the meridian of 117° 20′ is reached in western Nevada. It there recurs in immense volume, lying altogether west of the ranges which are made up of Palæozoic and Archæan members. In the ranges formed of the Triassic series in this western Nevada province there are no Palæozoic rocks, the Trias resting directly on Archæan granites and gneisses. The region has been subjected to severe crumpling, irregular local displacements, and faults of stupendous extent, and has been deluged with repeated outbursts of volcanic rocks. Finally, the depressed surfaces of the Triassic folds have been subsequently overlaid by extensive lacustrine deposits of Tertiary and Quaternary ages. As a result, the eastern limit of the Triassic formation touches the western limit of the Palæozoic, but their mutual relations are too much obscured by volcanic and Quaternary masses to be placed beyond doubt. Other arguments which will afterward be brought forward induce the belief that the Palæozoic and Mesozoic are strictly nonconformable and unrelated groups. The westernmost of the great Palæozoic folds which occupy Central and Eastern Nevada is an isolated mass of limestones and quartzites which form the higher portions of Battle Mountain and Shoshone Range. That chain of Palæozoic elevations continues in a line nearly due south, though slightly swerving to the west, until it comes into near connection with the Sierra Nevada south of Owen's Lake. The Wahsatch limestone and Ogden quartzite are easily recognized in Inyo Range, and this general north-and-south line, already mentioned as the western boundary of the Palæozoic exposures, is believed to have been the western shore of the Palæozoic ocean. West of the Sierra Nevada thin limestones of the Upper Carboniferous recur in connection with Triassic and Jurassic rocks, and have been considered by Professor Whitney as conformable with them. But from Battle Mountain westward to the western slope of the Sierra Nevada, over 200 miles, there are no Palæozoic rocks whatever.

This region is essentially made up of three geological elements: first, an underlying Archæan body; secondly, the conformable Mesozoic series, consisting of Trias and Jura, but no Cretaceous; thirdly, and of most superficial importance, the Tertiaries, volcanics, and Quaternaries, which cover fully half of the area. The Trias and Jura were deposited, as numerous exposures clearly show, upon an Archæan and granitic foundation which possessed a highly accidented topography. As a consequence, now that the Triassic and Jurassic series have been violently displaced and crumpled, erosion frequently lays bare the peaks and ridges of the original Archæan bottom, showing them to have been summits of erosion of considerable sharpness, and but slightly differing topographically from modern mountain peaks. The relation existing between the Archæan and the overlying Mesozoic is almost precisely similar to that described in the previous chapter between the Archæan and the Palæozoic.

The Triassic ridges north of the parallel of 40° 15′ have an approximately meridional trend. South of that latitude they swerve to a southwesterly trend, nearly at right-angles to the Sierra Nevada, which is the greatest of all the American Trias-Jura ranges and develops a northwest-and-southeast trend.

One of the most curious features of this western Trias and Jura province is the fact that the deepest developments are confined to the three ranges—Havallah, Pah-Ute, and West Humboldt—and that to the west the original granite topography must have risen, as the Jurassic slates overlap the Trias and come directly in contact with the granite, while west of the meridian of 119° the granite forms the principal feature, and the Jurassic slates are reduced to a thin edge. The deeper part of the sea, therefore, in which the strata of this province were deposited was narrow from east to west, and was characterized by granitic islands from the Sierra Nevada eastward to the meridian of 119°. Thence eastward it rapidly deepened toward the Palæozoic headlands of Battle Mountain and Shoshone Range, reaching a depth which permitted the deposition of 18,000 or 20,000 feet of strata in the region of Pah-Ute and West Humboldt ranges. The whole conditions of the Triassic strata, as developed in this province, are so different from the rocks of corresponding age east of the Wahsatch Mountains that in this connection it seems better to begin at once with the most characteristic, in fact the typical, locality, rather than follow a geographical description, beginning with the easternmost members. Accordingly, since West Humboldt Range offers the most extended and instructive displays, their occurrence there will be described, as furnishing a key to the sequence of the whole region.

West Humboldt Range.—This range is a fragmentary portion of an anticlinal fold whose axis is north 30° east, or diagonal to the meridional trend of the main northern portion of the range. The anticlinal itself is faulted on the axis, the western half forming the main body of the range, while the eastern member is depressed at the north, so that its beds rapidly pass under the Quaternary valley formation, but rise to the south until at Buffalo Peak they occupy heights nearly corresponding with the westerly dipping member of the anticlinal farther north. The range is further displaced by a northwest-and-southeast fault, which severs it into two distinct portions. The line of this fault is marked by a valley which extends southeasterly from near the mouth of Sacramento Cañon. The western member of the anticlinal, which occupies the whole range north of the mouth of Buena Vista Cañon, consists at the base of a great thickness of quartzitic and argillaceous beds, which in passing northward are gradually depressed beneath the Quaternary, but to the south rise to the summit of the range, and at the head of Buena Vista Cañon are seen to abut nonconformably against the mass of Archæan granite and schist, which is one of the mountain-tops of the Mesozoic sea-bottom. This series, in passing southward, is exposed more and more deeply, until in Indian Cañon a very great thickness is shown, probably not less than 4,000 or 6,000 feet. Sacramento Cañon also displays a vast thickness of these rocks. Toward the north they are simply argillites and siliceous beds interposed with siliceous argillites, but on approaching Buena Vista Cañon they are observed to become gradually metamorphosed until they finally pass into a porphyroid which *in situ* and in hand specimens remarkably resembles an erupted felsite porphyry. In the heart of the range south of Buena Vista Cañon are passages which show absolutely no stratification, and, but for the unmistakable transition into unaltered beds to the north, might well pass for erupted rocks. This whole series contains no distinct beds of limestone, and wherever analyzed is remarkably free from carbonate of lime. Its lower limit is nowhere seen, and, owing to the disappearance of the strata-planes under extreme metamorphism, there is no possible mode of arriving at its total thickness. The upper limit, however, is sharply marked by an abrupt transition from the schists into a body of dark, carbonaceous limestone. To this whole underlying group of schists and porphyroids we have given the title Koipato, from the Indian name of this range. The directly overlying limestone forms the base of a remarkable alternating series of limestones and quartzitic beds, characterized by fossils of the St. Cassian Alpine Trias age. The entire group, which is conformable within itself, and also conformably overlies the Koipato, consists of the following members, counting from the bottom upward:

	Feet.
1. Limestone	1,500
2. Slaty quartzite (capped with black slates, 250 feet)	1,500
3. Heavy ferruginous limestones	2,000
4. Pure, thinly bedded quartzite	800 to 1,000
5. Limestone (owing to peculiarities of structure, thickness somewhat in doubt) probably	1,000
6. Pure quartzite	2,200 to 2,800

To this whole body of 10,000 feet of strata we have applied the name of Star Peak group, from its characteristic development at that important mountain. Directly overlying the uppermost quartzite at the northwest point of West Humboldt Range is a body of limestone about 1,000 feet thick, capped with fine argillaceous slates from 1,000 to 1,600 feet thick, the upper members being concealed beneath the Quaternary. The lower part of this limestone contains fossils of distinct Jurassic species, and is only mentioned here to bring out the fact that the Trias and the Jura are perfectly conformable. The Trias throughout this region, therefore, begins with the Koipato or lower member, which is supposed to correspond to the dark Red-beds forming the lower half of our Triassic series east of Wahsatch Range. The Koipato group is devoid of fossils, with the exception of a few crushed and distorted remains of the genus *Nautilus*, which were found in the American District south of Sacramento Cañon. On the other hand, the Star Peak group yields an abundance of characteristic Alpine Trias forms. It will be remembered that the Trias east of the Wahsatch is also stratigraphically divided into two prominent parts of nearly equal volume: the lower Red-beds, which contain little or no limestone, and but few isolated beds of gypsum, and the upper Red-beds, which are characterized by occasional limestone seams of no great volume, and frequent occurrences of gypsum. These two Triassic seas, separated by a wide area of continental land, differ from each other in a manner which renders correlation next to impossible. If there is any correlation between the beds of the two series, it would seem probable that the Koipato is the equivalent of the lower Red-beds of the eastern sea, and that the overlying Star Peak group may be the equivalent of the upper Red-beds, the two being characterized by intercalations of limestone.

A glance at the map will show that the Koipato group occupies the whole body of the range in the region of Sacramento Cañon and Spring Valley Pass, and that it trends diagonally across the range, occupying the anticlinal fold, with the Star Peak group dipping to the northwest and southeast upon either side of this central mass. Passing north, the upper members of the Koipato form the foot-hills from Buena Vista Cañon north to Santa Clara Cañon, the valley Quaternary hiding the lower members. The greatest development is in the high hills directly north of Sacramento Cañon and Spring Valley Pass, but some of the most characteristic rocks are obtained from the head of Buena Vista, Cottonwood, and Indian cañons. Near the northern end of the outcrop, at the mouth of Star Cañon, the upper members of the Koipato are shown, consisting of slaty quartzites, with an imperfect, irregular cleavage, in general of dark greenish grays and brown colors, with a slight calcareous admixture near the upper limit, while the lowest members are more purely argillaceous. The very summit strata form a little transition-group of fine red and yellow marls, immediately succeeded above by the black basal limestones of the Star Peak group. Downward the marls become more arenaceous, and are followed by thickly bedded quartzites, more argillaceous below and more altered. Southward they pass gradually into the remarkable series of the Koipato porphyroids. In the region of Buena Vista and Cottonwood cañons the upper marls are rapidly succeeded downward by argillites and clayey mud rocks, with alternations of coarse grits and excessively fine hornstone. Pale olive argillites of remarkably impalpable grain are seen along the northern ridge of Cottonwood Cañon. The analysis of this bed is given in the Table of Stratified Rocks.

On the same ridge are some interesting light-drab cherts, having a conchoidal fracture, and showing under the microscope a very microcrystalline texture. For its chemical composition, see Analytical Table of Sedimentary Rocks. In general, the unmetamorphosed beds of the Koipato group are either purely siliceous or highly siliceous argillites, which are low in all chemical bases except alumina and potash. From these unaltered forms the transitions are very gradual, showing every change between the original condition and the purely subcrystalline metamorphic porphyroid, in which limpid crystalline grains of quartz and imperfectly developed orthoclastic and triclinic feldspars are clearly visible. One of the most interesting of the transitional forms is the development of parallel white planes of crystalline feldspar, interlaminated with dark felsitic zones, which owe their deep colors to freely disseminated microscopical carbon. These earlier stages of metamorphism usually show all the feldspathic material in parallel planes. A rather more advanced stage shows distinct individualized crystals of feldspar, more or less perfectly bounded in a true microfelsitic groundmass, which sometimes contains fully developed crystals of quartz or of feldspar, sometimes of both. The felsitic groundmass shades all the way from black through purple, gray, green, and brown, at times showing shades of pale gray and drab nearly reaching pure white. Under the microscope the quartz grains are frequently seen to enclose foreign fragments resembling the groundmass. These inclusions, however, do not in their form or arrangement resemble the inclusions of igneous rocks, but are rather to be classed with the dust-like microlitic impurities observed in the feldspars of diorite. Minute flakes of white mica and grains of magnetic iron not infrequently occur. The microscopical and chemical analyses unite to demon strate the invariable presence of carbon, which sometimes reaches so high a proportion as to render the thin section entirely opaque. In the region of Cottonwood Cañon the felsitic groundmass is more coarsely crystalline, and the feldspars more highly developed, many showing under the microscope the characteristic twin striation of the triclinic varieties. Local decompositions of this rock show cavities filled with ocherous substances, resulting from the decomposition of magnetic iron. Near the head of Indian Cañon, where the summit members of the Koipato group are reached, the metamorphism has extended upward into the horizon of the marly rocks which mark the summit of the group; and here the microscope shows a great deal of reddish calcite in the felsitic matter, the calcite containing a great deal of earthy oxyd of iron, besides some grains of quartz. Directly under these calciferous porphyroids are some brownish-gray rocks, in which the feldspar and quartz grains are very large and prominently developed. The analysis of the rock is given in the Table of Analyses of Sedimentary Rocks.

Here, then, is a group of rocks of the lower Triassic horizon, which are traceable from their original condition as siliceous and argillaceous sediments, through all the stages of metamorphism, up to the development of a truly crystalline rock, and, as the analyses show, without the addition of any further chemical constituents, the ultimate composition of the porphyroids agreeing absolutely with those of the unaltered argillites. They are characterized by the almost total absence of soda, the low percentage of lime, the high and almost uniform percentage of potash, and the comparatively regular ratios of silica and alumina. These rocks, it seems to me, possess an unusual importance, from the fact of this rapid transition into the crystalline state without the admixture of other elements, without the interference of subterraneous heat, and without having suffered a change at any great depth. They were never overlaid by more than 14,000 or 15,000 feet of rock at the utmost, and it is evident from the inspection of almost any deep section that the weight of that amount of overlying material is insufficient to produce the molecular change observed here. Moreover, the metamorphism is very much localized. It is contiguous to an underlying granitic mountain, and it is also within the arch of an anticlinal which has been subsequently subjected to very great compression and final fault. If my views concerning the origin of granite, as set forth in the Archæan chapter, are to have any weight, the production here of the purely crystalline schists within the compressed region of an anticlinal fold would seem, without violating the probabilities, to be due to local pressure alone. In treating of the interesting modification of the crystalline schists in Humboldt Range, (page 67), a series of changes was described by which the parallel gneissoid arrangement of the constituent minerals was broken up by longitudinal compression, and the granitoid result obtained. In this case there is the actual development of crystalline minerals—quartz, feldspar, and hornblende—and of a cryptocrystalline felsitic base. It is uncertain whether the flakes of mica are the result of a new crystallization or were originally constituents of the sedimentary beds. While the weight of overlying masses, such as we know must have overtopped the Koipato beds here, could not by any possibility be supposed to induce the observed metamorphic change, the enormous compression to which the axial region of an anticlinal of 20,000 or 30,000 feet of rock must have been subjected would probably afford the requisite pressure and mechanically disengaged heat for molecular rearrangement. In examining a series of rocks, from the loosest agglomerations of rounded sediments through the increasingly compact forms up to the purely crystalline state, the entire change may be expressed as a more and more intimate contact of the particles. It is not impossible that the granite mass which lay near this axis served as a fulcrum for the immense power of compression to work against, and this, perhaps, would account for the extreme forms of metamorphism in the immediate neighborhood of this granite mass. Granite having, if my views should be admitted, reached the limit of compression possible in the superficial crust, would offer a comparatively rigid body against which the beds of loosely compacted sediment might be crowded and their volume diminished by the obliteration of those spaces which intervened between the original sedimentary particles.

In Santa Clara, Star, Coyote, Buena Vista, and upper Cottonwood cañons the uppermost marls of the Koipato group are seen to be conformably overlaid by limestone No. 1, or the basal member of the Star Peak Alpine Trias group. This zone is 1,200 to 1,600 feet thick, and near the bottom is almost black, passing up into the ordinary grays and blues of a purer limestone. Between Star and Santa Clara cañons it is much fissured, and is stained red by infiltrated oxyd of iron. The carbonaceous matter which gives the black color to the rock is in varying proportion, but chiefly concentrated toward the bottom of the series. The analysis of a specimen of this rock is given in the table accompanying Chapter VI.

Immediately above the Koipato summit marls the carbonaceous limestones are richly charged with Alpine Trias fossils, the faunal equivalents of the St. Cassian and Hallstadt beds of the Austrian Alps. They include —

Halobia dubia, Gabb.
Halobia sp.?
Orthoceras Blakei, Gabb.
Endiscoceras Gabbi, Meek.
Trachyceras Whitneyi, Gabb.
Trachyceras Judicarium.
Trachyceras Judicarium subasperum, Meek.
Gymnotoceras Blakei, Gabb.
Arcestes perplana, Meek.
Arcestes Nevadensis, Meek.

From Buena Vista Cañon were obtained –

Modiomorpha ovata, Meek.
Modiomorpha alata, Meek.
Posidonomya stella, Gabb.
Sphæra Whitneyi, Meek.
Arcestes perplana, Meek.
Goniatites (*Clydonites*) *lævidorsatus*, v. Hauer.
Gymnotoceras Blakei, Gabb.
Fragments of sauroid vertebrata.

In Coyote Cañon but little search was made for organic remains. Nevertheless there were found, among poorly preserved forms —

Ammonites Blakei, Gabb.
Rhynchonella sp.?

In Bloody Cañon, a small ravine between Coyote and Star cañons, were collected from the upper beds of limestone *Ammonites* sp.?

Star Cañon furnished —

Ammonites Blakei, Gabb.
Halobia dubia, Gabb.
Arcestes perplana, Meek.

Besides the above, there have been described from this limestone in Star Cañon, by Professor W. M. Gabb, the following forms:

Spirifera Homfrayi.
Terebratula Humboldtensis.
Rhynchonella lingulata.
Posidonomya stella.
Monotis subcircularis.
Avicula Homfrayi.

And from Buena Vista Cañon:

Myacites (*Panopæa*) *Humboldtensis.*

The upper members of this limestone, not far below Star City, have yielded several saurian vertebræ. In general, the upper part of the limestone is more altered than the lower levels, and the fossils are correspondingly imperfect. The *Halobiæ*, although remarkably distinct in the lower part, in the upper are merely vague impressions. The rounder shells, like the *Nautilus* and *Rhynchonella*, although better resisting the prevalent alteration, are not infrequently replaced by crystalline calcite.

Directly over limestone No. 1 is a body of slaty quartzite, varied by greenish chloritic schists and capped by 250 feet of black, carbonaceous, argillaceous slates. The entire thickness is about 1,600 feet. No fossils were obtained here. The prevailing character is not unlike the unaltered part of the Koipato group. Chemically, it closely resembles it. The upper members of the black slates become perceptibly calcareous, the microscope showing minute striated crystals. The green chloritic schists appear a prominent feature of this group, and are scattered at intervals through the entire 1,500 feet, showing rudimentary feldspars. See analysis in table cited.

The microscope shows the same prevalence of carbon, the same unfinished feldspar crystals, evidently developed *in situ;* and looking back the reader will see that the analysis is quite like those of the Koipato group. This member is therefore essentially the chemical equivalent of the Koipato, but in a far less altered condition. The dip of these schists is about 40° to the west.

Directly above them, and quite conformable, is limestone No. 2 of the series, a very heavily bedded, gray, semicrystalline body, about 2,000 feet thick. This is much fissured and stained with oxyd of iron, and the few fossils which have been found are too indistinct for specific determination. They are known to belong to the genera *Ammonites* and *Rhynchonella,* however, and are most probably of the species more perfectly preserved in the lower limestone. A remarkable display of this limestone is made in the south fork of Star Cañon, and at the head of the north branch of Coyote Cañon. Here the abrupt slope of the prominent spur of Star Peak exposes a precipitous front of 800 or 900 feet, in which the beds of limestone, although rendered indistinct by crystallization, are seen in a general way to incline westward, quite conformable with the underlying quartzites and schists.

The top of this great body of limestone passes by a rapid marly gradation into a pure white quartzite, intercalated with finer siliceous schists. The thickness of this body is not known, but it can hardly be over 1,000 feet. It is essentially a true quartzitic member, and hence differs from the argillaceous strata of the Koipato and that which separates the limestones (No. 1 and No. 3).

The immediate summit of Star Peak is made of a black, carbonaceous limestone, which directly overlies this quartzite, and in the series is designated as limestone No. 3. While the trend of the range here is pretty accurately meridional, the strata all strike across the range at an angle of about north 30° east. In consequence, the members pass diagonally across the summit, and the quartzite which lies between the first two limestones is distinctly seen at the head of Buena Vista Cañon, occupying a position near the crest of the range. The quartzite which overlies limestone No. 3 probably crosses the top of the range at a point where it is so covered by soil and débris as to be unnoticeable.

Limestone No. 5, whose lowest carbonaceous members form the summit of Star Peak, slopes conformably to the west, and forms the surface of the mountain, extending some distance down toward Humboldt Valley. The varying dip and the accumulations of surface material make an estimate of its thickness difficult. It may be roughly set down at 1,000 feet. The dip of this limestone declines to about 18°.

Over it, and especially well exposed in Humboldt Cañon on the western side of the range, is a heavy body of quartzite of a pure siliceous type, characterized by many interesting cross-jointings. The character of the exposures makes this member also hard to estimate, but we consider it to be over 2,000 feet thick.

This closes the Alpine Trias group. It is immediately overlaid by a limestone containing different Jurassic types, which will be described in the Jurassic section. Here, therefore, the Alpine Trias consists of three limestones and three quartzites, the whole about 10,000 feet thick, making, together with the Koipato, a known thickness for the exposed Triassic series of about 15,000, or possibly 17,000 feet. As before noticed, the metamorphic character of the deep exposures of the Koipato renders an estimate of their thickness impossible, but from all that we could see there could hardly be less than 4,000 to 6,000 feet. The exposures of Alpine Trias in the Star Peak group are probably exceeded in California, but their extreme metamorphism again in the great belt of upturned rocks in the Sierra Nevada renders the reconstruction of a section exceedingly difficult.

The eastern half of the anticlinal of this range is a mere fragment, its eastern edge depressed beneath the Quaternary of the plain. The face corresponding to the axial fault is raised to a height nearly equal with that of Star Peak. The strata which dip eastward from 28° to 45°, and even 50°, are thoroughly conformable throughout, and display a partial repetition of the sequence already described at Star Cañon. Along the western face of the hills west of Buffalo Peak, northward to Sacramento Cañon, are found the porphyroids, less altered and rather more thinly bedded and regular than farther north. These partly crystalline schists contain half obliterated remains of the genus *Nautilus.* Limestone No. 1 of the Star Peak group occurs directly over these schists, and yields the following fossils:

Halobia dubia, Gabb.
Trachyceras Whitneyi, Gabb.
Ceratites Haidingeri, Gabb.
Ammonites sp.?
Ammonites sp.?
Goniatites lævidorsatus, v. Hauer.

The summit of Buffalo Peak consists of a heavy body of limestone, which is underlaid by a quartzite appearing to pass over limestone No. 1, described above as bearing fossils. This section of the range consists, therefore, of a small exposure of the upper part of the porphyroids of the Koipato, which contain fragments of *Nautili,* and limestones No. 1 and No. 3 of the Star Peak group, with their intermediate quartzite.

West of the northwest fault before mentioned as separating the range into two parts, outcrops a heavy bed of limestone, which is similar in all respects to the lower and middle limestones of the Star Peak group, darkly carbonaceous at certain levels, and again passing up into a pale gray rock. The lower dark members contain indistinct forms of *Ammonites* and *Rhynchonella.* The rest of the range, to its termination in the Mopung Hills, shows more or less altered members of the Star Peak and Koipato groups, dislocated, displaced, and deluged with subsequent volcanic rocks. They yield no fossils, and throw no additional light upon the characteristics of the Trias of the region.

PAH-UTE RANGE.—In its larger features, this ridge, next east of the West Humboldt, repeats the structure of that range in the same latitude. North of the great basaltic mass of Table Mountain, the range consists of a granite nucleus, which outcrops at Granite Mountain and north of Spaulding's Pass, unconformably overlaid by an immense but obscure series of dark, varied siliceous and argillaceous schists, considered to correspond with the Koipato group of West Humboldt Range. The orographical structure, however, is far more complicated, and the relations of the beds are never made out with the same clearness as at Star Cañon or Buffalo Peak. Directly south of Granite Mountain, the Koipato group, which here forms the eastern member of the anticlinal, dips east, and is overlaid by the heavy basal limestone of the Star Peak group, the latter overlapping the Koipato quartzites as it passes north, and coming into unconformable contact with the Archæan of Granite Mountain. As the limestones are thrown westward and wrapped in a curve around the western base of the Archæan mass at Wright's Cañon, so here the easterly dipping Star Peak group limestone trends in a curve around the eastern base of the Granite Mountain Archæan mass.

The whole northern part of the range is subject to severe local disturbances and dislocation. The Star Peak limestones rise in a nearly vertical position, developing a sharp anticlinal, whose eastern member rapidly passes under the Quaternary of the plain, while the western or more important member dips at angles varying from 20° to 80°, and is thrown into a variety of contorted positions, besides being broken by numerous faults, which are traced with difficulty. As a result, the section does not approach in value that of Star Cañon. In the dark limestones south of Dun Glen—the lowest member of the westerly dipping series, correlated by us with the basal limestone of the Star Peak group—were obtained the following forms:

Pentacrinites asteriscus, M. & H.
Spiriferina Homfrayi, Gabb.
Spirifera (*Spiriferina*) *alia*, n. sp.
Terebratula Humboldtensis, Gabb.
Edmondia Myrina, n. sp.

From the same formation Professor Gabb has described the following species:

Nautilus multicameratus.
Ammonites Homfrayi.
Mytilus Homfrayi.
Myophoria alta.
Rhynchonella æquiplicata.

Pentacrinus asteriscus, ordinarily considered a Jurassic species, is here found embedded with unmistakable Alpine Trias fossils, but associated also with *Spirifera alia*, a Palæozoic type. Messrs. Hall and Whitfield remark: "We know of no species of *Spirifera* or *Spiriferina* in rock of this age resembling the one under consideration, or with which it can be confounded. The substance of the shell, like all those from the same locality, is badly exfoliated, and has apparently undergone some change which has to some extent obliterated the natural features, so that we are not able to say definitely if it be punctate or not, and consequently are in some doubt in regard to its generic relations."

HAVALLAH RANGE.—Like the Pah-Ute, Havallah Range offers a very complex structural problem which would occupy a far greater space than I permit myself here. It consists of an elevated mass of Triassic rocks, exposing both the Koipato and Star Peak groups, resting, as in the case of the Pah-Ute and West Humboldt, unconformably upon Archæan bodies, and broken through by intrusive rocks of post-Jurassic age, and, finally, in Tertiary time deluged at the northern and southern extremities by outflows of rhyolite and basalt. Immediately north of Golconda Pass it will be seen that the range is a single ridge of the Alpine Trias group, which bifurcates, the rocks of one branch resting upon the Archæan granites in the region of Summit Spring, the other continuing northward to near the valley of the Humboldt, where it is masked by rhyolites. As shown upon the general section in the Geological Atlas in the cut corresponding to Map V., eastern half, the range consists of a mass of generally easterly dipping Star Peak rocks, of intercalated limestones, slates, and quartzites, which have minor folds, locally creating western dips. The angles in this part of the range are always low, and the surface of the country is so covered with débris that the actual sequence cannot be made out with clearness. The western ridge widens rapidly, gradually assuming the form of a broad anticlinal, which is much obscured by local disturbances. In the heart of the range, at Signal Peak, is a vast display of quartzitic and argillaceous rocks, considered to be the equivalent of the Koipato group, overlaid conformably by masses of limestone, quartzites, and slates, referred to the Star Peak group. For the detail of this structure, as well as that of Pah-Ute

Range, the reader is referred to Volume II., Chapter V. For our present purposes, it is sufficient to say that in the westerly dipping slates of the foot-hills has been found a single Triassic form, *Halobia dubia*, characteristic of the lower Star Peak.

The Triassic rocks of this range have a peculiar interest from their near approach to the Carboniferous of Battle Mountain. Thus far, in plicated and disturbed masses of this and Pah-Ute Range, no Carboniferous rocks have been discovered. It is possible that they may be found hereafter, and their relations to the younger Trias determined. But a glance at the eastern half of Map V. will show that there is nowhere a direct contact of the Carboniferous and Triassic series. The hypothetical relation of the two series is shown upon the general Atlas section-sheet in section corresponding to Map V., eastern half. There the Carboniferous rocks, both quartzites and limestones, are seen dipping westward at an angle of from 25° to 30°; and immediately west of the granite mass the Trias appears in a nearly horizontal position. The formations are too far apart to assert that this discrepancy of angle offers any true solution of their relation. For reasons hereafter to be brought forward, they are considered nonconformable; but it must be confessed that this conclusion is not derived from any observed contact of the series.

Fish Creek and Augusta Mountains.—This chain of elevations consists of a continuous mass of eruptive rocks, from granite to basalt, embracing the older rocks—syenite, diabase, and felsitic porphyries—and containing also andesites, trachytes, rhyolites, and basalt. Accidental erosion has laid bare at two points along the western foot-hills limited outcrops of sedimentary rocks. That near the western base of Mount Moses, in Fish Creek Mountains, consists of a body of quartzites closely resembling those of the Koipato group. They rest unconformably upon the granite, and are overlaid by a tremendous flood of rhyolites. Farther south, at the western extremity of Shoshone Pass, near Shoshone Springs, is another limited exposure of limestones and argillites, the dark color of the sedimentary rocks forming a conspicuous contrast with the pale shades of the surrounding and overlying rhyolites. These limestones are crumpled into a sharp anticlinal fold, having a north-and-south trend, the eastern member standing almost vertical, the western series dipping off at an angle of 20° to 25°. There must be at least 1,000 feet of limestone exposed here, with interstratified arenaceous and clayey beds. The limestones are at times very dark on their weathered surfaces, coated with a peculiar crust of carbonate of iron, and locally converted into nearly white crystalline calcspar, having a peculiar concretionary habit. South of the springs are some greenish cherts, quite like those of the uppermost quartzite member of the Alpine Trias, West Humboldt, and allied also to the conglomerates to be presently described in the Desatoya Mountains. The main body of limestone is characterized by numerous fossils of Jurassic facies, which will be described under their proper head. The rocks underlying the Jurassic are considered to belong to the Trias, and to represent the uppermost member of the Star Peak group.

Desatoya Mountains.—The conditions here resemble those of the Augusta. The entire mountain body is a vast series of rhyolite outbursts, piled one upon another, which have failed to overflow a high summit directly north of the New Pass Mines, where is exposed a body of Triassic rocks about six miles from north to south by four miles from east to west, occupying the central ridge of the mountains, and upon the eastern declivity passing under rhyolites, but constituting the whole western mountain slope quite down to the plains. The central mass rises about 4,000 feet above the surrounding valley, and consists of a monoclinal body striking north 20° east and dipping 30° to 35° westward. The larger portion of the mass, and the whole summit of the mountains, are composed of a great underlying member, not less than 6,000 feet thick, of greenish and purple cherty conglomerates with red cement, capped with about 1,000 feet of quartzites and conglomerates having a peculiar yellowish, weathered surface, passing up into a bed of purple argillaceous roofing slate. This series is considered to represent the Koipato group, and it is interesting as displaying, though in a less degree, some of the forms of metamorphism already described in West Humboldt Range. Green porphyroidal conglomerates are a prominent feature, bearing close lithological resemblance to some of the conglomerates found in American District south of Sacramento Cañon, in West Humboldt Range—the rocks mentioned as bearing distorted casts of *Nautili*.

The Koipato group in the Desatoya Mountains, so far as observed, bears no fossils. Indeed, its metamorphosed condition renders the future finding of fossils very doubtful. As compared with the same group in West Humboldt Range, the predominance of conglomerates is the main distinguishing feature. The zone of roofing-slates, also, which forms the uppermost member of the group, occupies the position of the summit marls which immediately underlie the basal limestone of the Star Peak group in West Humboldt Mountains. As exposed in Ammonite Cañon, the roofing-slate summit of the Koipato is succeeded conformably by dark, compact, earthy limestone, often extremely carbonaceous, and not less than 1,500 feet thick. A band of yellow calcareous shales forms the lowest member of this group, which is immediately succeeded by dark-blue, finely laminated, calcareous shales rich in Triassic fossils, especially of the genus *Ammonites.* From this horizon were obtained —

Halobia dubia.
Pteria (*Avicula*) sp.?
Pecten deformis (fragment).
Myacites sp.?
Orthoceras Blakei.
Ceratites Haidingeri.
Ammonites Billingsanus.
Goniatites (*Clyodomites*) *lævidorsatus.*
Ammonites (*Gymnotoceras*) *Blakei.*
Ammonites Ausseanus.

From the upper limestone beds were obtained —

Spiriferina Homfrayi.
Terebratula sp.?
Chemnitzia sp.?

From the limestones at the southern point of the range, near the head of South Cañon, were obtained also the following forms:

Halobia dubia.
Halobia (*Daonella*) *Lomelli.*
Modiolopsis (*Modiomorpha ?*) *ovata.*

Modiolopsis (*Modiomorpha?*) *lata.*
Lima (*Clenoides*) *Gabbi.*
Ammonites (*Gymnotoceras*) *Blakei.*
Acrochordiceras Hyatti.
Entomoceras Laubei.
Lima (*Limatula*) *erecta.*

As in Havallah Range, the Triassic and Jurassic exposures of the Augusta and Desatoya Mountains are never seen either in actual contact or even in proximity with the Palæozoic rock. As at the north, they are separated by broad Quaternary valleys or massive eruptions of Tertiary volcanic rocks. It is a matter of regret that the precise relations of the two series, as far as our work goes, are indeterminate along this line. West of West Humboldt Range, in the Kamma and Truckee Mountains, are two unimportant outcrops, which, from their petrological characteristics, have been referred to the Trias. They are, however, of no systematic importance.

SECTION II

JURASSIC.

Rocky Mountains.—In the conformable series of upturned foot-hill rocks along the eastern base of Colorado Range, next above the group of gypsiferous red sands of the Trias, lies a thin body of clays, shales, marls, and cherty limestones, varying from 75 to 250 feet thick, capped by the always easily recognizable conglomerate which forms the base of the Dakota or lowest group of the Cretaceous series. Along these foot-hills the group has yielded no organic remains, and it is referred to the Jurassic purely on lithological and stratigraphical grounds; but so great is the permanence of this narrow series between the Cretaceous conglomerate and the Trias Red-beds that there is not the slightest doubt in correlating it with beds of similar position and composition farther west, which carry an abundance of the distinctive Jurassic fossils.* The upper limit of this series is uniformly marked by the cessation of soft shaly and marly beds, and the sudden transition to Cretaceous conglomerates. The lower limit of the Jurassic series is more variable and less definite. In certain places the uppermost Red-bed of the Trias is directly followed by marly clays and shales similar to the fossiliferous Jurassic marls farther west. In such cases the line is drawn at the top of the red sandstone; but it should not be forgotten that the upper members of the Trias farther west are themselves not infrequently clay, and that the Jurassic fossils occur separated from the main body of the Trias Red by the similar marly and clayey material. At best, the line between the Trias and the Jura on the eastern base of the mountains is only indefinite. The variability in thickness from 75 to 250 feet, it would seem, may be due partly to the original thickness

* Since the above was in type Prof. O. C. Marsh has announced the discovery of gigantic Jurassic reptiles at Morrison and Cañon City, and at other points in middle Wyoming, where they are associated with *Belemnites densa* and other characteristic Jurassic mollusca. A fuller note of these discoveries will be found in the section of recapitulation of Mesozoic.

of the deposition, and in great measure to the variability in compression. As a whole, the colors of the series differ from the light creamy Cretaceous above and from the prevailing red of the foot-hill Triassic below. They are often pinkish, grayish, and yellow, with cloudings of reddish-purple and purplish-gray in the region of the calcareous beds.

A section taken near Box Elder Creek, where the stream leaves the mountains, at the maximum thickness of the series, gives a total of from 225 to 250 feet. At the base is a reddish-yellow, friable sandstone, followed by thin, gray, arenaceous marls. Above that, and fading gradually into it, is a grayish marl with reddish-brown bands of clay and thin layers of sand, followed by a rusty orange sandstone banded with light-yellow clay; above this a cherty yellowish and bluish limestone of varying thickness, passing, by a gradual increase of arenaceous material, into a yellowish sandstone; next a thin, white marl, only a few feet in thickness, shading into gray and streaked with clay at the top, the whole capped by a friable, yellowish sandstone. Owing to the softness and crumbling nature of a large portion of these beds, the actual thickness of each is difficult to determine, as they pass into one another by imperceptible gradations, and, with the exception of the limestones, show hardly any marked individualization.

The series has its greatest thickness in the region of the Big Thompson. Northward, toward Lodge Pole Creek, it is difficult to trace, on account of obscuration by loose soil and the increased resemblance to the Trias. Seventy feet will probably cover the extreme thickness in this region. Farther north the Jurassic again increases to 150 and 180 feet, the most characteristic beds being reddish-yellow sandstones, shales, and marls. In the period of conformable deposition the recurring concentration of limy strata increased during the Jurassic, rendering the actual beds of limestone thicker and more defined than in the Trias, and imparting to nearly all the sandstones a marly nature. There are two distinct types of Jurassic limestone; one hard, dense, and cherty, often of a very fine lithographic type, usually gray; the other less compact, exhibiting a greater variety of color and texture, and usually dolomitic. A specimen of the latter is given in the table of stratified rock analyses, Chapter VI.

Finally, gypsum, so prominently included in the Red-beds of the Trias, recurs at various horizons in the Jurassic, lacking continuity of stratification, and never reaching a thickness of more than two or three feet. It is natural that a body so soft and easily eroded as the Jurassic should be for the most part covered up with deposits of loose soil, and that in general it should be an obscure member of the whole series. As will be seen farther on, however, the main characteristics persist with the thickening to the west, where are ample organic remains.

In the geological province east of Wahsatch Range, the rocks of Jurassic age are the invariable and conformable accompaniment of the Trias. Its outcrops are brought to light by the same series of upheavals and subsequent erosions which has exposed the underlying Trias. While the rocks of the latter group are essentially a series of sand-rocks, those of the Jura are characteristically shales and shaly limestones. Their greatest thickness is immediately along the base of the Wahsatch, where the series attains a breadth of 1,800 feet. Thence they gradually thin out eastward, reaching a minimum of seventy-five feet along the eastern base of Colorado Range. This diminution of thickness from the most western to the most eastern exposures coincides with the habit of the whole underlying series. The Jurassic occupies an intermediate position between the varyingly coarse siliceous sediments below and the wide-spread sheet of grits and conglomerates of the Dakota Cretaceous above it. Between these two easily recognizable horizons the Jurassic series, where exposed, may invariably be recognized, and even in the absence of fossils its stratigraphical boundaries are so exceedingly well defined that throughout the area of the Fortieth Parallel Exploration its limitations are quite as clearly fixed by the character of its material as by palæontological evidence.

The light, cherty, Jurassic limestones are well displayed near Big Thompson Cañon, where the series is seen overlying the calciferous Trias. The limestone bed is here about ten feet thick, enclosed between fine, light-yellow marls. In the Big Thompson region, the plane of division between Trias and Jura is especially obscure, on account of the expansion of the calciferous marls, which pass downward by a series of sandy transitions into the upper horizon of the Trias.

Near the mouth of Box Elder Creek, where it emerges from the mountains, is a good exposure of the Jurassic series about 200 to 240 feet thick, the various members shading into one another so much as to render it difficult to distinguish them. Beginning at the top, it is capped by a reddish-yellow, friable sandstone, passing downward into gray arenaceous marls, the lower gray marls being banded with purple and grayish stripes and clay layers; these are underlaid by rusty orange sandstone with layers of light-colored clay; beneath this the cherty limestone passes down into yellow calcareous sandstone, which is followed by white marls descending into gray marls with clay, the whole resting upon fine gray and grayish friable sandstone, which is immediately underlaid by the upper part of the Triassic Red-beds.

This difficulty of separating the upper Trias and the Jura is again observed on the western side of Laramie Hills, near Red Buttes. In the upper part of the Jura series the limestone has a flesh-red color and uniform texture, and contains fine, gritty grains of sand. The pure limestone material, subjected to analysis, is shown in the table of analyses cited.

Jurassic rocks occur from the Red Buttes southwestward to Red Lake, usually showing but limited outcrops, and those confined chiefly to the calcareous portion of the series. Upon the summit of the high Triassic plateau southeast of Red Lake are exposures, about 200 feet thick, of Jurassic rocks, the summit members having been eroded off. Beginning at the top, the beds are as follows: a sandstone body 100 feet thick, white and friable at the top, reddish-brown, slightly intercalated with variegated, clays and marls in the middle, passing downward into cream-colored, marly sandstone; beneath this, 25 feet of bluish-gray, cherty limestone, followed by 75 feet of grayish-white sandstone, which rests upon the yellowish-red, cross-bedded sandstone of the top of the Trias.

At the dome-like quaquaversal upheaval at the northern edge of Map I., near the 106th meridian, at Como, the easily recognized Dakota sandstones and conglomerates overlie a series of Jurassic rocks, which are exposed from 175 to 200 feet in thickness. Passing downward from the base of the Dakota Cretaceous, the Jurassic consists of, first, gray clays and sandy marls, containing a great many gritty particles of angular siliceous sand; secondly, creamy marls, with thin, sandy layers; thirdly, bluish-drab, cherty limestones; fourthly, fine, ash-colored marls, with thin beds, varying in thickness, of light-colored limestones; fifthly, gray and orange-colored marls, with coarse sandy intercalations; sixthly, a reddish-yellow sandstone, which is immediately succeeded by brick-red compact sandstone of the Trias. In the marls, both above and below the limestone, which lies a little above the middle of the series, occur numerous Jurassic forms, among them the following:

Pentacrinus asteriscus.
Belemnites densus.
Tancredia Warreniana.
Trigonia quadrangularis, n. sp

The yellow and cream-colored marls two miles east of Como also contain lamellibranchiate fossils, though imperfectly preserved. While organic forms are so rare as never to have been observed by us along Colorado Range, the *Belemnites* and *Pentacrinus* in the Como marls are enormously abundant, their hard forms weathering out of soft enclosing marls and clays, and lying freely strewn upon the surface.

The Jurassic beds of North Park are recognized by their lithological characters, which are very persistent, and their unmistakable position between the red Trias and the Dakota conglomerate. The cherty limestone, so characteristic of the middle portion of the Jurassic, is very persistent through North Park, and wherever the surface of the series is not too much covered by Quaternary detritus, the limestone outcrops form a slight, perceptible ridge.

The dome-like uplift of Rawlings Peak exposes the Jurassic series, which is here seen to possess somewhat different characteristics from those already described. Directly under the Dakota Cretaceous conglomerates are found beds of limestone dipping conformably with the conglomerate 8° or 10° eastward. The surface is so cumbered with débris that the soft and marly parts of the Jura are nowhere exposed. Directly over the Triassic sandstone, however, are about 100 feet of soft, argillaceous beds, including some seams of arenaceous material. Coming to the surface through the soft detritus some distance above are two outcrops of limestone, a dark earthy bed ten feet thick, overlaid by fifteen feet of arenaceous limestone, containing—

Camptonectes bellistriata.
Eumicrotis sp.?
Astarte sp.?
Belemnites sp.?
Ostrea sp.?

Above these fossiliferous limestones is a gap of 100 feet obscured by soil, though showing slight outcrops of sandy argillites.

UINTA RANGE.—Among the inclined beds upon either side of the great anticlinal of the Uinta, the Jurassic series holds its appropriate place, and differs from the outcrops to the east, already mentioned, in a considerably increased thickness and large proportional addition of calcareous material. It is, however, still characterized by the predominating presence of clays and shales, whose habit of easy erosion gives to the general outcrop of the series the same débris-covered and obscure character which has been previously noticed. There are outcrops of considerable importance on the eastern edge of the O-wi-yu-kuts Plateau, extending in a northwest direction from the valley of Vermilion Creek. Here the calcareous members which occur in the middle of the group and at its base are reduced almost to a minimum. In the region of Flaming Gorge, and thence westward to Mount Corson, the displays of Jurassic rocks are more important and more clearly seen The general section is a basal member of limestone more or less shaly, and often almost entirely replaced by sandy shales, reaching a maximum, so far as our observations go, of 200 feet. It was observed by Major Powell reaching 250 feet. Above this is a variable thickness of sandstones and sandy shales, never in our observations exceeding 250 feet, succeeded upward by a body of limestone which has been noticed by us reaching 300 feet in thickness, and above that by a body of variegated clays intercalated with thin beds of sandstone and certain marly sheets These clays, besides the middle and basal limestones, have all been observed to carry well defined Jurassic types of fossils. In the Flaming Gorge region, from the middle limestones, we have obtained —

Camptonectes bellistriata.
Gryphæa calceola.
Pentacrinus asteriscus.
Rhynchonella gnathophora.

From the basal limestones at Sheep Creek have been obtained —

Camptonectes bellistriata.
Myophoria lineata.
Gryphæa calceola.
Pentacrinus asteriscus.
Belemnites densa.
Trigonia (two species).
Ostrea sp.?
Volsella.
Neritella (like *N. Nebrascensis*).
Chemnitzia.

Here also is a bed of gypsum.

Upon Black's Fork the upper horizon of the Jura is very well defined by the basal conglomerate of the Dakota Cretaceous, and its base equally well marked by the summit of the upper cross-stratified member of the Triassic series. In the basin-like head of Burnt Fork the middle group of Jurassic limestones outcrops, having a strike of 15° south of east and dipping 45° to the north, capped by white sandstones belonging to the upper part of the Jura. South from Dead Man's Springs, the first noticeable outcrops are peculiar metamorphosed sand-rocks, on a steep ridge overlooking the gorge of Sheep Creek. Underneath these, and probably representing the middle Jurassic limestone, are calcareous beds containing the following fossils:

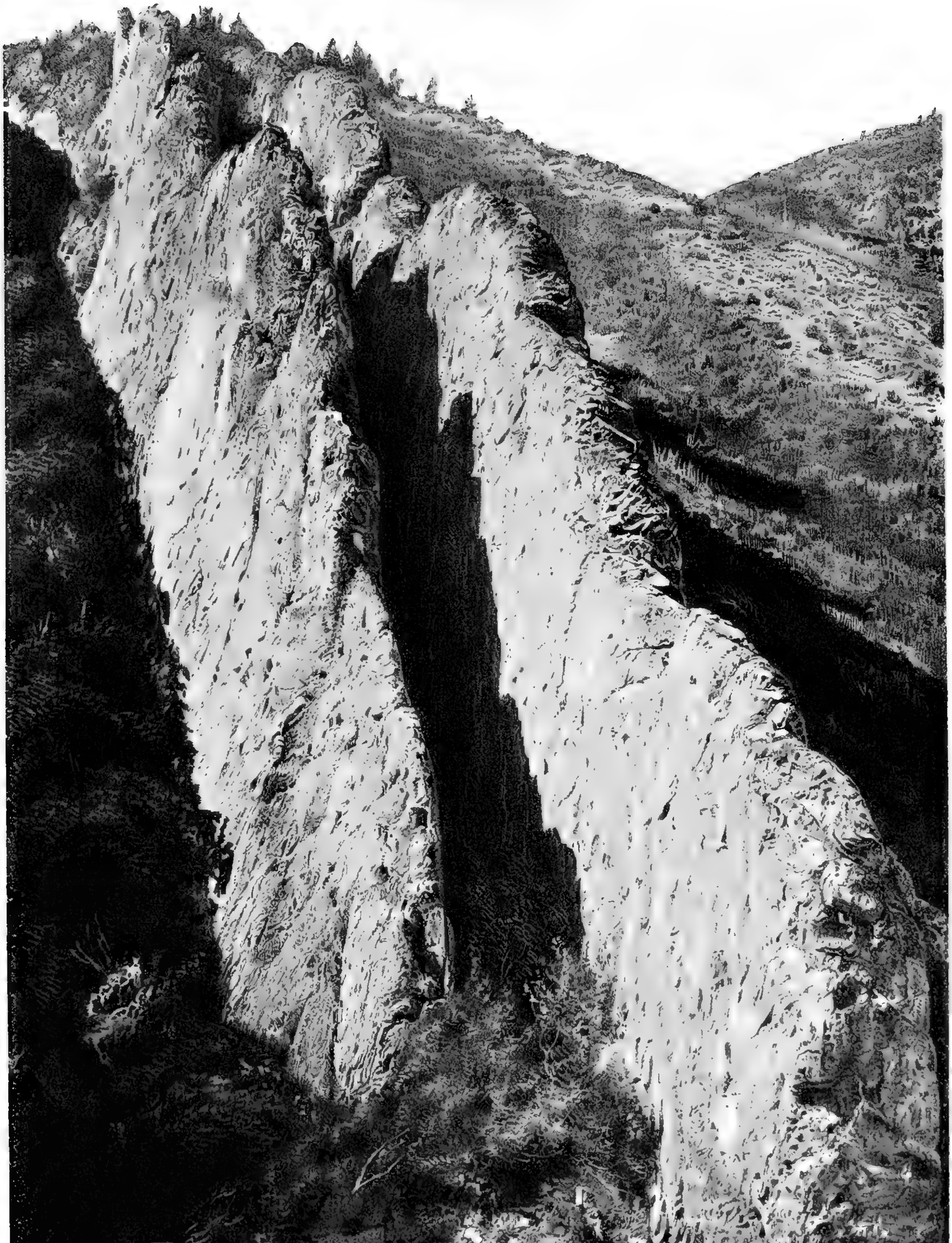
Camptonectes bellistriata.
Myophoria lineata.
Gryphæa calceola.
Pentacrinus asteriscus.

On the southern side of the Uinta, in the region of Ashley Creek, overlying the white sandstone ridges of the upper Trias, are intervals of clayey valleys, representing the lower shales and limestone of the basal part of the Jurassic series. They are here largely covered with soil and débris, and the limestone nowhere makes a clear appearance. A low ridge is traced through this clayey interval, which is formed of a gypsum bed. It is about 25 feet thick, and is quite massive and compact, only differing from the snowy-white gypsums in the neighboring Triassic rocks by a grayish-white color. On analysis it yields 75 per cent. of sulphate of lime and 21 per cent. of water. Like the Trias gypsums, these bodies are not exposed for any great longitudinal extent, and are considered as lenticular deposits in the clays. A little south of and hence overlying this, in a ridge of glistening light sandstone, is a second series of gypsum deposits. The sandstones are capped by about 50 feet of blue and drab limy shales and limestones, carrying the following well defined Jurassic fossils:

Gryphæa calceola.
Eumicrotis curta.
Belemnites densa.

The thickness of the series here is very difficult to estimate, but it is probably greater than on the northern slope of the mountains, and cannot fall far short of 750 feet. A little farther east, beneath the Wyoming conglomerate at the top of Obelisk Plateau, are clays intercalated with sandy shales, and having at times a somewhat oölitic structure. They carry numerous *Gryphææ calceolæ.*

At the western end of Uinta Range, near the village of Peoria, the cross-bedded Triassic sandstones are seen to be directly overlaid by a body of lithographic limestone, which has a peculiar habit of breaking into lenticular fragments. It is frequently intercalated with yellowish, earthy marls. Both the sands and marls carry numerous *Eumicrotes curtæ.* These marls and limestones are overlaid by a series of variegated shales and soft beds, all quite conformable, passing up into friable sandstones and mauve-colored shales, which in turn are overlaid by conglomerates of the Dakota sandstone, here exceedingly coarse. The middle of the Jura is somewhat



calcareous, but real limestone is mainly confined to the basal member, which rests conformably upon the top of the Trias.

Wahsatch Range.—At the head of the lower Weber Cañon the upper cross-bedded sandstones of the Trias are overlaid by a considerable body of yellow and blue limestone and calcareous shales, yielding—

Cucullæa Haguei
Myophoria lineata.
Myophoria sp. ?
Myascites subcompressa.
Volsella scalpra.

The lowest member of this basal limestone series is broadly and heavily bedded, but it passes upward into calcareous shales, which are interstratified with true lime-beds, the whole covering a thickness of about 600 feet. Above this is a long interval of soil-covered hill, through which the thin edges of shaly outcrops, both siliceous and argillaceous, are seen, growing more calcareous in passing upward, and at length covered by thin argillaceous shales carrying well defined ripple-marks. The whole Jurassic here is from 1,600 to 1,800 feet thick, and is prevailingly calcareous through the lower half and prevailingly argillaceous through the upper half, all its materials being of a very fine grain. The strike here is 16° or 18° east of north, and the dip from 78° to 80° east. It is quite conformable with the underlying Trias and Palæozoic series, and forms the uppermost exposed member of the great conformable group. The latest argillaceous members of the Jura series here have yielded no fossils. A little southward, in East Creek Cañon, at Parley's Park, the plane of demarkation between the Dakota conglomerate and the Jura presents a distinctly characterized change, and the upper Jurassic rocks are thinly bedded argillaceous shales, quite similar to those which overlie the Devil's Slide in Weber Cañon, opposite the mouth of Lost Creek.

Plate XII. is a view of the Devil's Slide, an interesting projection of the harder sandy beds of the Jurassic above the surface, from whose flanks the softer shales have been eroded away.

Western Nevada.—Over the Mesozoic region of western Nevada, within the Fortieth Parallel, and in the total absence of Cretaceous, the Jurassic is the uppermost member of the conformable group, and has hence suffered more from erosion than either part of the Triassic. In consequence only a small part of the Mesozoic exposure is of Jurassic beds. Characteristic fossils were collected by us at three points, and the range of the group was extended on competent stratigraphical evidence.

I have shown that the uppermost of the three limestone bodies of the Star Peak Alpine Trias group is overlaid by a quartzite, and that in turn capped conformably by a heavy, gray, subcrystalline limestone. This is seen on the northwest point of West Humboldt Range and south of Buena Vista Cañon on the east base. In these two positions the contrary dip and relation to the underlying Star Peak group show the upper limestone to be a high member of the great faulted anticlinal of the range.

In the dark-gray beds of the east base are found *Belemnites Nevadensis*, a new species, and several indistinct, badly preserved bivalves. From the upper limestone of the northwest part of the range were collected *Montlivaltea* and *Cardium* too decomposed and imperfect for specific determination.

A similar body of limestone about 1,200 feet thick has been exposed at the east base of the Augusta Mountains, nearly surrounded by great massive eruptions of volcanics; it is a mere isolated outcrop; all its orographical connections concealed by the lavas; even its stratigraphical base and summit lost; a mere fragment of limestone, but carrying in its upper members the following curious group of *Mollusca:*

Terebratala Augusta, n. sp.
Leptocardia carditoidea, n. sp.
Leptocardia typica, n. sp.
Aviculopecten (*Eumicrotis*?) *Augustensis*, n. sp.
Pecten sp.?
Pecten sp.?
Gryphæa sp.?
Descina sp.?

Meek, Hall, and Whitfield call attention to the extremely late facies of this collection, which, according to their judgment, has a Cretaceous and even an Eocene look. But the occurrence of Jurassic forms, which these undoubtedly are, having the facies of a later fauna, is distinctly paralleled by the extremely late aspect of the Cretaceous fauna of California, whose upper members will in future, in my belief, be correlated with our Laramie group.

Over the Jurassic limestone on the northern point of West Humboldt Range lies a very heavy body of variable but generally argillaceous slates.

The exposure on Humboldt Cañon is of over 2,000 feet. And on the north side of the Humboldt valley the same slate group is exposed with even greater thicknesses.

In the southwest extension of West Humboldt Range south of Oreana there is a very great thickness of the slates, which are there interesting from the great volume of extremely fine-grained papery shales intercalated in the other more slaty argillites. Under the microscope the Oreana shales and the slates from over the limestone at Humboldt Cañon are seen to be thickly crowded with pale microlites, probably of feldspar, which have a close external resemblance to colorless microlites in the Devonian slates of Germany. When looked at by reflected light through the loupe, all these microlitic slates show a peculiar fine play of light, evidently the effect of minute reflections from the microlitic facets.

The Jurassic limestones do not recur in our part of Nevada west of West Humboldt Range, but the slates form a persistent sheet, which is seen in nearly every range lying directly on the Archæan rocks or abutting against the slopes of the old schist ranges.

It is quite clear that these upper Jurassic slates are to be correlated with the similar rocks at Mariposa, in California, which are well charged with true Jurassic fossils, and are further interesting as being the containing rock of the great auriferous quartz lodes, as Prof. J. D. Whitney has shown.

In the Nevada province, then, the Jurassic consists of a limestone between 1,500 and 2,000 feet thick and overlying slates probably about 4,000 feet thick.

SECTION III.

CRETACEOUS.

At the close of the present chapter will be found an analytical map showing the distribution of pre-Mesozoic and Mesozoic exposures. The object of showing the superficial areas of pre-Mesozoic rocks is the same that induced me to show the Archæan masses upon the Palæozoic analytical map, namely, that the relation of the rocks of the period discussed, with the preëxistent masses may be clearly seen. A glance at this map will show where the Cretaceous rocks come in contact with older formations, and where they form the earliest masses of an outcrop.

The chief fact of interest connected with the whole Cretaceous development is, that it does not continue west of the meridian of the Wahsatch. East of that line its exposure is simply a question of sufficient stratigraphical disturbance to bring it to the surface, or the accidents of erosion which have removed it from its former high position. With the exception of a small Archæan region in the Rocky Mountains, altogether east of the 107th meridian, the whole region now occupied by the basin of Green River and the Uinta was evenly covered with Cretaceous sediments which are altogether marine, and are of interest as being the last oceanic strata covering the region between the 105th and 112th meridians in these latitudes.

The Cretaceous here represented a period of comparatively uniform calm, so far as orographic disturbances go; and although it is characterized by successive subsidences, they were so general and gradual as to leave no traces of their mode of operation, except the succession of conglomerate strata and tiers of coal-beds.

The Cretaceous formation is defined below by the occurrence of the Jurassic series, well identified through a considerable portion of its extension by characteristic fossils. Between the Cretaceous and the Jurassic there is absolute conformity, except upon the immediate flanks of the Wahsatch, where the evidence is decidedly obscure and quite contradictory, the majority of the appearances indicating the usual conformity between the Cretaceous and the Jura; others, which it must be confessed offer a poor quality of evidence, point to a nonconformity here between the Cretaceous and the Jura, such as is observed on the western flanks of the Sierra Nevada in California, which formerly led me to believe that the Wahsatch and the Sierra represented the two shore lines of a Jurassic continent against which the Cretaceous rested unconformably. But I am now obliged to modify that view, and to believe that the Cretaceous, Jura, Trias, and Permian of the Wahsatch are all conformable. However that may be, from the Wahsatch eastward the entire Cretaceous series certainly rests with absolute conformity upon the Jura.

Immediately succeeding the close of the Cretaceous deposition a most powerful orographical movement took place, resulting in the plication of the Cretaceous and underlying rocks, the relative lifting of the Rocky Mountain region as regards the basin of Green River, and the draining of the Mississippi or mediterranean ocean.

Within the area examined by us the rocks subsequent to the Mesozoic are altogether nonconformable with the Cretaceous, with the slight exception of a region in the middle of the Green River Basin, where the lowest of the Eocene rests upon the somewhat eroded top of the Upper Cretaceous with coincidence of angle. Elsewhere there is a discrepancy between the Cretaceous and the Eocene, the lower part of the Eocene itself being made in great measure from the disintegration of the Cretaceous.

There is no evidence whatever of the Cretaceous ever having passed west of the Wahsatch, and all the known facts contribute to support the belief that a region a little west of the Wahsatch, now faulted downward, marked the western limits of the Cretaceous sea. To the east it extended beyond the limits of the present Rocky Mountain system, and its deposits form a prominent feature of the geology of the plains eastward into Kansas.

The upheaved sedimentary rocks along the eastern foot-hills of Colorado Range offer several admirable sections from the base of the Cretaceous far up into the series, and these exposures have formed the subject of continued study by Dr. F. V. Hayden and the late Prof. B. F. Meek. The section, as elaborated by them, has been constantly re-observed by us with such concurrence of result that we have cheerfully adopted their nomenclature from the base of the series up to the summit as defined by them. Beyond that horizon, and conformably overlying the Fox Hill group of Hayden, is a considerable series of rocks over which a conflict of opinion now exists. These rocks Dr. Hayden has successively considered as Tertiary and as transitional between the Cretaceous and the Tertiary. They conformably overlie the Fox Hill of Meek and Hayden, and are developed throughout a large part of Wyoming, as well as upon the great plains east of the Rocky Mountains south of the 41st parallel. That there might be no misunderstanding as to the stratigraphical position and nature of the rocks themselves, Dr. Hayden and I mutually agreed to know them hereafter as the Laramie group, and to leave their age for the present as debatable ground, each referring them to the horizon which the evidence seemed to him to warrant. It is proper that I should say here that the result of our investigations leads me to the distinct belief of their Cretaceous age, and in this examination of the stratigraphical geology of the Fortieth Parallel they are assumed to be within the upper line of the Cretaceous. Excepting this point of difference, we unhesitatingly follow the stratigraphical division of the Cretaceous already instituted by Meek and Hayden. Over the great extent of exposures upon which these rocks have been observed from Missouri to New Mexico, it is not at all remarkable that certain of the minor groups should be found to vary stratigraphically, while others remain uniformly persistent. Dr. Hayden himself mentions the fact that the Fort Benton, Niobrara, and Fort Pierre—his Cretaceous Nos. 2, 3, and 4—were decidedly variable, and in some sections one or other of the members was entirely wanting, or its place was represented by a new petrological member. This experience of Dr. Hayden's was repeated by us, and I appealed to him to offer a name which would represent the three groups combined. Accepting his suggestion of the name of Colorado, we have applied it to our maps and sections; and, as the legend at the side of the map will show, it is intended to embrace the three divisions. I now proceed to the examination of the Cretaceous exposures.

Dakota Group.—Overlying the softer marls and shales of the Jurassic along the whole chain of foot-hill outcrops of Colorado Range, wherever the whole inclined series is not overlaid by Niobrara Pliocene, the base of the Cretaceous is seen in the Dakota sandstones and conglomerates, a body varying from 200 to 300 feet thick, a strongly coherent rock, which resists weathering; and since it is overlaid by the softer materials of the Colorado group, as well as underlaid by the equally soft Jurassic, it forms a prominent outcrop, and throughout a considerable portion of many miles of exposure along the eastern base of the mountains from north to south, it appears in wave-ridges with a sharp face toward the range, and the more gentle inclination of the backs of the strata toward the east. These ridges, which resemble the form of an in-rolling wave, have received the senseless name of "Hog-Backs." The base of the Dakota is usually a peculiar conglomerate, which passes upward into hard, yellowish-brown, rusty sandstone, containing an irregular dispersion of iron oxyds.

The basal conglomerate is a singularly persistent feature wherever we have found the lower Dakota exposed. Along the base of the Rocky Mountains it consists of a paste of gritty, fine, siliceous sand, containing small pebbles, subangular and rounded, of black, white, red, and brown cherts, with a few fragments of Archæan schist which contain the crystalline ingredients of a hornblendic gneiss, and a few pebbles of a mixture of red orthoclase and milky-white quartz, such as occur in the Archæan rocks of the Laramie Hills. An interesting feature of this conglomerate is the extreme induration of the cement. Under the hammer the conglomerate breaks with almost equal difficulty through the matrix and pebbles. But the looser texture of the paste is detected in the constant weathering out of pebbles. Where exposed to drifting sands, the cement and pebbles wear down almost evenly. The difference in weathering is due not so much to difference of hardness as to difference of porosity between the pebbles and the cement. These conglomerates are variable in thickness, and pass up into hard, yellowish-brown sandstone, with distinct heavy bedding.

The uppermost member is an exceedingly friable, nearly white sandstone, characterized in some places by large amounts of carbonaceous material, and in others by a great deal of clayey iron ore. Along the northern part of Colorado Range, by Laramie Hills, the Dakota is often considerably shaly, while to the south it is more coherent and weathers in blocks of considerable size. Analysis proves it to be very free from calcareous material. The microscope shows it to be made up predominantly of fragments of quartz, but to contain a good deal of fine argillaceous matter, and not a little of a chloritic earthy mineral. Its exact chemical constitution will be found in the table of analyses of stratified rocks.

The Dakota sandstones occur very prominently in the mouth of Big Thompson Creek, where they form a powerful ridge 300 feet thick, which is their greatest development east of the mountains. The basal conglomerate is here seen to be overlaid by sandy, saccharoidal beds, followed by a white, almost quartzitic zone resembling the matrix of the conglomerate. The section is as follows:

	Feet.
1. Coarse yellow quartzitic sandstones, frequently conglomeratic, passing up into a yellowish-brown sandstone, almost a quartzite....	200
2. Coarse yellow sandy beds, with frequent clay-seams, capped by a coarse, sugary sandstone	100
Total	300

On the western side of the Archæan spur, directly north from Big Thompson, they dip 45° westward, with a general trend of north 35° or 40° west. On the eastern side of the same Archæan body they resume their gentle eastern dip of 14° to 16°.

Between the Cache la Poudre and Park Station is an admirable display of this formation in a strong outcrop with a north-and-south strike, dipping to the east at angles varying from 15° to 20°. Indeed, from the Big Thompson to the 41st parallel the Dakota forms an almost continuous ridge. It is again traceable from Wallbach Spring to Shelter Bluffs, and around the peculiar southwardly projecting promontory of Archæan at the Chugwater forms a marked horseshoe ridge rising above the low, valley-like outcrop of the soft, underlying Jurassic.

On the west flank of Colorado Range, partaking of the gentle westerly dip of the stratified series which margin the western base of Laramie Hills, the Dakota group forms a wide belt, extending from the northern limits of our map in a due south line as far as Red Butte Station, when, following the curve of the conformably underlying rocks, it deviates to the southwest until it abuts against Sheep Mountain. It thus forms a broad band from three to four miles in width, at the southern part lying nearly horizontal, and having an inclination of only 3° to 5° at the northern limit of the map. So gentle is the slope, and so thoroughly covered is the surface of the plain with Quaternary accumulations, that outcrops are very rare. Here and there over the Jura shales are seen the harder conglomerates, passing up into rusty coarse sandstones. On the whole the majority of outcrops are formed of a yellowish-brown sandstone, the upper members characterized by scattered occurrences of carbonaceous clays.

South of the railway the inclination of the beds to the northwest is only from 1° to 3°. It is difficult in this nearly horizontal region to obtain the thickness accurately. Like all the gently dipping sedimentary rocks upon the western side of the range, this member seems to be thicker than in the corresponding positions on the eastern side, where the steeper easterly dips have been accompanied by much greater compression.

At the little quaquaversal uplift near Como Station, the northern face of the ridge south of Como is formed of a reddish sandstone bearing Jurassic fossils, and immediately over this is the Dakota sandstone, here a compact, yellowish-brown rock, which readily breaks into huge cuboidal blocks, as observed in North Park and at various points along the wave-ridges of the eastern foot-hills. North of the lake a low wall of Dakota sandstones is seen dipping northeast at an angle of 35° or 40°.

Along the eastern side of North Park the Dakota presents features very similar to those already described on the eastern side of the range. It overlies the soft, marly shales of the Jurassic, which, as usual, are eroded out, forming a shallow valley to the east and underneath the Dakota. The latter, with a dip of 19° southwest, forms a bold ridge, which is continuous in front of the Archæan spurs, and is cut down by the streams that cross its trend. As a whole the strike is due northwest, but is subject to a remarkable sinuosity, which produces short, broken ridges, and not the long, smooth, continuous wave-lines seen elsewhere. The exposure here, as shown on Retreat Creek, is about 350 to 380 feet in thickness, and is composed of the usual yellowish-brown sandstones, not infrequently compacted into a quartzitic condition, together with the characteristic basal conglomerate, the pebbles of which here were usually about the size of a filbert, and conspicuous among them were fragments of pure white quartz and jetty-black chert.

On the western side of the Park it comes directly in contact with the Archæan along the eastern slopes of the great mass of Ethel Peak. It outcrops at intervals through an immense amount of glacial débris, dipping to the east at angles from 25° to 50°. Here, as at Retreat Creek, the black shales of the lower member of the Colorado are clearly seen in contact with the yellow sandstones. The thickness of beds here seems to have increased considerably over those displayed on the eastern side of the range. There can hardly be less than 400 feet.

One of the most interesting features of the geology of the whole Rocky Mountain region is the manner in which the sedimentary beds describe free continuous curves around promontories of Archæan. At Elk Mountain, a circular, nearly isolated mass of Archæan schists and granites, this phenomenon is well shown. Overlying the Jurassic marls, which, as usual, form a region of comparative depression, the Dakota rises in the characteristic sharp wall which is cut through by only two or three creeks. At its northern base are seen the overlying Colorado clays in distinct conformity. The dip-angles here rise to 85°, with a strike of remarkably bold horseshoe curvature, as may be seen from the geological map.

In a similar manner, around the entire quaquaversal uplift of Rawlings, above the earthy slope formed by the Jurassic marls, is seen the outcrop of powerful Dakota sandstones. An excellent exposure is that about four miles east of Rawlings Springs, where the characteristic basal conglomerate is seen to be made up of the usual dense cement, with pebbles the size of a filbert, of black chert and reddish-brown jaspers. The matrix, as developed here, is seen under the microscope to be largely made up of the fractured and partially rounded fragments of crystalline quartz. Large blocks which result from the disintegration and degradation of the Dakota again display the fact that the matrix is as unyielding as the jasper pebbles. The western faces of bowlders, swept by the prevalent west wind, which often blows with great violence and is freighted with sharp, cutting sands, display excellent examples of wind-polish. The surface is as brilliant as glass, and is modified by peculiar irregular protuberances and drill-holes, which cut through pebbles and matrix indifferently. The Dakota sandstones here show a large amount of limpid quartz-grains and partially kaolinized orthoclase crystals.

The heads of Yampa River, Elk River, and Moore's Fork converge from a remarkable recurve in the Archæan mass of Park Range. South of the great curve of Moore's Fork the lowest of the younger series is the Trias, but north of Yampa Springs the Dakota sandstones overlap the Jurassic, coming into contact with the Archæan, as they do directly across the range at the base of Ethel Peak.

In Uinta Range, above the cañon of Vermilion Creek, is a broad, open valley, carved out of Cretaceous strata. The heavy masses of Triassic sandstones are overlaid by the usual variegated shales and marls of the Jura, which are here much eroded away. The quartzitic conglomerate appears at the base of the Dakota series, containing the well known black and white chert pebbles, which are unusually small. Besides the ordinary rusty-yellow sandstone, the group here encloses nearly 100 feet of yellow and grayish sandstones containing clay-seams. The total thickness is about 500 feet.

South of the Uinta, at Ashley Creek, the ridge of Jurassic limestone is followed by a deeply eroded trough which the overlying soil shows to be made up of red and purple Jurassic shaly clays. Immediately above this comes the pebble-bearing conglomerate at the base of the Dakota, which passes upward into a white sandstone. Over it are 150 feet of blue clay slates, again overlaid by compact brown sandstones, which form the summit of the Dakota and which here carry *Inoceramus Ellioti*, *Cardium* n. sp., and *Lucina* or *Astarte*. In this ridge of Dakota sandstone, on the southern side, Mr. Emmons found a coal-bed ten feet thick, having a brilliant lustre and clear black color, and apparently of excellent quality, being altogether free from clay or selenite seams.

Just north of Peoria, on Weber River, overlying the variegated Jurassic shales, appears the Dakota. The basal conglomerate has here increased to 200 feet in thickness, the cement being still of the characteristic fine quartzitic material, while the pebbles have increased to the size of a cobblestone, some even reaching nine inches in diameter. They pass upward into light yellow sandstones, from 200 to 250 feet thick, with a very little display of blue shale near the middle of the sandstones. The strike here is a little north of east, and the dip varies from 50° to 60° northward. The total thickness is about 400 feet.

Up Chalk Creek, about half-way between Coalville and Bear River, is a considerable mass of conglomerate trending north-and-south and dipping at a high angle to the west. From its position underneath the black shales it is considered to belong to the Dakota. A similar outcrop standing vertically at the Needles, a limited body altogether surrounded by Eocene, from lithological resemblance alone is also referred to the Dakota.

In the Wahsatch, along the divide between Emigration Cañon and East Cañon Creek the relation between the Cretaceous and underlying rocks is certainly very obscure. North of Kimball's the old relation of conformity between the Jura and the Cretaceous is distinctly seen. The conglomerate at the base of the Dakota is finely displayed at least 100 feet thick and carrying large pebbles from the size of a fist to eight inches in diameter The ordinary sequence is very clearly shown in the natural section exposed in East Cañon Creek. In the hills to the north and west, however, the relations are obscure. The country is much covered with soil and forest, the outcrops are not continuous, and over the older rocks, especially on the Mountain Dell road, is seen a conglomerate closely resembling that at the base of the Dakota, which rests unconformably upon the whole older series, from the Upper Coal Measures up to the Jura. This conglomerate outcrops about six miles up from the mouth of Parley's Cañon, on the road to Parley's Park. The discrepancy of angle between the conglomerate and the Trias which underlies it amounts to this, that the latter has a high dip, rising to 60°, while the conglomerates are at an angle of 25° or 30°. Physically these conglomerates closely resemble those of the Dakota, and it is noticeable that when struck with a hammer the cement and the pebbles break with equal ease; a feature I have never observed in the overlying Eocene. From this arose the impression which I formerly held very strongly, that the Cretaceous was unconformable with the Jura; but the region is one of great structural disturbance, and the outcrops are insufficient to prove this absolutely; and since it is an exception to all the other appearances, it is perhaps best to await further facts before finally accepting the idea of a nonconformity. This conglomerate, however, is lithologically identical with that displayed at Peoria, which is unmistakably conformable with the underlying and overlying rocks.

Colorado Group.—With strict conformity the sandstones of the Dakota are overlaid by the triple group of the Colorado. As stated in the opening of this section, the Colorado Group is a combination agreed to between Dr Hayden and myself, including the three variable numbers, 2, 3, and 4 of the old Meek and Hayden section. The following is a generalized section of the occurrence of this group, as shown along the eastern base of Colorado Range, counting from the base up:

Fort Benton Group (Cretaceous No. 2, M. & H.):

1. A dark plastic clay series, with varyingly ferruginous and argillaceous layers.
2. Grayish-blue clays, often inclining to black, more or less calcareous toward the top.

For the whole group, 200 to 450 feet.

Niobrara Group (Cretaceous No. 3, M. & H.):

1. Argillaceous limestones, often based directly on the dark shales of the Fort Benton, but sometimes merging into it when the upper Benton shales are calcareous.
2. Light, variegated marls, prevailingly yellow, but often characterized by a variety of brilliant colors.
3. Yellow, white, and cream-colored marls, with gypsum.
4. Whitish-gray marls.
5. Yellow marls and intercalated saccharoidal yellow limestone.
6. Bluish-gray, soft, earthy beds, partly calcareous and partly argillaceous.

All of these members are extremely variable in thickness, owing partly to the irregular compression and partly to the actual change in the original deposit, the whole series being from 100 to 200 feet thick.

Fort Pierre Group (*Cretaceous No.* 4, *M. & H.*):

1. Grayish-black carbonaceous shales and marls.
2. Nearly black arenaceous clays.
3. Interstratified beds of clay and sand; in many localities the clay predominates; in others the sand.

Altogether, 250 to 300 feet.

Total Colorado, 600 to 1,000 feet.

This combination of the three members of the old Meek and Hayden section into a new group is rendered of value for the reason already expressed in the opening of this section, namely, the great variableness of the three members in detail, but is even more satisfactory in that it gathers into one member the great clay formation of the lower Cretaceous.

The whole Colorado group, composed of these three members, is bounded on the upper surface by the heavy sandstones of the Fox Hill, and below by the still more compact sandstones of the Dakota. It is essentially a great body of shales and clays, divided in the middle by a zone of marls and calcareous beds. Its usual mode of weathering is to form a deep trough directly upon the back of the inclined Dakota. Whether horizontal or inclined, the outcrop of the Fort Benton is usually below the neighboring level. Directly above it the marls and sandstones of the Niobrara group offer a greater resistance to erosion, and consequently form a series of slight, outcropping ridges, beyond and above which the soft clays of the Fort Pierre again form depressions, and the typical appearance is therefore two depressions, separated by the hard, ridgy outcrops of the Niobrara.

The exposures along the eastern base of Laramie Hills, north of the railway, are rather slight. But they are always seen wherever any considerable section is opened across the Colorado, as around the promontory of the Chugwater; the stream-bed showing upon its banks numerous exposures of soft clays, outlining a low valley of erosion around the harder sandstones of the Dakota. On the north-and-south ridge, between Lodge Pole and Horse creeks, the lower marls of the Niobrara carry immense numbers of the genus *Ostrea*, mainly *Ostrea congesta*, these making up nearly the whole of the rock. The overlying carbonaceous clays of the Fort Pierre carry also numbers of the form *Baculites ovatus*. The same topographical features are traceable from Shelter Bluffs to Wallbach Springs. In both cases, however, the uppermost part of the Colorado is unseen, the beds being hidden underneath the overlying Tertiary.

South of the 41st parallel, from under the escarped edge of the horizontal Pliocene plateau, appears the whole Colorado series, dipping—if we may judge from the Niobrara, which is the only group whose position is characteristically shown—about 16° to 18° to the west, while a little eastward the Fort Pierre declines to a dip of 6° or 8°. At Park Station, in beds probably belonging to the Niobrara, were found —

Inoceramus problematicus.
Inoceramus deformis.
Inoceramus Barabini.

From there southward the Colorado outcrop describes a changing curve conformable with the sinuosities of strike of the underlying rocks. It varies from two to three and a half miles in width, and is characterized by a rather smooth, grassy plain, defined along the middle at the horizon of the Niobrara by successive ridges of marls and limestones, which rise a few feet above its level, presenting an escarped face toward the mountains and a more gentle inclination toward the plain. Only in certain favored localities, where surface-accumulations of soil are insufficient to mask the outcropping beds, or where the shallow erosion of the rivers and stream-beds lays them bare, are the shales of the Fort Benton seen; but upon any cross-section line the successive ridges of the Niobrara shales can be traced. They form a curious topographical feature, because so limited and yet so persistent. What is true of the Fort Benton is also true of the Fort Pierre shales above the Niobrara. They are often recognized only by the color of the earth where vegetation exposes the decomposed shaly surface, or where some trivial cut of erosion lays them bare. In certain places the upper part of the Fort Benton is extremely calcareous, and then the line of separation between it and the calcareous base of the Niobrara becomes impossible.

There is great variety in the limy and marly beds of the Niobrara. One of the most characteristic features is its base, a bluish-gray limestone intercalated with a few varyingly thick beds of light-colored clays, which are frequently fossiliferous. Above the limestones are yellowish white and cream-colored gypsiferous marls. The mode of occurrence of the gypsum is quite interesting. It is seen occurring as thin sheets and lenticular masses parallel to the stratification of the marls, and again occupies thin seams of jointing. Often upon the surface of the weathered marl-slopes glittering flakes of gypsum are thickly strewn. Above the sulphate-bearing marl occurs a deep-yellow marl, having generally a saccharoidal look, and capped by the bluish-gray, soft, earthy beds, which are considered the uppermost members of the group.

From Park's Ranch southward to La Porte, and from La Porte to Big Thompson Creek, these colored marls are seen outcropping at horizons about 300 feet above the prominent ridge of the Dakota. From the bluish-gray limestone, which is the base-member of the Niobrara, we obtained *Inoceramus problematicus.* Chemical analysis proves this rock to contain 65.93 per cent. of carbonate of lime, the residue consisting of fine blue clay. Single beds of the overlying marls, even when not more than eight inches thick, may be traced outcropping for several miles in a low ridge above the grassy level of the plain. At the Big Thompson the marls are seen to describe a semicircle around the lower sedimentary beds, curving westwardly into a bay, and again trending southeasterly, passing, at the southern edge of our map, under the beds of horizontal (Pliocene) conglomerate.

In the province of the Plains the whole Colorado series is 600 to 700 feet thick north of the railway, thickening southward until probably it is fully 1,000 feet in the region of the Big Thompson, although the accurate measurement is exceedingly difficult, if not impossible. There the lower shales are always seen conforming to the dip of the Dakota, namely, about 14° to 20° eastward. A good instance is the dip of 16° shown by the Niobrara, just below La Porte. But a little higher in the series, and a little farther east, comes a very decided change of inclination, and the shales decline, reaching angles as low as 3° and 5°. This change of dip is altogether confined at the surface to the soft, flexible shales of the Fort Pierre, and is an interesting instance of sharp flexure without dislocation. From the character of the underlying beds, it would seem probable that underneath this flexure their more rigid bodies have suffered actual rupture. The group as a whole is highly fossiliferous, yielding, along the eastern base of the mountain, the following forms:

Inoceramus problematicus.
Inoceramus deformis.
Inoceramus Barabini.
Ostrea congesta.
Scaphites nodosus
Baculites ovatus.
Ammonites sp.?

The lower Fort Pierre yielded *Scaphites nodosus* and an undeterminable *Inoceramus.* The upper outlines of the Fort Pierre, and those of the Colorado, are indicated by a mural face of sandstone turned toward the mountains, rising only 3, 4, or 5 feet above the surface of the Plains. The sandstone strata dip off very gently to the east, and may be traced in a slightly sinuous line from Box Elder Creek to the southern limit of the map.

Laramie Plains, the great depressed region between Colorado and Medicine Bow ranges, is essentially a broad level upland of the Colorado group of the Cretaceous. On the eastern base of Bellevue Peak, in the bay-like recess, the Colorado clays come into direct contact with the Archæan rocks. For the rest, they overlie the belt of Dakota sandstones which sweeps uninterruptedly around the east and south margin of the plain and forms a continuous exposure of rock from the region of Sheep Mountain north to the northern extremity of our map, the belt varying from 12 to 25 miles in width. The valleys of the Big Laramie, Little Laramie, and Dutton and Rock creeks are eroded through the Colorado shales and marls. Their banks are in general rather low, and the exposures are decidedly imperfect. Where the North Park road approaches the mountains, dark, thinly bedded shales are seen dipping to the north, intercalated with impure limestones, more or less varied by arenaceous material. Underlying the carbonaceous clays are outcrops of variegated marls rising a few inches above the level of the Plains in a manner characteristic of the Niobrara, and carrying immense numbers of *Ostreæ congestæ.* These beds all dip away from the mountains from 8° to 15°. Below the light-colored, almost white marls are calcareous, slate-colored, muddy rocks, increasingly argillaceous as they descend, and gradually losing the calcareous character. These are underlaid by brownish rusty sandstones.

Where the Big Laramie leaves Medicine Bow Range, in bluish-gray marls marking the junction of the Fort Benton and Niobrara, occur numerous *Inoceramus problematicus.*

Near Bellevue Peak the same interesting change of dip already mentioned east of the Colorado, recurs in the Fort Pierre horizon. The calcareous beds of the Niobrara, containing numerous *Ostreæ,* decline at gentle angles of 8° or 10° to the north, while the Fort Pierre black clays, after continuing the angle of the marls for a short distance, rapidly curve into a nearly horizontal position.

At Como and Rock Creek stations the Fort Benton beds are well shown, exposing here 350 or 400 feet of dark, more or less carbonaceous clays, with intercalations of sandy clay and pure sandstones. The Fort Benton at Como carries certain strata strongly impregnated with iron oxyds, frequently resulting in concretionary structure. These ferruginous bands are exceedingly well developed at Rock Creek, where the varying oxydation gives to the exposed strata all the alternating colors of volcanic ash. These argillaceous iron-stones, thus far of no practical value, may eventually be found rich enough to prove valuable as ores of iron. The ferruginous strata vary in thickness from a few inches to three feet. Chemically, they are argillaceous carbonates, more or less oxydized, effervescing freely under acids, and leaving a residuum of clay and sand. After passing the station, Rock Creek continues its course in a sharp cañon through the Fort Benton clays. A few miles east of Como Station one of the upper sandstone beds of the Fort Benton is compact enough to afford a good building-stone, and is used by the railroad company for the construction of culverts and other stone work. These sandstones carry numerous but imperfect leaves and stems of deciduous trees.

Within North Park, following the outcrops of the Dakota sandstones already described upon the mountain foot-hills, the Colorado group is exposed to a very great thickness, overlaid at the horizon of its uppermost members by the undisturbed Tertiaries which occupy the main area of the park. All three divisions of the Colorado are distinctly seen, though the limestones and marls of the Niobrara are perhaps less characteristically developed than on the eastern slope. The dark clays and ferruginous layers of the Fort Benton are capped by a buff and gray limestone which marks the base of the Niobrara. This limestone forms an admirable datum-level throughout the whole North Park. It has a thickness of only 20 feet, but is remarkably persistent, of extremely fine texture, somewhat siliceous, breaking with a fine conchoidal fracture, and when struck with a hammer emits a peculiar bituminous odor. It is essentially a bituminous, siliceous limestone. The marls directly overlying this, which form the body of the Niobrara, are extremely variable in the proportion of lime and sand in their composition. At times they are clear marl; again, tolerably pure yellow saccharoidal sandstone, with hardly a trace of lime. The Fort Pierre group consists of extremely fine black shales, passing into yellowish-white sandstones, very friable and roughly bedded, developed to a considerable thickness, though probably not reaching the base of the Fox Hill. These upper beds yield *Baculites ovatus* and *Inoceramus Barabini*, forms thus far more characteristic of the upper Fort Pierre than of the overlying Fox Hill. Throughout these sandstones there is also a considerable proportion of intercalated clay-zones, more than we ever observed in the Fort Pierre. The entire thickness of the Colorado series as developed here is between 1,600 and 2,000 feet. The lower members of the group are well exposed on the south flanks of Bruin Peak, near Platte River. Overlying the lower clays is seen a steep bank of marls and dark, earthy limestones, crowded with a species of *Ostrea.*

The Colorado beds are also interestingly seen on the southern slope of Sentinel Peak, where they incline southward at an angle of 22° to 25°, overlying a fine development of Dakota sandstones. All along the eastern margin of the Park, from Sentinel Peak to East Camp, wherever not obscured by soil, the Colorado beds are finely developed. Ordinarily the clay and shale portions are hidden by soil and disintegrated clay; but, as usual, the bituminous limestones and overlying marls of the Niobrara horizon are traceable with great continuity. At Parkview

Peak there are irregular displays of limestone, in great measure masked by the outbursts of trachyte, and the exposed masses of Cretaceous sandstone are themselves interrupted by numerous dikes. Here is seen quite an exhibition of caustic contact-phenomena.

The best display of these rocks on the ridge which separates North and Middle parks is at Ada Spring, where the clays and marls of the Colorado are overlaid by the trachytes at the south and overlapped by the horizontal Tertiaries at the east, north, and west. The ravines east of Ada Spring cut the groups at right-angles, showing the bituminous limestones and argillaceous marls of the Niobrara and the overlying intercalations of clay and sand belonging to the Fort Pierre. From the lower bed of limestone was collected a specimen of *Inoceramus*, together with an oyster that Professor Meek ascribes to the Fort Benton horizon. The marls here are not above 150 feet thick, and pass into yellowish-gray shales above. The Colorado group is also well displayed at the eastern base of Ethel Peak and on the foot-hills north of Crawley Butte.

South of the uplift at Como the clays and marls of the Colorado cover the whole plain in a southwesterly direction, occupying the valley of the Medicine Bow, or rather the southern half of its water-shed, and filling a deep reëntering bay between Rock and Elk mountains. Around the northern base of the sedimentary series of Elk Mountain, the Colorado, or at least its lowest members, continues as far as Rattlesnake Pass, where the horizontal Tertiaries of the Platte overlap it. It is interesting to observe the mode of overlap of the Colorado. At Rattlesnake Creek it lies at the base of the slope of the hard Dakota sandstones, separated from the Archæan mass by the Jura, Trias, and Carboniferous limestones; but sweeping around to the northeast point of Elk Mountain it gradually overlaps all the other formations and comes directly into contact with the Archæan, maintaining this contact around to the northwestern point of Rock Mountain, and forming a deep bay through which the upper waters of Medicine Bow River have their course for twelve or thirteen miles. An interesting topographical feature of the Cretaceous in this region is the manner in which Medicine Bow River flows northward through the easily eroded beds of the Colorado till it reaches a mural escarpment of the overlying Fox Hill sandstones, whose harder material forms a barrier to its farther northern flow, and deflects it into an easterly and northeasterly direction; the river, after it encounters the Fox Hill, following approximately the contact-line between that formation and the Colorado. The exposures of the Colorado beds through this region are very variable, but on the whole sufficient to make out clearly their presence and relations.

Just north of Medicine Bow Station the beds strike north 65° to 70° west, and dip 17° to 18° southwest. Here the white marls of the Niobrara yield *Ostrea congesta*, with an imperfect *Inoceramus;* and below the Niobrara series, in the sandy beds of the Fort Benton, occur *Inoceramus altus* and, a little higher in the series, *Scaphites Warrenianus.* Northwest of Elk Mountain the recognizable portion of the Niobrara between the two sets of clays appears to be hardly more than 100 feet thick. Northwest of Sheep Butte and south of Rattlesnake Road the Fort Benton beds are present, carrying a high proportion of ferruginous clays. The iron here is in concretionary and lenticular masses, black and brownish-black, with a conchoidal fracture and a hardness of 4. Throughout the cracks and fissures of these ferruginous clay-stones there is more or less spathic iron and a good deal of carbonate of lime Besides this, the whole formation is varyingly characterized by carbonaceous matter in clays. A specimen of this clay-iron is analyzed in the table of chemical constitution of stratified rocks. Although rich enough for smelting, it nowhere occurs here of workable magnitude. The strike north of Elk Mountain is north 35° to 40° east, dipping 52° to 57° northwest.

Under the conglomerates which cap the northern edge of Savory Plateau appears a mass of conglomerate-bearing sandstone, evidently the Dakota Cretaceous, dipping in such a manner as to show a local quaquaversal uplift. The conglomerates dip at a slope of 55°, the angle declining as they descend into the valley. Following down a line from the northern point of the plateau directly across Sage Valley, the conglomerates and sandstones are overlaid by blue clay-shales, followed by thin-bedded sandstones and interstratified clays. These are succeeded by yellowish-brown, concretion-bearing sandstones, considerably calcareous, followed by 100 feet of blue and white clays containing thin limestone beds full of *Ostrea congesta.* A little way above is a second thin, shaly limestone, also abounding in *Ostrea congesta,* and characterized by the presence of much aragonite. It would seem here that the sharp division-line found so often between the Benton and the Niobrara is wanting, and that the former is prevailingly calcareous at the top, the line being impossible to draw, as is so often the case along the Laramie Hills. Over this calcareous region the character of the soil shows that the Fort Pierre clays are present, although their attitude is masked. Along the northwestern side of Bridger's Pass and the northern side of Sage Creek the area of the Colorado beds is sharply defined by a mural face of the Fox Hill sandstone, which future description will show to be of great geological importance.

Around the quaquaversal uplift of Rawlings the Colorado beds occupy the base of the slope.

North of Hantz Peak outcrops a considerable mass of conglomerate-bearing sandstone, almost a quartzite, overlaid by shales, which are surrounded and almost overlaid by the trachytes of Steves's Ridge. There is evidence of a great deal of local crumpling against the Archæan; and in some vertical shales, doubtless of the Colorado group, were obtained unidentifiable species of *Ostrea* and *Inoceramus.* Farther down the river the shales of the Colorado overlap the Dakota and come directly into contact with the Archæan. Outcrops are never continuous, but they consist of blue and drab shales, and slight developments of marl, the whole overlaid westward by the grayish-white sandstones of the Fox Hill. Between the isolated trachyte body known as Sugar Loaf Peak and the Archæan is a local anticlinal of which the lowermost exposure is Jurassic, capped by the sandstones of the Dakota, and those by the shales of the Colorado.

The exposures of Cretaceous along the northern slopes of the Uinta are confined to three areas—the eastern end of the O-wi-yu-kuts Plateau, a region extending from Bruce's Mountain to Mount Corson, and the extreme western end of the range at Kamas Prairie.

At Vermilion Creek the clays of the Colorado, with the middle zone of the marly Niobrara limestones, are seen overlying the Dakota conglomerates and sandstones. The outcrops form a series of smooth, clayey ridges, from 1,500 to 1,800 feet in thickness.

Where Green River enters the Uinta, over a broad region extending twelve or fifteen miles on each side of the river, and from four to six miles in a north-and-south line, the overlying Tertiaries have been eroded away, showing the whole series of sedimentary beds from the Weber quartzites up to the higher members of the Cretaceous. Overlying the Dakota, which is here expanded to about 450 feet, and contains within the sandstone the prominent body of blue shale already described, the flat plain country to the north is composed of a broad exposure of Colorado beds. They are for the most part covered with soil, but here and there the lateral ravines on the immediate foot-hills display the contact between the upper sandstone of the Dakota and the blue Fort Benton shales. The latter are here remarkably fine-grained and papery in structure. They carry fish-scales and fragments of fish vertebræ, and are overlaid by the calcareous Niobrara zone which comes to the surface in yellow and gray marls and sandy limestones. The line of demarkation between the Benton and the Niobrara is altogether obscure, and the region as a whole serves only to show that the Colorado group is persistent to this longitude, and is here fully 1,800 feet thick.

Around the southern and western margins of the Yampa Plateau its complicated orographical boundaries are bordered by sinuous outcrops of Cretaceous, as shown upon the map. The troughs which lie between the prominent anticlinal projections are altogether composed of softer beds of the Colorado Cretaceous, which extend down Green River for several miles, and form an important area drained by the lower parts of Brush and Ashley creeks. Upon Ashley Creek, directly above the Dakota sandstones and conglomerates which here rest upon the soft shales of the Jurassic, are about 100 feet of blue-clay slates, forming the base of the Fort Benton, which passes upward into a brownish sandstone yielding the following fossils:

Inoceramus Ellioti.
Cardium, n. sp.
Lucina or *Astarte.*

On the southern face of the ridge, on the top of this yellow and white sandstone, was found a seam of coal ten feet thick, of remarkably good quality Above this the succession of clays and marls is obscured by débris. Where the Indian trail crosses Brush Creek this coal recurs at a corresponding horizon, fossils characteristic of the Colorado group being found both above and below the coal-bed. The strata enclosing the coal have a dip of 45° to 50° to the northeast, and represent the southern member of the deep synclinal which lies between the Split Mountain projection and the main mass of the Uinta. The coal-seam here, as on Ashley, is about ten feet thick, and is divided by several seams of sandy and argillaceous matter. About 200 feet above this, on the ridge, though geologically below it, occurs a second coal-bed, within the limits of the Dakota and perhaps not far from its base, although the Jurassic outcrops which should mark the horizon of division are here obscure. This coal-bed recurs near the western end of the Uinta upon Red Fork. The upper part of this stream flows parallel to the strike of the upturned beds, and displays the identical coal-seam enclosed in a white, friable sandstone. Along the singularly curved ridge constituting the western base of Split Mountain, the main coal-seam, which forms a distinct monoclinal trough fifteen or twenty feet wide, is bounded by an overlying series of sandstones that contain globular concretions from six to ten feet in diameter, which weather out from their loose sandy matrix and cumber the slope. These great spheroids are marked with projecting ridges checked off at intervals on their surface into meridians and parallels, like a globe. On analysis they yield 45 per cent. of carbonate of lime and a considerable proportion of alumina, which was not estimated. The beds here dip 40° to 50°. Directly overlying the spheriferous sandstone which adjoins the coal are the lower clays of the Fort Benton.

In the angle between the Wahsatch and the Uinta the greater part of the area is covered by either horizontal or gently dipping beds of the Vermilion Creek Eocene. In the valleys of Weber River and Chalk Creek, and in the hills upon either side of these two lines of erosion, is laid bare a considerable area of Cretaceous rocks, as may be readily seen on the map. Along the Uinta, as displayed in the valley of Weber River below Peoria, the Dakota sandstone, there a conglomerate carrying very heavy beds, is overlaid by a broad mass of the Colorado series, which consists only partially of the clays and marls that are typical farther away from the Wahsatch. It is here characterized rather by sandy than by argillaceous and shaly materials. Although there is a hint of the softer clays, they are neither so conspicuous nor so pure as farther east. The dip from the high angle of the Dakota, as seen below Peoria, declines to 30° to the north, and the valley thence down to Coalville is entirely in the beds which we conceive to belong to the horizon of the Colorado. There are several minor folds, and a considerable amount of dislocation, the faults having a trend nearly at right angles to the strike of the strata.

Between Rockport and Wanship there is an anticlinal developed in the Colorado beds. The strata, which down to that point have dipped to the north, rise with a southerly slope, pass over the anticlinal, and again incline to the north. Here also occurs an interesting change of strike. The parallelism with the Uinta is entirely lost, and at Coalville the beds strike only a little east of north, dipping to the northwest. Below the little town of Wanship, on the left bank of Weber River, the prevailing beds are a mixture of clays locally intercalated in yellow and gray sandstones, with some massive white strata carrying pebbles. The beds just above Wanship, where they pass under the horizontal Tertiary, are considered to be about on the horizon of those exposed at Coalville. The bed of coal which is shown at the Spriggs mine, and which appears to have been locally thrown to the southeast, recurs on the western bank of the river, and passes above Wanship. A better section is exposed upon the Coalville side of the river. The hills to the southwest of the village, which are capped with horizontal Tertiary, are much covered with detritus; but in the valley of Chalk Creek are exposed at numerous places the black shales and marly beds of the Colorado, trending in the region of Coalville to the northeast. In passing eastward the strike curves around to a nearly east-and-west line, and six miles east of Coalville it is due east-and-west. Again, east of Uptown it curves into a nearly north-and-south line; so that between Wanship and Castle Rock, on the Union Pacific Railroad, the strata make two bends, each nearly at right angles, the northwardly strike developed at Coalville recurring south of Castle Rock. These two great flexures are accompanied by a series of faults, both longitudinal and transverse, which divide the whole exposure into dislocated blocks on a grand scale, and render the examination of single sections exceedingly uncertain, probably exaggerating our ideas of the local thickness. About a mile up Chalk Creek valley, and a quarter of a mile to the north of the stream, the rock as exposed on the surface of the spur is a buff and gray sandstone, carrying frequent pebble-zones intercalated with thin, laminated clays. About 100 feet below the horizon of the Chrisman mine, which is evidently the same bed opened in Spriggs's mine at Coalville, the interlaminated clays and sandstones contain the following fossils:

Inoceramus problematicus.
Cardium subcurtum
Lucina.
Macrodon.
Modiola multilinigera.
Arcopagia Utahensis.
Corbula.
Martesia.
Neritina pisum.
Turritella Coalvillensis
Eulima funiculus.
Fusus (Neptunea?) Gabbi.
Melampus.

This list is completed from the section of Professor Meek,* although most of the species were first collected here by us, and the locality thereby brought to Meek's attention.

Above the coal horizon are yellow sandstones which, both in the regions of the Chrisman mine and in the Spriggs mine, carry *Inoceramus problematicus* and *Ostrea soleniscа.* Above this, and forming the valley-bottom at the mouth of Chalk Creek, is a thickness of 50 or 60 feet of soft, black clays, which represent the lower clays of the Fort Pierre group. Along the northern side of the valley, and forming a cliff which rises in the angle of the confluence of Chalk Creek with Weber River, is a body of sandstone showing

* Geological Survey of the Territories, 1872, p. 439.

a cliff 30 or 40 feet high, and containing casts of *Avicula*, *Cardium*, *Trapezium*, and *Tellina*. These sandstones are prevailingly white at the bottom of the cliff, and at the top are coarser, being yellowish in the middle. Following down the strata-backs, on the northern slope of the hill, the ravine along the north is composed of clays intercalated with sandstone, the base of the second ridge yielding, from sandy beds of a rusty yellow color—

Avicula gastroides.
Cardium.
Tellina.
Gyrodes depressa.
Fusus Utahensis.

This whole group of sandstones, beginning with the *Avicula* beds above the black shales which overlie the black clays carrying *Inoceramus problematicus*, is considered, from lithological resemblance to the Fox Hill beds, as developed farther east and northeast, to represent the bottom of that group. Below that horizon clay-beds recur, though not with the regularity and volume that we have seen farther east. Still, they form as prominent a member as do the sandstones; whereas from that horizon upward through an exposure of over 3,000 feet the beds are prevailingly sandstones which bear a close resemblance to the main body of the Fox Hill farther east. With this important stratigraphical change there is a great break in the organic remains, the prominent species, *Inoceramus problematicus*, not passing above the top of the Colorado, so far as observed. *Inoceramus problematicus* was also found in Chalk Creek valley, above Uptown, in dark clays which apparently represented those that underlie the Spriggs coal-bed.

The conglomerates of the Dakota form a very powerful feature in East Cañon below Parley's Park, and are overlaid by a considerable thickness of intercalated clay beds, gray sandstones, and conglomerates. From the uppermost sandstones, directly where they pass under the horizontal Tertiary, were obtained a large number of casts of bivalves in a white, almost quartzitic sandstone immediately overlying a heavy bed of conglomerate. They are specifically undeterminable, but closely resemble those found in the laminated clays and sandstones 100 feet under the Spriggs mine.

A further outcrop of the Colorado beds is observed near Croydon, where a rusty yellow sandstone forms a considerable cliff, underlaid and overlaid by dark clays. The fossils obtained from these sandstones, although specifically undeterminable, belong to the genera *Inoceramus* and *Macrodon*.

As between the Colorado group, in the Rocky Mountain region, and the Wasatch, it will have been perceived that the pure clays and brittle marls of the eastern region have in the main given way to sands and conglomerates, and that in the western area coal-beds, which are wanting at the east, are frequent all the way through the group.

Fox Hill Group.—North of the 41st parallel on the Great Plains the horizontal Niobrara Pliocenes, in stretching westward, have overlapped all the Upper Cretaceous, and the Fort Pierre beds are the uppermost members exposed. But south of that parallel the Fox Hill sandstones form a broad belt extending from the escarpment of the Tertiary southward to the southern limit of the map, along the Plains. In the region of our map this belt varies from six to nine miles in width. The partition-plane between the Fort Pierre and Fox Hill is the junction of the upper dark clays of the former with a rusty, coarse, loose-textured, yellow sandstone of the latter. It will be remembered that the upper clay-beds of the Fort Pierre on the Plains dip at a very gentle slope, averaging 2° to 4°. Over this the basal sandstone of the Fox Hill group shows itself in a low ridge five or six feet high, which is traced in a meridional direction southward on the Plains, as shown on Geological Map I. This sandstone, in several localities, carries the characteristic fossils of the Fox Hill group. They are first found by us east of Park Station, about a mile north of Cache la Poudre Creek. Here were numerous specimens of *Inoceramus*, well preserved, including *I. Barabini*, associated with *Ammonites*. The exposures of this belt are always extremely limited, outcropping on the slightly undulating plain, which for the most part is covered with earth and well grassed, the underlying rock being concealed. Occasional outcrops, however, prove the Fox Hill formation to be well developed here, with a thickness of 1,200 or 1,500 feet, and to consist of the ordinary soft, yellow, friable sandstones, rendered impure by more or less argillaceous material, and containing distinct but always quantitatively unimportant beds of clay. The upper 300 feet are a more compact sandstone which so far yields no fossils.

On Laramie Plains the only development of the Fox Hill is that which lies to the north and east of the projecting mass of Medicine Bow Range marked by Rock and Mill peaks. Here the friable yellow sandstones of the Fox Hill overlap the Colorado beds and come directly into contact with the Archæan. They form a gentle, sloping plateau, almost horizontal, though dipping slightly to the east and extending out from the Archæan mass from six to eight miles. Along its outer margin it is clearly seen to overlie conformably the sandy beds which there cap the clays of the Fort Pierre division of the Colorado. The main color of the Fox Hill sandstones is here more reddish than east of the mountains. Directly south of Mill Creek is a body of brownish gray sandstones carrying layers of rich carbonaceous shales with seams of coal, the shales reaching three feet in thickness between massive sandstone beds, the latter yielding a few impressions of deciduous leaves. This is a region of extreme local disturbance, the strata striking from north 30° to 40° east, and dipping 50° or 60° north.

Between Cooper and Four Mile creeks, the plateau of Fox Hill sandstones is traversed by two wagon-roads. South of the upper one was found a new species of the genus *Axinea*, described as *A. Wyomingensis*, occurring with *Inoceramus Barabini*. The valley of Rock Creek shows excellent exposures of Fox Hill beds, which rise on either side of the stream for about 300 feet. Enormous numbers of the genus *Inoceramus* occur in the sandstones here. To the south of Rock Creek, and between there and Cooper Creek, sandstones rather low in the Fox Hill series are seen to be intercalated with various beds of carbonaceous shales, and with unimportant beds of lignitic coal. East of Colorado Range the Fox Hill beds contain no lignites, and these are the first which have been observed in passing westward. On the north side of Cooper Creek valley, enclosed in beds of hard slaty clay, which are underlaid and overlaid by massive, light-colored sandstones, are further developments of coal. It is clear that these stratigraphically underlie the beds which carry the distinct Fox Hill fossils, *Inoceramus Barabini* and others. The Rock Creek coal-outcrops are on the old Overland Stage Road, occurring in a similar manner to those at Cooper Creek, and on about the same geological horizon. It is singular that these extremely promising coal-bearing beds have never been more thoroughly explored for commercial purposes.

By referring to the sheet of general sections in the Atlas, a better idea of the relations of the Fox Hill sandstones may be obtained than by following the very complicated structural details shown upon the general maps. In the uppermost partial section shown upon the sheet, the division corresponding to Map I. of the Northern General Section, it will be seen that the narrow bed of the Colorado series, in all not over 1,500 feet thick, is capped by 7,000 or 8,000 feet of sandstones, of which the Fox Hill forms about 3,800 feet. These consist of red and yellow rusty sandstones, characterized by a good deal of ferruginous material, varyingly coarse, almost always of loose texture, and carrying throughout the whole extent limited and irregular beds of shales and clays, some carbonaceous, others highly calcareous. It will be seen how these heavy masses of sandstone come to the surface near Medicine Bow Range and against the sides of the anticlinal of Rawlings Peak.

From Medicine Bow Station they form the surface to within three miles of Carbon. Along that line all the beds dip westward. The surface is a gently rolling country, with occasional sharp edges of sandstone rising a few inches or a few feet above the plain. The base of the series consists of coarse yellowish beds interstratified with ferruginous clays, shales, black carbonaceous clays, and steel-gray-colored beds, the clay intercalations being an insignificant part of the great sandstone group.

In the region of Carbon, the Fox Hill sandstones are very well developed, and dip from every direction inward toward the town. To the southwest they are well exposed in Simpson's Ridge, where they rise 800 feet above the village. The general trend of this ridge is north-and-south, and it is built of an imperfect anticlinal, the beds on the eastern side dipping eastward at 50° or 60°, while upon the opposite side they incline westward at 35° or 40°. In the axis of the fold are seen some medium-grained, pearl-gray sandstones, passing upward into arenaceous clays, characterized by the presence of a considerable amount of iron, the following subdivisions being noted:

1. Thinly laminated arenaceous clay.
2. Rusty sandstones with ferruginous seams.
3. Ferruginous fine-grained clay-stone, 4 feet.
4. Fine black clay, 50 feet.
5. Ferruginous clay-stone, 3 feet.
6. Crumbling, rusty sandstone.

Overlying the last member are white sandstones, passing into red. North of the railway and east of the North Platte is a noticeable ridge having a monoclinal structure, dipping to the northeast, and composed of Fox Hill sandstones. Below Fort Steele this ridge determines the course of the river, exactly as the Fox Hill bluffs to the east have deflected the Medicine Bow from its normal direction.

The characteristic feature of the outcrop of the Fox Hill throughout all this region of Wyoming is the bold bluffs of massive sandstone standing out in powerful escarpments above the always topographically lower areas of the Colorado clays. These bluffs, as in the case of Separation Peak, rise 1,000 feet above the clays of the Colorado. The maximum thickness of the Fox Hill here cannot be less than 3,500 to 4,000 feet. There are a few casts of *Inoceramus* and *Baculites*, together with some plant remains.

A section across the ridge on the western side of the Platte, south of Fort Steele, shows that the lower 2,000 feet are principally beds of massive sandstone, 50 or 100 feet thick, with but very little shale. Above these are about 1,500 feet of more thinly bedded sandstones, whose individual members vary from five to fifteen feet in thickness, and contain a great many interlaminated shales, which are often bituminous, and thin seams of coal. In the valley south of the ridge, south of Fort Steele, the younger sandstones are decidedly ferruginous, show a considerable change of character, and are supposed to represent the bottom of the Laramie. The entire Fox Hill here is estimated at about 3,500 feet. About four miles northeast of Fort Steele the river cuts a cañon through nearly horizontal beds of the Fox Hill. A friable yellow sandstone, shown about thirty feet above the river level, is rich in fossils of the genus *Ostrea*.

The middle of the interesting oval uplift of Bitter Creek quaquaversal is occupied by a Quaternary valley, whose longer expanse is with the axis of upheaval, north-and-south. It is crossed diagonally by the valley of Bitter Creek. The lowest Cretaceous exposures, which are laid bare in the middle of this upheaval, are obscure occurrences of shaly beds of the Colorado, which, for the most part, are covered with Quaternary débris, but outcrop in the little hill in the middle of the valley, and on the south, toward Quaking Asp Mountain, constitute a considerable area, although they are to a large extent concealed by more recent débris. Around this nucleus of the Colorado are traced, in irregular but nearly continuous concentric ovals, the outcrops of the Fox Hill, and over them those of the Laramie. On the eastern side of this oval body the dips are from 5° to 7° to the east, as shown by the railway-cuts from Black Butte to Salt Wells. On the opposite side they decline to the west from 12° to 15°, as seen in the region of Rock Springs, while toward the south, beyond Quaking Asp Mountain, the outcrops of Laramie sandstones dip 25° to 30° to the southwest.

About six miles east of Rock Springs is seen a compact sandstone of almost quartzitic nature, containing casts of *Ammonites*, *Cardium*, and *Inoceramus*, specifically undeterminable. This is overlaid by coarse gray sandstones, dipping 13° to the west. Continuing down in the series, the Fox Hill beds quickly pass under the Quaternary. In the region of Quaking Asp Mountain is a fine display of Fox Hill sandstones. This peak is quite a plateau-like summit, made of sandstones dipping southwest and striking northwest. They are decidedly compact. The central Quaternary plain is edged upon the southwest by a line of bluffs referred to the Fox Hill. Again, north of Salt Wells Station the Fox Hill beds describe an oval curve, with the convexity to the north, and there contain fragments of *Ammonites* and *Inoceramus*. The upper strata of the Fox Hill, where they approach the Laramie group here, are often very thinly bedded, and show a tendency to split up into broad flakes like flagstones. They are also more compact than the overlying Laramie series. Coal-seams are decidedly infrequent, and the presence of *Ammonites*, *Baculites*, and *Inoceramus* is confined to the Fox Hill series. Reckoning by the average dip and width of outcrop, the transverse section of the Fox Hill here gives about 3,000 feet. In the sandstones east of Salt Wells is found a compact, green, argillaceous rock, close-grained and lithologically not far removed from one already described on the eastern side of the Platte at Fort Steele, and in Oyster Ridge. It is a slightly calcareous clay-rock, and is not seen in the Laramie.

From Bear River City, on the Union Pacific Railroad, in the southwestern corner of Wyoming, is an exposure of the narrow crest of an anticlinal of Cretaceous, called Oyster Ridge, which, with the exception of slight intervals, where it is masked by overlying unconformable Eocene rocks, continues to the northwest for 50 miles, passing beyond the limit of our map north of Ham's Hill. The chief exposures are at Bear River City and in the valleys eroded by Ham's Fork and the Little Muddy. In general, this is a long, narrow chain of outcrops, partly an exposure of the axial region and partly rocks of the western half of the fold. The strike of the bed varies from north 30° east to due north. There is evidence of a considerable amount of faulting and a good deal of erosion before the deposition of the overlying Eocene Tertiaries. At Ham's Hill the Fox Hill series are exposed as massive sandstones and intercalated sandy shales dipping 20° to the west. Farther north, and beyond the limit of our map, on Fontanelle Creek, the axis of this anticlinal is observed, showing that it is a very long, persistent fold. Where the Little Muddy cuts through Oyster Ridge the Fox Hill sandstones are again seen dipping to the west and striking north 15° east. In a little shallow valley within Oyster Ridge some disintegrated clay-beds are seen, succeeded along the east by the Fox Hills, dipping easterly. They are undoubtedly the upper members of the Colorado series, occupying the crest of the anticlinal; the Fox Hill, which has been eroded from over them, dipping to the east and west of them. Nowhere else in Oyster Ridge has the eastern member of the fold been observed. In this ridge *Ostrea solenisca* forms solid beds of great thickness, the individual shells reaching twelve inches in length. The sandstones contain some peculiar intercalations of siliceous clay-slate made up of fine grains of pellucid quartz in a clayey matrix. At the extreme southern end of the long, longitudinal valley of the south fork of the Little Muddy, the stream-bed occupies a synclinal trough in the Fox Hill sandstones, which seems to be a minor secondary synclinal on the western flank of the main upheaval. There is a good deal of local disturbance, and at the southern end of the valley the rocks on the western side of the synclinal dip to the east at an angle of 45°. At the very upper end of the valley they dip from both sides 60° toward the centre. Some clays underlying the lowest Fox Hill on the eastern side of the synclinal contain *Cardium auperculum*. The clays out of which these fossils were obtained have been bored for petroleum, and a small amount of it has been obtained. They are doubtless the upper members of the Colorado, and are only mentioned here as forming the lower boundary of the Fox Hill. East of this, again, are found the regular western-dipping Fox Hill sandstones, the continuation of Oyster Ridge, which here incline 20° to the west, carrying a twenty-foot vein of coal. The reference of these beds to the Fox Hill, however, is rendered somewhat uncertain by the amount of local faulting. It is quite possible that the sandstones belong to the Colorado, and that the coal corresponds to that found on the southern slope of the Uinta, and indeed at Coalville.

The southward continuation of this series, after an interruption of a few miles by overlying Tertiaries, reappears at Aspen, on the railway. Here over the Colorado clays, which are well developed, carrying fish-bones and fragments of *Ammonites*, besides beds of grayish limestone which mark the Niobrara horizon, the sandstones of the Fox Hill are well exposed, dipping from 10° to 15° westward, carrying numerous *Ostrea solenisca*.

At Bear River City the hills to the north and west of the station are formed of heavy whitish sandstones, standing nearly perpendicular and enclosing several beds of coal. The sandstones are rich in *Inoceramus problematicus* and some undetermined univalves. Above the Colorado clays the exposure of these sandstones amounts to 7,000 or 8,000 feet in thickness. They are for the most part white, though occasionally inclining to brown, and carry at intervals beds of heavy conglomerate and irregular intercalations of clay. Of this whole mass about 3,000 to 3,500 feet are assigned to the Fox Hill series.

The Big Horn Ridge, an interesting topographical feature east of Green River, near where it enters the Uinta Mountains, consists of the full series of the Fox Hill sandstones overlying the soft intercalated clays and marls of the Colorado, which occupy a broad valley depression between the ridge and the slopes of the Uinta, which are here of the solid Dakota sandstones at the base of the Cretaceous. The Fox Hill sandstones are sharply defined at the base by the clays and clayey shales of the Colorado, and are bounded in the ascending series by the rusty red sandstones of the Laramie, but are partly margined on their northern flank by the Eocene, which overlaps the greater part of the Laramie series. The powerful Fox Hill sandstones passing eastward are faulted down into contact with the Red Creek Archæan at one point, where their average dip of 25° to the north is suddenly increased to a vertical position; and farther eastward they are again underlaid by the Colorado beds, and near Bruce Mountain pass finally under the overlapping Eocene beds. South of Big Horn Ridge and in the clays near Green River the upper part of the Colorado formation yielded *Baculites* and *Inoceramus* of undeterminable species. The Fox Hill in the Big Horn ridges is hardly less than 3,300 feet thick.

The only considerable exposure of this group south of the Uinta within our belt is at Wansit's Ridge, where, over the Colorado clays and sandy shales, is a brown shaly sandstone passing up into 100 feet of white massive sandstones, overlaid by 50 feet of bituminous sandstone, the latter a greenish, coarse-grained rock, over which are 50 feet more of sandstones slightly bituminous. This bituminous sandstone is a very peculiar occurrence, not observed elsewhere in the Cretaceous of the Fortieth Parallel. Seen upon the weathered surface, the rocks present the ordinary appearance of a light yellowish sandstone, but the fracture is pitchy black. A specimen analyzed yielded 11 per cent. of bituminous matter and 85.5 of silica. These beds strike 20° south of east and dip 20° to the southwest. They recur on the eastern side of Green River, forming ridges along the valley of White River.

In the section exposed at Coalville the boundaries of the various members of the Colorado are no longer distinguishable. The shales are constantly interrupted by sheets of sandstone, which here form decidedly the predominating feature. The immense beds of black clays of the Fort Pierre and Fort Benton, which along the eastern part of the Uinta are so easily distinguishable, are here so subdivided by sheets of sandstone as to be no longer clearly recognizable. Moreover, the characteristic limy zones of the Niobrara are not observed. Directly north of Coalville, on the north face of the first ridge, in the shales which overlie it, and in a yellowish-gray sandstone, are specimens of *Inoceramus problematicus*, which have been assigned by Professor Meek to the horizon of the Niobrara, and were not supposed to pass above it. It would seem here that it must have a higher range and pass up into the Fort Pierre. Be this as it may, the alternation of clays, shales, and sandstones continues upward in the series from the *Inoceramus problematicus* bed for about 280 feet. At that point occurs a heavy, massive bed of whitish sandstone, carrying *Ostrea soleniscа* and *Cardium*. This appears to be the lowest horizon of the *Ostrea solenisca*, and corresponds to the uppermost level of the main intercalations of sand and clay. I am inclined to regard the 280 feet above the *Inoceramus problematicus* clays which closely overlie the Spriggs coal-vein as equivalent to the Fort Pierre, and to draw the base line of the Fox Hill at the bottom of the heavy white *Ostrea solenisca* sandstones. These sandstones occur on the northwestern side of the valley beyond the first ridge north of Coalville, and are seen on the southern base of the second ridge. From that point upward there is an exposure of 3,000 feet, chiefly sandstones, though more or less intercalated with local clay and shale-beds of moderate dimensions and some considerable sheets of conglomerate. About 800 feet up in the series, on the face of the third ridge, overlaid and underlaid by sandstones, occurs a dark clay-shale, containing the interesting mixture of marine and fresh-water fossils so fully described by Professor Meek. The list which is made up from his collection and ours includes —

Anomia,
Inoceramus, and
Cardium,

and is reënforced on the opposite side of the river, where the same horizon is again identified at the Carleton Mine, by —

Unio,
Cyrena Carletoni,
Neritina Bannisteri,
Neritina (*Dostia?*) *bellatula*,
Neritina (*Dostia?*) *carditiformis*,
Eulima chrysalis,

Eulima inconspicua,
Turritella spironema,
Melampus antiquus,
Physa, and
Valvata.

The occurrence of such an association of fossils, with distinct marine forms above and below them, requires no remote explanation. We are here close to the original shore of the Cretaceous ocean; immediately westward, beyond the longitude of the Wahsatch, lay the continent from which these sediments were derived. Evidences of deep-water deposition are unfailingly observed wherever the lower part of the Colorado group is exposed in this neighborhood. There is equal evidence of increasing shallowness, with frequently varied sediment during the upper part of the Colorado. Throughout the Fox Hill limited sheets of clays, local conglomerates, sandstones, and shales are intercalated. For the explanation of these fresh-water forms embedded in marine strata it is superfluous to argue an elevation of the marine beds. It is entirely unnecessary to suppose anything more than the washing in of fluviatile shells, exactly as to-day anywhere on the Atlantic coast the river species are swept out through the estuaries, and mingle with true marine forms. The real point of interest about these fresh-water shells is the marked affinities with known Tertiary types. If found by themselves, dissociated from the acknowledged marine Cretaceous forms, they might have been referred by almost any palæontologist to the Tertiary age. Oceanic conditions, by the variations of the general marine area and consequent shallowing or deepening of pelagic basins and the ever-increasing salinity, should more powerfully modify marine species than the fresh waters of continental rivers would their forms. The early differentiation of fresh-water types should create no surprise, and the discovery of this singularly Tertiary-like group deep in the Cretaceous should no more than open our eyes to the early specialization of fresh-water molluscan types. Above the horizon of these shells are about 1,000 feet of gray sandstones, the lower portion of which carries at several horizons compacted masses of *Ostrea solenisca*, both casts and shells. At the upper part of the 1,000 feet, in a soft gray sandstone, are indistinct *Inoceramus, Ostrea,* and *Cardium.*

On the southern slope of the high hill directly south of the mouth of Echo Cañon are seen the last members of the conformable Cretaceous series in this region. They consist of an exposure of about 700 feet of a pink, red, and striped mixture of conglomerates and sandstones, with a few shaly intercalations. These I refer to the base of the Laramie. The exposure of Fox Hill, therefore, as shown in this section between Coalville and Echo City, embraces about 3,000 feet of rocks, for the most part gray, buff, and yellow sandstones, carrying purely marine Cretaceous types to the very uppermost edge, where, however, the chronologically rather valueless forms of *Ostrea* abound. One thousand feet up in the series lies the group of coal-beds opened at the Carleton Mine, both underlaid and overlaid by distinct Cretaceous types, and carrying the admixture of fresh-water Cretaceous shells already mentioned. In this whole series the species *Inoceramus problematicus* does not occur, but there are two other species of *Inocerami*.

Ferruginous beds, which have been heretofore described in the Fox Hill, occur about 1,000 feet from the base of the series. North of Echo City the Eocene conglomerates and sandstones which cover that region are eroded away on both sides of the river, displaying an almost continuous outcrop of Cretaceous from a mile north of the town to Croydon. The conglomerates which first make their appearance in the neighborhood of Witch's Rocks are supposed to be correlated with the conglomerates which along the Wahsatch mark the base of the Laramie. For three miles after passing Witch's Rocks, the mixed sandstones and shales of the Fox Hill, which here have a predominant buff color, are exposed along the right bank of the river, the hill-slopes above being made of the horizontal Eocene. The edges of the Cretaceous strata are presented to the valley, and it is chiefly the harder or sandstone portions which come to the surface through the débris that has rolled down from the Eocene. In general, the type of rocks is a reduplication of that exposed south of Echo Cañon. Innumerable oysters occur near the upper regions, and, in descending, *Inocerami* and *Corbulæ* make their appearance, together with a large number of indistinguishable bivalves. The occurrence of conglomerates is here even more noticeable than south of Echo Cañon.

Laramie Group.—Throughout the whole Cretaceous, up to the upper limit of the Fox Hill group, there is among the geologists who have lately studied these formations, so far as I know, neither doubt nor dispute. With the exception of a few instances—where purely fresh-water fossils occur, both underlaid and overlaid by marine Cretaceous forms, and therefore clearly referable to that age—all the series from the top of the Jura to the top of the Fox Hill are characterized by an uninterrupted succession of marine Cretaceous forms. The great sandstone series of the Fox Hill is conformably overlaid by a continuation of the sandstones, which attain a thickness of from 1,500 to 5,000 feet, varied very greatly in lithological character over different areas, but in general characterized by the frequent occurrence of workable beds of lignite and innumerable seams of carbonaceous clay. The fossil forms which are found in this series have led to a disagreement which has now become historic as to the age of the beds. They were at first, by Meek and Hayden, held to be distinctly Tertiary. That opinion has since been so modified as to lead those gentlemen to designate them as beds of transition. On the other hand, Dr. Le Conte, Professor Newberry, Professor Stevenson, and Major Powell have all committed themselves to the view advanced by me in Volume III. of this series in 1870, that the whole of the conformable series is Cretaceous. During the slow gathering of the evidence which shall finally turn the scale, I proposed to Dr. Hayden that we adopt a common name for the group, and that each should refer it to whatever age his data directed. Accordingly, as mentioned in the opening of this chapter, it was amicably agreed between us that this series should receive the group name of Laramie, and that it should be held to include that series of beds which conformably overlies the Fox Hill.

As we have seen, the characteristic of the Fox Hill upon the Great Plains is that of general lithological uniformity throughout considerable stratigraphical depths. These sandstones pass imperceptibly into the Laramie group, a series of strata which in this portion of Colorado are characterized by the occurrence of numerous workable lignite-beds. It is also the Lignitic series of Meek and Hayden in the Upper Missouri section. Much greater lithological variation is evident over the area shown on the map as Laramie than in the underlying Fox Hill. A great amount of argillaceous and shaly intercalations, with some pure clay beds and frequent carbonaceous shales, is the main characteristic of the Laramie. The prevailing colors are deep rusty-yellow, pink, red, and buff The position of this series on the Plains shows either a slight dip to the east or west or perfect horizontality In other words, it is a region of slight wave-like undulations, the inclination of whose flanks is always under 5° or 6°. Since this is the uppermost member of the great conformable series, extending upward from the Cambrian base, the upper limit is perhaps never reached. About 1,500 feet only are exposed. Below this group there are, so far, in this region, no workable deposits of coal, either in the Fox Hill, Colorado, or Dakota. Near what we consider to be the base of the Laramie is a prominent yellowish, friable sandstone, which may be traced north and south by a low ridge outcrop, the sandstone carrying beds of coal and carbonaceous clay. Six or seven miles west of Carr's Station, this red sandstone is found carrying a bed of coal near where the Cretaceous passes under the escarpment of the overlying Pliocene. The strata here dip to the east from 8° to 12°. The coal-bed itself is more than three feet thick, overlaid by blue clay and underlaid by black, carbonaceous clay. The sandstones overlying the coal carry a large number of fossils of the genus *Ostrea.* This red sandstone bed, with its enclosures of coal and clay, continues quite down to Cache la Poudre Creek, and is conspicuous in the latitude of Park's Station. Considerably above this horizon of coal—as, for instance, on the high bluffs of the Cache la Poudre west of Greeley and Evans, the most westerly occurrence being seven or eight miles west of the former town, but still far above the horizon of the coal-bearing red sandstone—in beds dipping 1° to the east, were found marine Cretaceous fossils. They also occur on Lone Tree Creek and Crow Creek. The following types have been identified:

Avicula Nebrascana.
Nucula cancellata.
Cardium speciosum.
Mactra Warreniana.

In addition to these species collected by us, J. J. Stevenson, from near Evans and Platteville, the latter just south of our map, obtained—

Ammonites lobatus,
Mactra alta,

and an undetermined species of *Anchura.* It is admitted that two of these forms—*Cardium speciosum* and *Mactra Warreniana*—are characteristic of the upper part of the Fox Hill series, and therefore this marine series which overlies the coal may, with a certain degree of fairness, be considered to belong to the upper part of the Fox Hill. All these fossils, it will be observed, are found at points lying west of the Denver Pacific Railway. Either the coal-beds mentioned in the red sandstones, which are clearly overlaid for a considerable thickness by the sandstone-beds carrying the above-described fossils, are Fox Hill (in which case the horizon of the coals is brought lower than has been formerly admitted in this region), or else the marine Cretaceous forms elsewhere characteristic of the upper part of the Fox Hill have lived over into the Laramie or Lignitic period. No animal forms have been found by us in connection with the higher coal-seams in the Laramie here. The occurrence of this group of fossils at so many places above the horizon of the coal-beds of the lower part of Hayden's Lignitic (now the Laramie) series, in my opinion indicates that Dr. Hayden was in error in marking the lowest limit of the Laramie by the occurrence of the sandstones and coal-beds. It was very natural that he should draw here the line which he had formerly drawn on the Upper Missouri, establishing the top of the Fox Hill by the lower beds of lignite; but since in Utah, Wyoming, and southern Colorado the coal-beds are found to descend quite to the base of the Cretaceous, it is evident that no group-lines can be drawn on the coal-beds, except in the most local and restricted way. These marine fossils are so plainly Fox Hill that in my judgment they should be included within it, and the base of the Laramie moved up so as to exclude the beds which bear them. Thus drawn, the upper coal-beds east of the Denver Pacific Railway would be left in the Laramie, but the formation would here be characterized by no marine fossils. In order to prove a marine origin for the whole Laramie series, it will be necessary to bring to light new evidence east of any fossiliferous beds which we have seen. In spite of the fact that thus far I am not aware of the upper part of this series having yielded any marine fossils in this region, I am of unwavering opinion that it should be classed as Cretaceous, from reasons which will appear later.

Good exposures of the Laramie group beds may be seen along the railroad just east of Separation Station, where they show the peculiar ashen-gray sandstones, containing a considerable development of argillacous beds and a great number of coal-seams, and contain plentiful plant-remains, generally as leaf-impressions, and frequently also as indistinct and partially carbonized stems in the impure sandstones. In the ridge south of this station they dip at an angle of 10° north, but flatten out to the north, assuming a practically horizontal position, so that the line between them and the overlying Tertiaries is even more difficult to determine than the exact division between them and the underlying Fox Hill group. Perhaps a better section of these beds may be obtained north of Muddy Creek, where they have a strike of northeast, and dip 20° northwest. Even here the section is only partial, as a gap or valley occurs northwest of Separation Ridge, where it is cut by Muddy Creek, and the top of the series is not reached. Counting from the top downward, were observed —

	Feet.
1. Thin brown sandstone (nearly horizontal).	
2. Whitish-gray sandstone	200
3. Coal-seam.	
4. Gap.	
5. Sandstones, hard, bright vermilion color, with leaf-impressions	20
6. Sandstones, with clays; coal-seam	100
7. Banded red and gray sandstone	500
8 White sandstone, rather heavily bedded, with red seam	850
9. Yellowish sandstones, with clays	1, 000

Along the western base of Park Range the character of the country, consisting generally of flat, gently sloping benches, is unfavorable to good geological sections. The Cretaceous beds, which are probably Laramie, lie nearly horizontal and are only seen in the deeper cuts of the streams, and even here the exposures are much concealed by the gravels of the talus slopes.

Along Little Snake River, in the banks, are seen the yellow and white sandstones with coal-seams, and isolated sections of thin beds of clay and sandstone carrying abundant leaf-remains, some bituminous seams, and a few fossils having a general resemblance to those of the Bear River City beds, but which have not been specifically determined. In lithological character, however, these beds are equally unlike the heavy sandstones of the Fox Hill, or the coarse gravel and striped arenaceous clay beds of the Vermilion Creek Tertiary. In the lower Yampa Valley, where the formations lie in broad, gentle undulations, the Laramie has been distinguished from the Fox Hill Group by general considerations of its higher geological horizon, and by a prevalence of reddish and impure sandstones in the outcrops, which are too much covered by surface-accumulations to give detailed sections.

Around the irregular oval described by the Fox Hill sandstones of the Bitter Creek uplift occurs one of the finest exposures of the Laramie series. From about six miles east of Salt Wells Station, on the Pacific Railroad, it dips at gentle angles of from 4° to 7° to a little north of east, the strike being about north 15° west. A continuous series is exposed as far as Black Butte, where, upon the top of the bluff, the Cretaceous passes under the beds of the Vermilion Creek, with no appearance of angular nonconformity. The exposure, judging by the angle of dip and the distance across the line of strike, appears to be between 5,000 and 6,000 feet; but from the known slight dislocation it is probable that this is partially due to reduplication, and should be reduced to between 4,000 and 5,000 feet. Taken as a whole, whether a given zone is examined for a considerable distance longitudinally on the strike, or observed in cross-section, it is seen to be composed of remarkably variable beds of sandy and argillaceous matter. The conformity between the cleavable sandstones and bedded masses of the Fox Hill is distinctly seen about six miles east of Salt Wells, and may be traced north and south in a general way. The two formations pass into each other, and the variability which marks both series is characteristic of their plane of junction. On the western side of the quaquaversal uplift, the railway exposes the Laramie group for about five miles on either side of Rock Spring Station. To the east it is seen to overlie conformably the Fox Hill beds already described. This western exposure dips about 14°, striking a little east of north, while farther south in the Quaking Asp region it dips as high as 25° and has curved around to a northwest strike. We consider the boundary-line between the two great groups to consist of a bed of Fox Hill sandstone, which carries fragments of *Ammonites*, whereas that genus has not been discovered in the Laramie group, the most of its marine fossils being represented by the genus *Ostrea*.

As a whole, the Laramie beds are here less compact, more frequently iron-stained, and more subject to local concretionary structure than are the Fox Hills. There is also more clay, and the Laramie is further characterized by the presence of a large number of beds of coal, fifteen or twenty frequently occurring in the course of 1,000 feet. As a whole, the series is also distinguished by the frequent occurrence of beds carrying leaf and plant remains, particularly in the upper part.

On the eastern side of the anticlinal the Laramie is in general made up of low, broken ridges of coarse, friable sandstone, with a general north-and-south trend, but with local disturbances resulting in dips as high as 16° or 18°. Beginning at the Fox Hill summit, the Ammonite-bearing sandstone, four miles east of Salt Wells, the exposure up half-way to Point of Rocks consists of rapid alternations of friable rusty and light-colored sandstones, drab and gray, yellowish clays, and dark, carbonaceous clays, with important coal-seams. In a gray sandstone about three miles below Point of Rocks were obtained oysters, *Anomia*, *Corbicula*, and *Amodiola*. Mr. Bannister also reports *Goniobasis* and *Corbula*. Above this point the coal-beds become a very important element in the series, although the same rapid alternation of strata is continued. Occasional ripple-marked sandstones are observed, and reddish sandstones carrying *Ostrea*. Passing east from Point of Rocks to Hallville, massive sandstones bound the railway valley upon the east. At intervals they are striped with gray and drab shale-bands, which at times are quite carbonaceous. Continuing to Black Butte, and still rising in horizon, is a sequence of the same loose-textured sandstones, clays and drab shales, the sandstones marked by occasional carbonaceous beds, some thin seams of coal, and occasional beds of *Ostrea*. At Black Butte itself the section shows the upper part of the Laramie beds passing under the Vermilion Creek with little or no nonconformity. The bluff-face offers exposures of both gray and yellow sandstone, varied with bluish and whitish streaks, carrying five noticeable coal-seams. About half-way up from the base of the bluff are some laminated gray and light shales, directly over a bed of coal which is about two feet thick. These shales contain *Ostrea*, *Anomia*, *Corbicula*, *Cyrena*, and *Goniobasis*. About 100 feet from the top, in a dark-gray sandstone characterized by the presence of a great number of leaves and stems, Bannister (and afterward Cope) exhumed the remains of a Dinosaurian, *Agathaumas sylvestre*. The beds of the summit of the cliff are believed to be quite conformable with the series which carry the Dinosaurian bed. Following this horizon a few miles north of Point of Rocks Station, an apparent discrepancy of angle of about 2° is seen. From the summit of Black Butte the overlying Tertiaries sweep north, south, and east.

The distinct evidence of the Tertiary age of this series will be presented still farther on, in the proper chapter. It is enough here to assert, in following the reference of Cope, that the Cretaceous extends to the top of Black Butte.

The highest coals are seen at Black Butte and Hallville. In the clay-seam which caps the highest bed at the latter locality were found *Corbicula fracta*, *C. crassateliformis*, and a *Unio*, some of which forms are represented in the similar bed overlying the coal of Black Butte Station. Iron pyrites accompanies almost all the carbonaceous clays and coal-seams. To its decomposition are due the sulphur springs of the neighborhood, and the reddish stain which characterizes all the places where the coal-beds have suffered spontaneous combustion. To the north, in the region of the Leucite Hills, the only fossils which have been obtained are *Ostrea*. In general, the sand-rocks, from Black Butte downward through the Laramie series, are more intercalated with clay and shale than the Fox Hill. In the corresponding section exposed on the western side of the anticlinal, from the entrance of Bitter Creek Cañon to Rock Springs, were observed the identical alternating series of sandstones, shales, and clays, whose special members cannot be correlated with the beds on the eastern side with any exactness. Numerous coal-beds are exposed, the lowest of which is that opened by the Van Dyke mine, where there is a bed of four feet of excellent coal, overlaid by red, iron-stained beds, containing masses of limonite. This bed is near the base of the Laramie group, and not far from the Ammonite sandstones which cap the Fox Hill. In the artesian borings at Rock Springs Station no fewer than seventeen coal-seams were crossed in a depth of 700 feet. The principal bed, having a thickness of about eleven feet, dips northwestward at an angle of 15°, striking about 30° east of north. A few *Ostrea* and *Corbicula*, of identical species with those found on the eastern side of the anticlinal, are obtained from the western member. The highest outcrops observed on this side are to the north and west of Rock Springs, where, between the base of the bluffs of Green River Eocene and the upper members of the Laramie, is interposed a thin covering of reddish clayey soil, resulting from the decomposition of the upper beds of the Vermilion Creek, which here rest unconformably upon the Laramie. The Vermilion beds are not well exposed, but the discrepancy of angle between the Tertiaries is shown by the difference of dip between the Green River, which here has an inclination of 4° to the west, and the Cretaceous, which inclines at 12°.

As to the precise upper limit of the Cretaceous series, the character of the sediment, the ambiguity of fossil forms, and the absence of any sharp physical break or nonconformity have led to a variety of readings of this region. Powell and White draw the line below the Hallville and Black Butte coals, leaving these upper beds, including the Dinosaurian and leaf-beds of Black Butte, in the Tertiary. They describe a slight "nonconformity of erosion," producing little irregularities in the upper surface of the bed directly above the horizon of the *Anomia* and *Odontobasis* in the lower strata near Point of Rocks. This, however, draws an arbitrary line between groups of fossils of close relationship; some of the identical forms occurring in their upper Cretaceous appearing in their lower Tertiary at Black Butte. Moreover, they disregard entirely the evidence of the Dinosaurian, which would seem to be conclusive proof of Cretaceous age. We prefer to draw the line on the top of Black Butte, including the Dinosaurian and plant-beds in the Cretaceous, believing also that in tracing the contact between the beds next over the Dinosaurian series and the ashy beds which overlie them, we detect a slight nonconformity which, when traced north, seems both more persistent and more observable than the nonconformity of erosion noted by Powell, which we fail to follow north. The Vermilion Creek series, which here rests upon the top of the Laramie in conformity, is elsewhere seen where the nonconformity is violent, the difference of angle reaching often 20° and sometimes 80°.

SECTION IV.

RECAPITULATION OF THE MESOZOIC SERIES.

Analytical Geological Map III. accompanying this section shows the exposures of all the Mesozoic rocks within the Fortieth Parallel area, consisting of the Triassic and Jurassic, and four grand divisions of the Cretaceous. It will be seen that between the Wahsatch Mountains and the meridian of 117° 30′ no Mesozoic rocks are laid down. It will further be noticed that west of the Wahsatch the Cretaceous is not seen.

The foregoing detailed description of the leading Mesozoic outcrops will have shown that the little Mesozoic province in western Nevada differs widely, both as regards the subdivisions of the rocks and the character of their fauna, from the broad Mesozoic area east of the Wahsatch. The absence of the rocks of middle age over western Utah and eastern Nevada is, at the present writing, a problem of little difficulty. The precise relation between the Mesozoic and the Palæozoic rocks in the Wahsatch region and eastward, is very clearly seen to be that of entire conformity, there being no cessation of conformable deposition, from the lowest Cambrian to the uppermost Cretaceous rocks. Wherever the Mesozoic rocks are exposed and deeply eroded, the underlying conformable Carboniferous series are invariably seen, with the single exception of overlaps where the later Mesozoic series comes into contact with Archæan masses. In the western Nevada province the relations are totally different. There, the Mesozoic series rests directly upon a foundation of old Archæan mountain ranges, with no intervening Palæozoic. The latter rocks end abruptly where the Mesozoic rocks begin, and thereafter westward for 200 miles the general structure is that of an Archæan foundation, thickly overlaid by Mesozoic beds. The explanation of the absence of Mesozoic rocks between the Wahsatch and the meridian of 117° 30′ might be accounted for in two different ways. First, supposing the Mesozoics to have been continuously deposited over the whole intervening area, in the great subsequent erosion they might have been entirely removed from the middle country, leaving only the older Palæozoic rocks exposed. Or, secondly, there might have been an upheaval of the country between the meridians of 112° and 117° 30′, making a land area at the end of the Carboniferous period, and the Mesozoic rocks would then have been deposited unconformably in the oceans upon either side of the new land. In the latter case we should expect to find some evidence of the unconformable relations between the Mesozoic and the older shores. In the case of the western line of contact, we have nowhere been able to find the Triassic and Carboniferous rocks in contact. But the general stratigraphy of the section is such that we feel altogether assured in the belief that they are nonconformable, and that the Palæozoics never extended beyond their present area. But when we come to examine the relation between the Mesozoic and the underlying Palæozoic in the Wahsatch, it is found to be that of absolute conformity. However, in the very next range westward, that which is made up of the Oquirrh, Promontory, and the eastern islands of Salt Lake, the Palæozoic rocks are found, but no Mesozoic. The region of Wahsatch Range and of the eastern portion of the valley of Salt Lake has been the theatre of the most tremendous mechanical violence. It has been repeatedly lifted and depressed, faulted and degraded, and although the entire series is conformable from Cambrian to uppermost Cretaceous in Wahsatch Range itself, the probability is that the exact shore-line lay somewhere in the longitude of the present depression of Salt Lake, and that erosion has carried away the evidence of a nonconformity which must have existed.

Another point of difference between the Utah and Wyoming Mesozoic area and that of western Nevada, namely, the absence of Cretaceous in the western field, is easily accounted for from the known facts of California geology. The great folded and lifted mountain ranges of Triassic and Jurassic rocks, which begin in the Fortieth Parallel with Havallah Range and extend westward to and include the Sierra Nevada, were all upheaved, making at the close of the Jurassic period a great system of chains which were at once lifted above the ocean-level. The shore was moved westward from 117° 30′ to the western base of the Sierra Nevada, thus adding a post-Jurassic extension of 280 miles to the continent. The Pacific Cretaceous ocean-shore extended, as Whitney has shown, from Southern California along the western base of the Sierra, up to the region of

Mount Shasta, and then, as my observations prove, skirted in a northeasterly direction, touching the west base of the Blue Mountains of Oregon, south of Columbia River. Against this post-Jurassic shore the enormous Pacific Cretaceous series was conformably laid down. The ancient coast is clearly defined by the long line of nonconformable contact traced from southern California north to Columbia River. In the western part of the Cordilleras, therefore, there is a strict and palpable nonconformity, often amounting to a full right angle, between the Jurassic and the Cretaceous.

There are some extremely interesting facts to be observed in the region where the Palæozoic and Mesozoic approach one another, near the 117th meridian. When followed from central Nevada up to that longitude, the Palæozoic rocks are seen gradually to thicken, the greatest fragmentary members of the conformable Palæozoic series are seen to grow coarser and coarser, and to bear more and more angular shore conglomerates up to the time when they suddenly give way to Mesozoic rocks. There is no serious reason to doubt that at this longitude was the shore of the Archæan continent, whence was washed down the detrital material that made the fragmentary members of the eastward-stretching sheets of Palæozoic rocks. The Palæozoics resting on an Archæan basis come directly up to the continental shore with a thickness of over 30,000 feet, in which, from the sequence of material, there is abundant evidence of successive subsidences as indicated by plant-bearing carbonaceous beds and sheets of conglomerate. Directly west, resting upon a precisely similar floor of Archæan ranges, is the Mesozoic series of about 20,000 feet, superposed upon what just previously was the continental land bordering the Palæozoic ocean. It therefore becomes evident that in the brief interval of time between the uppermost Carboniferous beds and the lowermost Triassic strata there was a complete displacement and faulting between the Palæozoic sea and the Archæan continent, by which the beds of the Palæozoic ocean were lifted above sea-level, and the old Archæan continent depressed far below sea-level.

It has been before mentioned that from the interval between the Wahsatch and this interesting 117th meridian region, the shales and argillaceous limestones of the Permian series have not been found. It is true that as they are very soft and easily disintegrable they might readily have been totally removed from the whole surface of the country, and their absence to-day may therefore be no proof that they were not deposited conformably over the Coal Measure limestones, as they were east of the Wahsatch. If they were deposited, it seems quite possible that the era of the great displacement by which the western Archæan continent went down and became submerged, took place in Permian time. A color of probability is given to this by the observed symptoms of slight nonconformity between the Coal Measure limestones and the Permian already mentioned on the flanks of the Wahsatch. It would seem not improbable that the upheaval was made at the beginning of Permian time, and that deposition went on continuously east of the upheaved region, namely, east of the present Wahsatch; in which case the Permian, if existing in the west, will be as an underlying and thus far unexposed member of the conformable series, of which the lowest Trias are the lowest present known beds. In this remarkable revolution the sea-beds of the Palæozoic emerged and became land, while the land went down and formed a deep ocean area, in which the sediments thereafter derived from the Palæozoic land-mass were accumulated in the thick deposits now seen in the conformable Mesozoic series.

Leaving the subject of the Cretaceous to a later part of this section, a brief comparison of the Triassic and Jurassic formations of the two great provinces will be here attempted. In the region of the Rocky Mountains we have seen that the Trias frequently overlaps the older rocks and comes directly into nonconformable contact with the great Archæan islands that now form the three ranges of the Rocky Mountain system in our latitude. The Trias is in general a series of sandstones; the upper half is always of lighter colors than the lower half, and is always intercalated more or less with beds of dolomitic limestone and gypsum. The series varies from 300 to 1,000 feet in thickness. Wherever it stands at a high dip, it is most compressed in thickness and most compacted in lithological character. Wherever its position approaches horizontality, the texture of the rock is that of a loose, friable sediment. The lower half of the series is usually from brick to vermilion red, the upper half pale pink, pale red, and buff, with occasional exceptions of white and brilliant vermilion. The intercalated dolomitic and gypsum beds are never continuous, but are shallow deposits of no great lateral extension. On approaching the Archæan rocks, the Trias have always more or less of local conglomerates, derived directly from the shores against which they abut. There is considerable variability in color, in thickness, and in the special arrangement and sequence of the sediments. From 1,000 feet maximum in the region of the Rocky Mountains, the deposit thickens in passing westward, until, in the neighborhood of the eastern part of the Uinta, it is fully 2,000 or 2,500 feet thick. The division between the lower dark-red member and the upper buff or white member is much more distinct in the Uinta region than to the east. Here, however, are still the intercalated gypsums or dolomites in the upper half of the series, the gypsum sometimes reaching forty feet of pure white crystalline sulphate. There are also in the Uinta considerable intercalations of clayey matter, which are rare in Colorado.

Passing still farther westward, against the Wahsatch there is again a noticeable diminution of thickness and a corresponding increase of stony compactness. Under the microscope, no single specimen was observed that had not a considerable amount of carbon and a trace of crystals of carbonate of lime. In approaching the Wahsatch, also, there is a sensible increase of conglomerates. This constitutes another argument indicating the approach of a land-mass to the west, whence detritus is derived. But one fossil, a new species, was found in the entire Triassic series of the east, and that was obtained from one of the limestone beds—a greenish-drab lithographic limestone—a little above the middle of the series, on the south flank of the Uinta. That fossil had a distinctly upper Triassic or Jurassic facies. The upper horizons, especially the uppermost member of all, varying from 200 feet in the Colorado to 600 in the Uinta, and sometimes more than that upon the flanks of the Wahsatch, is characterized by remarkable cross-stratification, which is prominent over most of the exposed area east of the Wahsatch. The flow-and-plunge structure is developed in a perfection rarely seen, the plane of the cross-stratification often inclining to the true bedding-planes at an angle of 30° to 35°.

The upper half, bearing irregular sheets of gypsum and of dolomitic limestone, is always directly conformably overlaid by the Jurassic beds, which, when first seen on the east flank of Colorado Range, vary from 250 to 275 feet in thickness, and increase steadily eastward till, on the flanks of the Wahsatch, they have reached fully 1,800 feet. There is a very great physical contrast between the general character of the materials of the Triassic and the Jurassic series. The former is, on the whole, free from lime, except in the sulphate and dolomitic beds, and with the exception of certain parts of the Uinta is rather free from intercalated clays. On the other hand, the Jurassic, in the Rocky Mountain region, is entirely made up of soft clays, argillaceous and calcareous marls and thin intercalations of fine lithographic limestone. In the Uinta and Wahsatch region the lower 600 or 700 feet are a bed of solid but very fine-grained, slightly argillaceous limestone, and the upper 800 feet are made of fine calcareous argillites. As a whole, the series is a lime and clay deposit.

In the Rocky Mountain region, and at certain points still farther west, it is a little difficult to fix the exact plane of demarkation between Trias and Jura. The latter is more sandy at the bottom, the former more limy at the top, and they often pass one into the other by insensible gradations. In places, as in case of the section exposed in Weber Cañon, the limestones of the Jurassic rest directly upon indurated, cross-bedded sandstones of the Upper Triassic. There is never any doubt as to the upper limits of the Jurassic. The soft calcareous and argillitic beds are sharply followed by a wonderfully characteristic heavy bed of conglomerate, the base member of the Dakota Cretaceous. The maximum development of the Trias and Jura in our latitudes east of the Wahsatch is 3,800 feet.

The Jurassic of the Eastern province is abundantly charged with characteristic mollusks as far east as Fort Steele, but in eastern Wyoming and Colorado in our latitudes there have yet been found no fossil shells. The eastern foot-hills of Colorado Range have, however, of late yielded a remarkable reptilian fauna of Jurassic types. The upper clay and sandstone beds directly under the bottom of the Dakota conglomerate have been called by Marsh the Atlantosaurus beds.

Besides the occurrences in Colorado, important localities are now being opened in middle Wyoming.

In the Atlantosaurus beds of the upper Jurassic the Dinosaur remains are the most abundant fossils, and most of them belong to reptiles of gigantic size. The largest have been found at Morrison and Cañon City, Colorado, and others of huge dimensions at various localities in Wyoming. *Atlantosaurus immanis*, Marsh, had a femur eight feet four inches long, which would indicate, if the animal had the same proportions as a crocodile, a length of over one hundred feet. *Atlantosaurus montanus*, Marsh, was nearly as large, and both were far larger than any land animal, recent or fossil, hitherto discovered. Other huge Dinosaurs from the same horizon are—*Apatosaurus Ajax*, Marsh; *Apatosaurus grandis*, Marsh; *Allosaurus fragilis*, Marsh; *Allosaurus lucaris*, Marsh; and *Morosaurus impar*, Marsh. *Creosaurus atrox*, Marsh, was a smaller carnivorous Dinosaur. With these were found two small Dinosaurs of the genus *Laosaurus*, Marsh (*L. celer* and *L. gracilis*, Marsh), and also the two smallest Dinosaurs known, viz, *Nanosaurus agilis*, Marsh, and *N. victor*, Marsh, the former about as large as a cat. A peculiar reptile, allied to the Dinosaurs, but representing a new group, is *Stegosaurus armatus*, Marsh. The crocodiles are represented in this horizon by *Diplosaurus felix*, Marsh, which had biconcave vertebræ. There was also among the fishes a species of *Ceratodus* (*C. Güntheri*, Marsh).

Under date of May 13, 1878, Marsh announces the further discovery from the Wyoming Jurassic of a mammal, a small marsupial, to which he has given the name *Dryolestes priscus*.

Passing now to the district of western Nevada, the sections, which often do not reach the base of the conformable series, expose two distinct, easily recognizable groups of the Trias. The Koipato, already described, is made up of siliceous and argillaceous beds, whose chemical peculiarity is the almost total absence of soda and lime and the high percentage of alumina and potash—a series probably derived from the disintegration of the heavy Weber Carboniferous quartzite, which must for a long time have constituted the main surface of erosion of the newly lifted Mesozoic land. This series has an observable thickness of about 6,000 feet, with an unknown quantity to be added for the bottom, unseen beds. Conformably over the Koipato is the great Alpine Trias Star Peak series of 10,000 feet, composed of an alternation of three great limestone zones and three interposed quartzite zones, the lower quartzite closely following the physical and chemical peculiarities of the Koipato series below, the upper two quartzites representing moderately pure siliceous sediment. The fossils of these limestones, as already described, repeat, with marvellous exactness, the facies of the St. Cassian and Hallstadt beds of the Austrian Alps.

Directly overlying the uppermost Star Peak quartzite, the summit member of that group of 10,000 feet of strata, is a limestone carrying low Jura or Lias forms, and succeeded upward by an immense series of argillites of unknown thickness. The conformable Mesozoic development, therefore, is here about 20,000 feet. Under the great folds into which this series of rocks has been thrown, interesting examples of Archæan peaks are found, around which the Triassic beds have been deposited. In some instances the partially buried peaks show a height little inferior to the great granitic Archæan mountains, around and over which the Palæozoic beds were laid down.

With the exception of the Archæan mountain masses of the Rocky Mountain group of ranges between the meridians of 105° and 107°, which during the deposition of the conformable series from the Cambrian to the close of the Cretaceous were islands lifted above the sea, the whole Fortieth Parallel area east of the Wahsatch was covered with a very great development of Cretaceous rocks. Against the Wahsatch—that is, against the western shore of the ocean—there is a total thickness of from 11,000 to 13,000 feet, the series gradually thinning eastward until, as exposed east of Colorado Range, they have been reduced to a thickness of 4,200 to 4,500 feet. There is entire conformity between the base of this series and the summit of the Jurassic. There is also complete conformity through the whole Cretaceous series from bottom to top. All observers have united in the common assertion of this absolute conformity up to the close of the Laramie group.

The Cretaceous, as defined by the studies of Meek and Hayden, consists, first, of the Dakota sandstones and conglomerates, being the basal member of the series; secondly, of the group which, as already mentioned, Dr.

Hayden and I have agreed to call the Colorado, made of his former Cretaceous members, Nos. 2, 3, and 4, namely, the Fort Benton, Niobrara, and Fort Pierre groups; thirdly, the Fox Hill group, a heavy body of sandstones.

Here, with those who follow Hayden, the Cretaceous series comes to an end. Conformably over this lies the group which Hayden and I have agreed to call the Laramie, which is his Lignitic group, and is considered by him as a transition member between Cretaceous and Tertiary. There is no difference between us as to the conformity of the Laramie group with the underlying Fox Hill. It is simply a question of determination of age upon which we differ.

The basal member or Dakota group consists of a persistent conglomerate of remarkably indurated cement, in which are fine chert pebbles the size of filberts in the east, but reaching nine or ten inches diameter against the Wahsatch. Over this is a varying series of yellow and gray sandstones, with, in the Uinta region, a prominent belt of dark-gray clay shales. At the very base of the Dakota, in the Uinta, is a very fine coal-bed, which never recurs to the east.

The Colorado is essentially a group of calcareous shales and clays, with a sandy region about the middle of the group, which is made up of calciferous sand-rocks, marls, and argillaceous limestones. Above and below this lie the dark-clay shales of the Fort Benton and Fort Pierre sub-groups. The entire thickness of the Colorado east of the Rocky Mountains is from 800 to 1,000 feet. At its greatest development in the Uinta and Wahsatch it reaches 2,000 feet, and while even there, in the neighborhood of the Cretaceous ocean coast, it is still largely made up of the same clay, shales, and marls which characterize it in the eastern region, yet it is frequently interrupted by considerable sheets of friable, yellow, slightly calciferous sandstones. In the Fort Benton shales, the lowest of the three divisions, are frequently collected —

Ostrea congesta,
Inoceramus problematicus,
Prionocyclas Woolgari, and
Scaphites Warrenensis.

In the middle Niobrara sub-group, usually in heavy beds of chalky marl, or in soft arenaceous marls, interlaminated with bituminous limestones, occur —

Ostrea congesta,
Baculites, and
Inoceramus deformis.

From the uppermost region of the Fort Pierre, at the plane of its contact with the overlying Fox Hill, were obtained *Inoceramus Barabini,* associated with *Ammonites.* In the region of Coalville, and to the south for several miles in the characteristic exposures of the Colorado group, are several workable coal-mines. East of Colorado Range there are absolutely none at this horizon. With the exception of the region bordering immediately on the Wahsatch, the most characteristic point about the whole group is the extreme fineness of its sediments, their very great variability, and the comparative thinness of their bedding.

The Fox Hill group, made up almost altogether of gray, rusty, and buff sandstones, containing a few earthy, clayey intercalations, reaches a development of about 1,500 feet in total thickness on the Great Plains, and increases toward the Wahsatch to 3,000 and 4,000 feet in the basin of Green River.

East of the Rocky Mountains the Fox Hill contains but one coal-bed, and that at its extreme upper limit. As already indicated in the description of the country east of the Rocky Mountains, the lowest coal-bed is overlaid by a sandstone carrying marine fossils characteristic of the Fox Hill group. In drawing the line upon our map, the division between the Fox Hill and the Laramie was made so as to include the lowest coal in the Laramie or Lignitic series. The subsequent discovery of these fossils above this coal-bed leads me to place the line higher, bringing the summit of the Fox Hill group immediately above the sandstone carrying the marine fossils.

Passing westward to the region of Cooper Creek and Rock Creek, the Fox Hill has several considerable beds of coal. Stratigraphically its most characteristic features are the enormous beds of gray, white, and pale-buff sandstones, which in the basin of Green River form the lowest horizons of the Fox Hill. These reach, not infrequently, single beds of fifty or sixty feet in thickness, without a shadow of a stratum-plane. In the basin of Green River, especially in the Bitter Creek anticlinal, which forms such magnificent exposures of the Fox Hill and Laramie group, the former carries a great number of coal-beds throughout its whole thickness. In the region of Coalville all the workable beds above that of the Spriggs Mine are included in the Fox Hill. At the Carleton Mine, very close to what must have been the Cretaceous shore, a little group of fresh-water shells is intercalated between horizons rich in marine mollusks. So far as our observations go, these are the only fresh-water forms anywhere contained in the Fox Hill group, and they are doubtless attributable to some estuarial current which brought down the river species and deposited them in the marine muds of the shore, a phenomenon too common on all coasts to require further notice.

The line between the Fox Hill and the Laramie, as drawn upon our maps, is based on the cessation of true pelagic forms. It is made on the summit sandstone of the Fox Hill, as indicated at various points of the map, a stratum containing *Ammonites* and *Inoceramus*. Above that horizon, conformably extends the enormous thickness of the Laramie, a series of rather loose sandstones, buff and gray, frequently striped with alternating strata of rusty red, and carrying repeated intercalations of carbonaceous clays, and a considerable number of coal-beds. This great series, embracing a thickness of over 5,000 feet in the Green River Basin, is characterized throughout by molluscan forms which are of both salt and brackish-water types, and by several important zones of plant-bearing beds, which have yielded abundant flora illustrated with great fullness by Mr. Lesquereux.

Aside from the Taconic system, no single geological feature in all America has ever given rise to a more extended controversy than the true assignment of the age of this group. On data which will presently be set forth, it is assumed by us to be the closing member of the Cretaceous series, and the last group of the great conformable system which east of the Wahsatch stretches upward from the base of the Cambrian.

The upheaval of a continental mass at the close of the Carboniferous extending from the Wahsatch west of the meridian of 117° 30′, and an addition to that continent of a westward extension of 200 miles at the close of the Jurassic, left a wide area of land, from which was derived the enormous mass of detrital material making up the Cretaceous series. Fully four fifths of the 12,000 feet are of sandy materials, which are always more or less mingled with fine lime. The shales of the Colorado, and the shaly strata which are intercalated in the Fox Hill and Laramie, are all highly calcareous; yet it would be safe to say that fully seven tenths of the entire material resulted from the destruction of siliceous rocks.

In regard to the Laramie group, Hayden, Meek, and Lesquereux have held:

First, that it was conformable with the Fox Hill;

Secondly, that its molluscan fauna indicated a brackish-water origin;

Thirdly, that its general facies was more nearly related to the Tertiary than to the Cretaceous;

Fourthly, that the abundant plant-remains were distinctly Tertiary. Lesquereux has divided the Laramie flora into three sub-groups, designated after prominent localities, as the Bitter Creek or lower group, the Evanston or second group, and the Carbon or third and upper group; referring the first of these from its flora to the Eocene, the second generally to the Miocene, the third or Carbon to the middle Miocene.

Fifthly, that the Laramie group passed upward conformably into the purely fresh-water Wahsatch group;

Sixthly, as expressed in the introductory letter to Volume VII. of the "Report of the United States Geological Survey of the Territories," the "Wahsatch group as now defined and the Fort Union group are identical as a whole, or in part at least";

Seventhly, the name "Wahsatch group" was applied by Dr. Hayden to the heavy conglomerates and sandstones displayed at Echo Cañon and other points in the neighborhood of the Wahsatch.

In regard to assumption number one, there is no doubt that Dr. Hayden is correct. The Fox Hill and Laramie are always strictly conformable

As regards assumption number two, it must be said that there is considerable obscurity as to what molluscan species are strictly fresh-water, what are brackish-water, and what are truly marine. However this may be, the occurrence of beds of *Ostrea* throughout the whole series up to the very summit indicates the access of salt water at all times to the sedimented region, and while it may be admitted in general that the fauna might all belong to estuarial or littoral regions, at the same time (and this is a point upon which I wish to insist) there is no general fresh-water fauna, such as characterizes the immediately succeeding group. While east of Colorado Range, as we have seen, coal-beds did not make their appearance in the series until at the very close of the Fox Hill group, they occurred, as I have already shown, at intervals from the very base of the Cretaceous over the region adjoining the Wahsatch, and indeed throughout the Green River Basin. In other words, the whole enormous thickness of 12,000 feet in the Green River region was subject to repeated subsidence, having land-surfaces stretching gradually farther and farther eastward until, at and after the close of the Fox Hill period, there were intervals of land-surfaces from the Wahsatch far east of the Rocky Mountains into the province of the Plains. It is obvious, therefore, that the subsidence was greater in the west, and directly proportionate to the superior thickness of the beds in that region. Various exposed sections throughout the whole Cretaceous field show that the individual coal-beds were of no great geographical extent, and that they represented marshy basins, often detached from one another, rarely occupying any very great range of country. Yet over the whole area repeated subsidence permitted the ocean waters to flow back to the base of the Wahsatch. Up to the close of the Fox Hill, it is evident that the subsidences were at rarer intervals, or the land remained above the water for smaller intervals of time, recording its more rapid subsidence in the more thorough sway of the ocean, and consequent predominance of marine life. This state of things obtained until the close of the Fox Hill, after which the subsidences were more frequent and of less vertical depth, and the accession of the ocean was more and more retarded. However, through the shallow sounds and broad lagoons and estuaries the salt waters still found their way back to the Wahsatch, and the general character of the molluscan fauna is that of a sound region or of a brackish estuarial type.

A complete refutation of assumption three, that the fauna proves a Tertiary, not a Cretaceous age, is found in the fact that the evidence of a meagre molluscan life and a large range of plants cannot be held to weigh against the actual presence of *Dinosauria* in the very uppermost Laramie beds, and, as will appear in the sequel, of an abundant *lowest Eocene* mammalian fauna in the unconformably overlying Vermilion Creek group.

In regard to assumption number four, let it be admitted that the facies of the flora bears a noteworthy resemblance to that of the Eocene and Miocene of Europe, a correlation which I am not prepared to criticise.

Assumption number five, as to the conformity of the Laramie with the Wahsatch group, I shall presently proceed to show, is based upon imperfect knowledge, and is abundantly disproved by repeated sections.

In regard to the sixth assumption, concerning the Fort Union group, never having visited that locality, I cannot speak with any definiteness; but I consider it worth while to point out here a noticeable ambiguity in its evidence. Cope, in the introduction to his volume on the Cretaceous, cites Dinosaurians as coming from Fort Union, from which he refers the fauna to the Mesozoic series. On the other hand, the characteristic plant-life of the country differs entirely from that described by Lesquereux in Volume VII., Tertiary Flora. It is noticeable that he nowhere describes in that volume any of the plants from the classic Fort Union locality, a series which has been studied by Newberry, and which contains not only a general resemblance, but some actual species identical with the Miocene flora of Greenland and northern Europe. It is mentioned by Meek that the flora of Miocene facies from Fort Union come from higher beds than the Dinosaurians, while the correlation of the Dinosaurian beds, which occur far down at Fort Union, with the Black Butte Laramie horizons, as made by Cope, seems undoubtedly warranted. The further correlation of the upper plant-beds of Fort Union with the Wahsatch (my Vermilion Creek) seems the most prodigious strain. The Wahsatch (Vermilion Creek), or unmistakable lowest Eocene is nonconformable with the Laramie. The relations of conformity or nonconformity between the plant-bearing beds of Fort Union and the Dinosaurian beds are not given, and there is reason to believe that the plant-beds represent a horizon of the great White River Miocene series which underlies the Pliocene over so large a part of the Great Plains. Until fresh evidence of the stratigraphical relations, and a full discussion of the fauna of the whole series of rocks at Fort Union is fully made, a definite correlation is impossible; and at present writing the entire difference between the plants at Fort Union and anything in Colorado or Wyoming that is of value at all, suggests that they cannot be related to any of the southern groups. I apprehend that the plant horizon at Fort Union will be found to be nothing but the northward extension of the White River Miocene.

As to assumption number seven, the term "Wahsatch" was originally applied by Dr. Hayden, as I have before said, to the group of conglomerates and sandstones displayed in Echo Cañon, and in the Narrows and at other points in the immediate neighborhood of the Wahsatch. In attempting to follow his nomenclature in this region I have been led to reject this name, and to apply to those rocks the name "Vermilion Creek group," because upon Vermilion Creek was exposed the whole thickness of the series, while at the Wahsatch the full volume of the group was never seen. It consists of a series of conformable beds of sandstones, conglomerates, and clays, having a total thickness of about 5,000 feet. It appears where Hayden gave it the name of Wahsatch; also, between Washakie and Black Butte stations, and over a wide area of the Green River depression. Its organic remains are exclusively either fresh-water lacustrine mollusks and fishes or abundant mammals. This series will be fully described in the following chapter upon the Tertiary age, and its relation to the preceding Laramie Cretaceous and succeeding Tertiary groups will be treated in detail. For the purposes of the present discussion, the question of conformity is of the first importance. At the classic locality which has served to fix a very grave error, namely, at Black Butte Station, the uppermost Laramie beds are found containing mollusks, which have already been mentioned, the numerous plant-remains described by Lesquereux and referred by him to the lower Miocene, and, besides these, the unmistakable Dinosaurian described by Cope. Overlying the Dinosaurian bed is a distinct stratum carrying oysters; and passing up quite conformably, the brackish forms and the *Dinosauria* disappear together, giving place to the fresh-water lacustrine mollusks of the Wahsatch group. There is no angular nonconformity at this locality, and this single fact is always appealed to as proof of the uninterrupted passage of the Laramie beds, with their brackish forms, upward into a conformable series, carrying distinctly fresh-water mollusks, and no longer bearing any trace of brackish-water organisms. Were this locality the sole exposure of the contact-relations of the uppermost Laramie Cretaceous and Vermilion Creek Tertiaries, the assumption of their conformability would rest upon solid ground; but, on the other hand, in numerous localities along the flanks of the Uinta, upon Oyster Ridge in the Green River Basin, and all along the flanks of the Wahsatch, it is evident from abundant exposures that the relation of conformity at Black Butte is a solitary exceptional instance, and that everywhere else the two series are in absolute angular nonconformity, amounting in some instances to a full right-angle. It is clearly seen that the Vermilion Creek Tertiary overlaps not only the whole Cretaceous series, with which it has been alleged to be in conformity, but the entire Palæozoic series also. An examination of Geological Map II. and the eastern half of Map III. of our Atlas shows the relation of these two series in an unmistakable manner. They exhibit as a whole one of the most striking, one of the most distinct, and one of the most extensive nonconformities which can be observed anywhere in the Cordilleran system, second only to that which divides the Palæozoic from the Archæan. Let it be remembered that it is held by Hayden and Lesquereux that the uppermost Laramie members are lower Miocene.

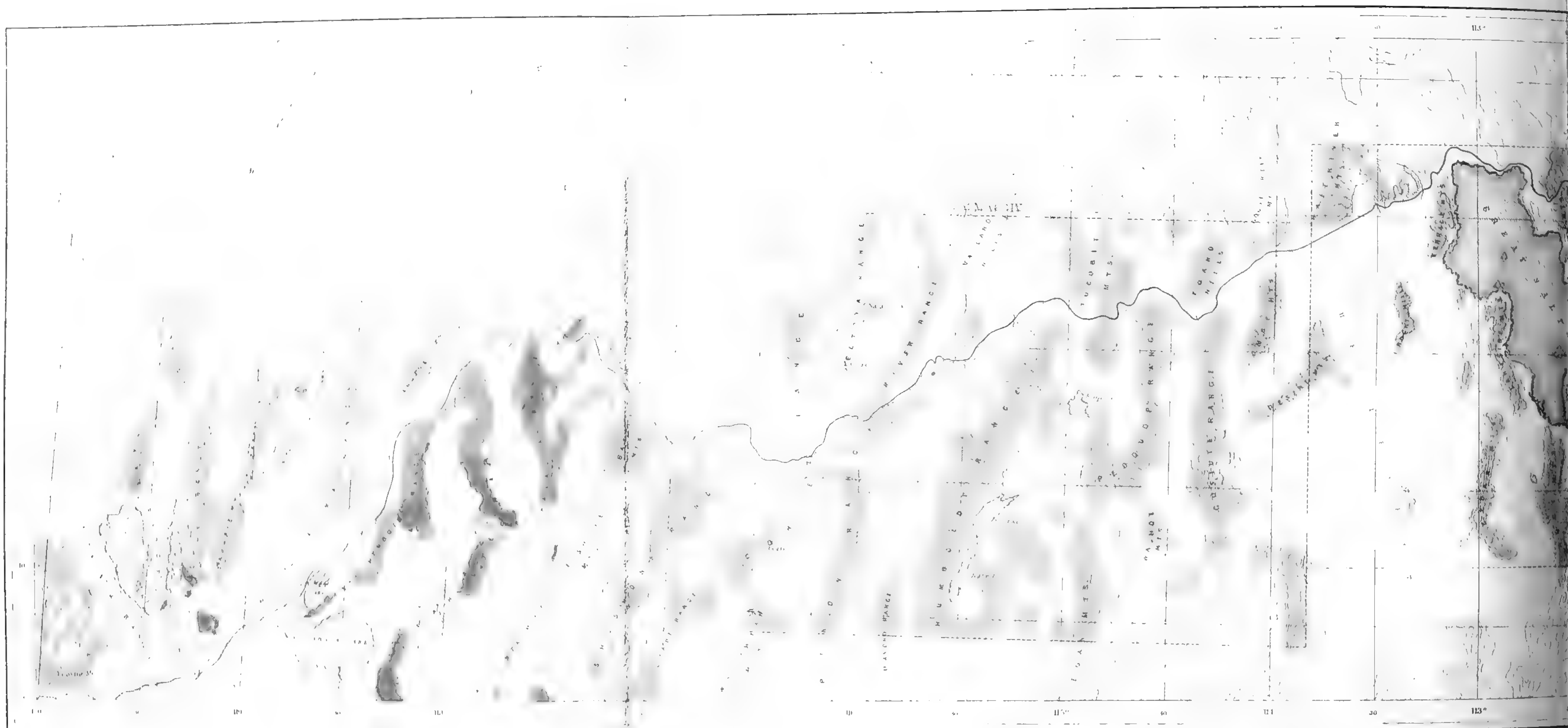
Turning now to the Vermilion Creek group, a body of 5,000 feet of strata, which I assert to be, with the sole exception in the Fortieth Parallel area of the Black Butte region, distinctly nonconformable, what are the characteristics of the organic life entombed in the Vermilion Creek series? It consists, first, of a remarkable abundance of uncharacteristic fresh-water mollusks. But besides that, in beds very near its base, certainly down 4,400 feet in the series, have been found, as will appear under my description of the Eocene, an extended vertebrate fauna readily to be correlated with a horizon recognized in England and on the Continent as characteristic of the lowest Eocene. We have, then, over the Miocene of Hayden a nonconformable body of 5,000 feet, all of whose vertebrate remains refer it to the lowest Eocene; and I may add, as the reader will perceive in the succeeding chapter, that this 5,000 feet of lowest Eocene is overlaid by 4,000 feet more of middle or upper Eocene, whose abundant vertebrate remains are of unmistakable Eocene type.

To this discussion, therefore, I add the statement of the absolute nonconformity of the Vermilion Creek with the Laramie. I fix the beds in which the lowest Eocene mammals occur abundantly, near the bottom of the Vermilion Creek group. We have, therefore, a brackish group closing the Laramie, referred by Hayden and Lesquereux to the Miocene, but which carries Dinosaurian reptiles thoroughly characteristic of the Mesozoic age, and this is followed by a period of immense disturbance and with complete nonconformity, by a subsequent group of purely fresh-water rocks distinctly lower Eocene. It will be seen that the stratigraphical break, with its unmistakable Eocene facies at the base of the one group, and the Dinosaurian reptile at the close of the other, marks the limits of the period of nonconformity as distinctly at the close of the Cretaceous.

In order to accept the theory of Hayden, the entire Vermilion Creek series, the overlying Green River series, and the still overlying Bridger series—in all 10,000 feet of Eocene rocks—must be explained away. Likewise, the evidence of the Dinosaurian must be ignored. Let it be remembered that until the close of the Cretaceous, the country from the Wahsatch eastward to the Mississippi Basin had been subject to the constant incursions of the ocean; that all its beds, with the exception of the Laramie, were marine; and that the Laramie itself is never distinctly fresh-water. What, then, would have caused a profound fresh-water lake, in which 10,000 feet of Eocene strata could be deposited? It was nothing more or less than the great orographical disturbance at the end of the Cretaceous which acted over the whole country between the Wahsatch and the Mississippi region, causing the sea to retire altogether from the interior of America, absolutely obliterating the mediterranean ocean which had divided the eastern and western land-masses of America since the close of the Carboniferous. Not only is the Vermilion Creek series thoroughly nonconformable with the Laramie, but without the orographical movement at the close of the Laramie there would have been no interior basin isolated from the sea, in which the lacustrine sediment of the Vermilion Creek group could gather.

MAP OF THE AREA OF

PRE-MESOZOIC AND ME



30 Statute Miles

TRIASSIC

PRE MESOZOIC

RED BEDS

STAR PEAK

JURASSIC

...ZOIC EXPOSURES

CRETACEOUS

DAKOTA · COLORADO · FOX HILL · LARAMIE

I C E

Finally, the Laramie, by its own vertebrate remains, is proved to be unmistakably Cretaceous, and the last deposit of that age, and it contains no exclusively fresh-water life. Its plants resemble European Tertiary, but its Dinosaurs are conclusive of Cretaceous age. It was the last of the conformable marine deposits of middle America. Its latest period of sedimentation was immediately followed by an energetic orographic disturbance, which closed the Mesozoic age. In that orographic action the inter-American ocean was obliterated, and the Cretaceous locally thrown into great steep folds. The following deposits over the Green River area were fresh-water lacustrine lowest Eocene strata laid down nonconformably with the Cretaceous, except in accidental localities. This lowest Eocene has its age abundantly proved by vertebrate life, as will appear in the succeeding chapter.

CHAPTER V.

CENOZOIC.

SECTION I.—EOCENE TERTIARY.—VERMILION CREEK GROUP—GREEN RIVER GROUP—BRIDGER GROUP—UINTA GROUP.

SECTION II.—MIOCENE TERTIARY.—WHITE RIVER GROUP—TRUCKEE GROUP.

SECTION III.—PLIOCENE TERTIARY.—NIOBRARA GROUP—NORTH PARK GROUP—HUMBOLDT GROUP—WYOMING CONGLOMERATE.

SECTION IV.—RECAPITULATION OF TERTIARY LAKES.

SECTION V.—QUATERNARY.—GENERAL REMARKS—EXTINCT GLACIERS AND CAÑONS—LAKES OF THE GLACIAL AGE AND THEIR DESICCATION.

SECTION I.

EOCENE TERTIARY.

In the region of the Fortieth Parallel the changes of configuration brought about by orographical movements at the close of the Cretaceous period, resulted in the complete extinction of the American mediterranean sea, which, since the close of the Coal Measure age, had stretched from the Wahsatch to the longitude of eastern Kansas, dividing the east and west areas of American land into two distinct bodies. In Eocene time, so far as we now know, the entire continental area had a free drainage to the sea, with the exception of a long, basin-like depression extending from Wahsatch Range eastward to the meridian of 107° 30′, with a north-and-south extension not yet definitely known. This depression was immediately occupied by an early Eocene lake, whose northern portion corresponded with approximate accuracy to the present drainage-basin of Green River. Southward it extended through portions of Utah, New Mexico, Colorado, and probably into Arizona.

The series of marine Eocene deposits of the Alabama period are placed in a higher horizon than the beds of the Vermilion Creek group, which were the first to be laid down in the interior lake. On the western coast, in the California region, the uppermost members of the ocean Cretaceous are conformably overlaid by other marine deposits, of which certain members are unmistakably Miocene. For the lower members, those directly contiguous to the Cretaceous summit, the organic remains thus far collected are too indistinct to lead to a firm belief as to their exact age. There are indications of Eocene in the series overlying the Cretaceous of Oregon and Washington Territory. West of the Sierra Nevada, all the series are purely marine, and those of the Alabama and Vicksburg groups, also marine, are the only Eocene found east of Colorado Range.

As yet the great Eocene lake, whose main deposits are circumscribed by the boundaries of the basin of Colorado River, is the only one of any considerable geographical area known in the middle Cordillera region. In its earlier stages this lake was coextensive with the rocks of the Vermilion Creek period, the lowest division of the American lacustrine Eocene.

The great Eocene formation of this region is divided into four prominent groups:

1. Vermilion Creek Group, 5,000 feet thick, lowest Eocene.
2. Green River Group, 2,000 feet thick, middle Eocene.
3. Bridger Group, 2,500 feet thick, upper Eocene.
4. Uinta Group, 500? feet thick, latest Eocene, approaching Miocene.

Vermilion Creek Group.—Between the uppermost members of the Laramie Cretaceous and the lower beds of the Vermilion Creek Eocene, there is but very slight lithological difference. They are both reddish, friable, sandy rocks.

After the post-Cretaceous uplift had raised the Rocky Mountain barrier to the east, forming the basin of Colorado River, the original bottom of the newly formed lake was made of the uppermost Laramie beds, of which limited portions were left horizontal. When these exceptional localities were subsequently covered by Eocene strata, and the two uplifted together, they were, so far as angle of position is concerned, conformable. But a total break of organic life is observable between them; and as stated at the close of the Cretaceous section, there is elsewhere a true general nonconformity between the Laramie and Vermilion Creek groups, amounting in some places to an angle of 90°.

Along the eastern limit of the outcrop of the Eocene its beds lie upon nearly horizontal Laramie rocks. The line of demarkation, in the frequent absence of fossils, is always more or less indefinite, and in consequence there may be to the east of our eastern boundary of the Vermilion Creek certain outliers in the general Laramie area which truly belong to the Vermilion Creek; but since we are unable to determine these, we have given a generalized boundary-line. The rocks colored Laramie may be relied on as chiefly of that age, the same being true of the Vermilion Creek group. This doubt only applies to the horizontal region along the railroad and a few miles north and south.

The most eastern outcrops recognized by us are in a bay-like recess between Mount Weltha and Navesink Peak, in the Elk Head region. The surface is here composed of coarse red sandstones, interbedded with more or less clays and arenaceous marls of pinkish and creamy colors. Tracing this formation westward, although the surface is in considerable measure made up of decomposed earthy material, yet its character is such as to leave little doubt that the subjacent strata are continuous with the more solid Vermilion Creek beds which are seen to the west. They present little or no difference of angle with the underlying Cretaceous strata at this locality.

Along the banks of Little Snake River the series is better displayed, and is seen to consist of coarse gritty sandstones, containing numerous siliceous casts of *Melania*. There is the same want of definition between the Laramie and Vermilion Creek beds, from the junction of Little Muddy and Snake rivers northward quite to the Pacific Railroad.

In the region of the Washakie and Red Desert, and northward as far as the boundary of our map, the country consists of a deposit of more or less decomposed Vermilion Creek strata. Where they retain their original structure, they are seen to be nearly horizontal, and to consist of very easily eroded red clay and sandy beds.

From a little west of Rawlings Peak, the Vermilion Creek beds occupy the surface westward nearly to Bitter Creek Ridge, the country characterized by irregular barren plains, devoid of the dry water-courses which are features of the region to the south. From the Rawlings Peak uplift, the Laramie Cretaceous strata were described as falling off with rapidly decreasing dip, reaching an almost horizontal position north of the railway, between Washakie and Creston. They pass with no unconformity of dip under the eastern edge of the Vermilion Creek series.

There is no doubt that in former times the Eocene beds extended considerably farther to the east, though it seems improbable that they ever passed over into the valley of the North Platte, certainly not into the depression of Laramie Plain. The exact boundary of the lake, therefore, in which this lowest Eocene group was laid down cannot be given along the east in the northern portion of our work.

South of the parallel of 45°, however, the Cretaceous rocks have a higher dip, and a nonconformity with the overlying Vermilion Creek is clearly seen. Furthermore, in passing eastward the Green River overlaps the Vermilion Creek, and itself comes in contact with the Cretaceous, thus clearly proving that the boundary of the Vermilion Lake was in the neighborhood of Fortification Peak. About six miles east of Washakie Station, Laramie beds are undoubtedly reached, and are recognized in outcrops of a thin bed of sandy argillites of a strong vermilion hue. They are fine-grained and remarkably fissile, splitting into exceedingly thin laminæ, which are covered with well preserved impressions of deciduous leaves, and are underlaid by the sandstone carrying coal-seams. Ten miles northwest of this spot they may be again observed, capped by thinly bedded sandstones. In both cases their position is approximately horizontal, the slight observable dip being to the west. This red leaf-bed, characteristic of the upper region of the Laramie series, serves as a basis for the Cretaceous upper limit as colored upon the map.

About sixteen miles southwest of Washakie, in the near vicinity of well recognized Laramie beds, in a rather shallow valley, are beds of greenish marls and clays, weathering in the peculiar manner of the Bad Lands, developing smooth, rounded, dome-like forms. Their dip of 5°

westward would carry them under the Vermilion Creek beds at Cathedral Bluffs. A little south of this a discrepancy of angle appears between these soft clayey beds and the sandstones of the Laramie, which here rise at an angle of 15° to 20°, dipping northwest and striking northeast. East of Muddy Creek the bases of the Vermilion Creek benches are made up of loosely aggregated sandstones of chocolate, buff, and gray colors, carrying *Goniobasis* and *Viviparus* in a yellow sand-bed, which appears to represent the base of the series in this region. On the western borders of Muddy Creek Valley, however, upon the upper edge of the high plateau, are very distinct and characteristic outcrops of the bright pinkish and reddish mixture of sands, clays, and marls which form the upper part of the Vermilion Creek series. Their planes of stratification are to be traced by changes of color rather than by abrupt changes of material, or those distinctly marked surfaces which characterize temporary cessation of sedimentation. The faces of these bluffs have a peculiar striped, banded appearance, given by local variations of green, white, and almost brick-red colors, alternating through the general pink mass. Wherever these beds are worn away, the sandy particles are most easily transported, and there is invariably a residuum of red clay, which gives the peculiar color to the soil of the country. The best exposures of these upper striped beds are at Washakie Mountain and Cathedral Bluffs. The former is a flat-topped ridge, lying about seven miles east of Little Muddy River, and reaching an elevation of 1,500 feet above the surrounding plain, the surface being composed of a remnant of the Pliocene conglomerate, afterward to be described.

Washakie Peak affords an admirable point of view for studying the relations of the three different groups of Eocene. A broad expanse is opened westward, of 75 or 100 miles. The Green River series which directly underlies the Pliocene summit of the mountains is seen to describe a rude circle of bluffs having a general dip toward the middle of the Washakie Basin. The line of contact between the Green River and the Vermilion Creek trends a little west of north from Washakie Mountain to Cathedral Bluffs, thence westwardly to Table Rock near Bitter Creek Station, thence southwest to Pine Bluffs, and from there southeast to the Vermilion Bluffs; and upon the southeast the line is approximately that of Little Snake River.

Outside of this line, which represents the outer boundary of the Green River formation in this basin, are the broad undulating plains of the older Vermilion Creek Eocene, everywhere dipping under the Green River series.

The middle of this Washakie Basin, as shown upon the map, is occupied by a small area, about sixteen by twenty-four miles, of the next higher member, the Bridger group. With the exception of the rocks in the region of Cherokee Ridge, there has been no considerable plication since the deposition of these series. The slight dip toward the middle of the basin marks the result of orographic action, and cannot be accounted for from dips of deposition toward the deepest point of the lake.

Washakie Mountain itself has a special geological interest, as the upper beds of the Vermilion Creek are here seen to underlie the Green River series, with a distinct nonconformity of 4° or 5°. The importance of this observation will be seen later.

Between Washakie Mountain and Barrel Springs, and indeed on as far as Cathedral Bluffs, the division-plane between the Vermilion Creek and the overlying Green River beds may be easily traced by the differences of color and texture of the series. This plane of division is depressed in passing northward as far as Barrel Springs, and again rises as far as Cathedral Bluffs. The whole plain from Washakie Station to Black Butte Station is characterized by earthy deposits resulting from the decomposition of the Vermilion Creek beds, as usual of prevailing red color from the fine Vermilion Creek clays, which have given the local name of Red Desert to these plains.

A few miles west of Washakie are some low bluffs extending toward Red Desert Station, showing some outcrops about the middle of the Vermilion Creek series. They are thin, reddish, flaggy sandstones about 200 feet thick, underlaid by whitish clays, and have yielded some fragments of Eocene mammals, of genera which will be found in the list appended to the account of this group. South of Red Desert Station, the country gradually rises in broad terraces, the first formed of whitish clays overlaid by sand-rocks, the outcrops being traced nearly parallel to the line of the railway. About four miles south of this chain of bluffs is a line of still greater elevations, composed of striped pink, white, and red upper members of the Vermilion Creek. To this line has been given the name of Cathedral Bluffs, owing to the remarkable architectural forms which have been developed by erosion in the soft, easily wrought material. On the northern fronts of these bluffs are exposed about 600 feet of the variegated upper Vermilion beds, overlaid by drab limestones which mark the base of the Green River series. The summit member of the limestones is a seam about four inches thick of oölites, chiefly silicified, and resulting in a dark-gray chert or chalcedony-like material. The plane of junction between these two Eocene groups is also shown along an irregular line between Cathedral Bluffs and Table Rock, the latter being made up of sandstones and calcareous shales, with slight seams of lignite and several thin beds of a limestone which is characteristic of the base of the Green River series. These limestone beds are almost entirely made up of *Melania*, *Viviparus*, and *Unio*, together with the agatized oölitic bed before mentioned. The beds here, as usual, dip inwardly toward the centre of the basin in a southeasterly direction, at an angle of 4° or 5°. The main body of the Vermilion Creek beds at the north dips only 2½° to 3°.

From Table Rock westward and in the region of Black Butte, is a low, open country made up of the disintegrated Vermilion Creek beds, in which appear a few outcrops of the still coherent members of the group. Along the line of contact with the Green River shales, southward as far as Pine Bluffs and even to the old Cherokee Trail, the upper striped part of the Vermilion Creek series is conspicuous. The lower members, as seen at Black Butte, Hallville, and on the upper part of South Bitter Creek, rest with apparent conformity upon the Laramie Cretaceous, and are only to be distinguished by the change in vertebrate fossils. As is the case between the lower members of the Vermilion Creek and the Laramie, on the east edge of the Washakie Basin the lithological changes are such as to render any stratigraphical division valueless. It is therefore true of both sides of the Washakie hollow, that the Eocene is practically conformable with the Upper Cretaceous. At various points there is a slight appearance of nonconformity by erosion, but this is necessarily somewhat deceptive, and the line is only to be drawn here with real security upon the basis of vertebrate remains which will be mentioned hereafter

The upper portion of the Vermilion Creek series is observable near Otter Gap on Little Snake River, east of Cherokee Ridge. Here the interstratified red sandstones and clays give their characteristic color to the country, which for the most part is made up of the débris of these beds. Between Otter and Elk gaps, the river follows pretty nearly the plane of junction of the Vermilion Creek and Green River groups. In the region of Sunny Point, however, erosion has carried off the Green River series from the immediate hills bordering upon the stream, and there are extensive exposures of the upper part of the Vermilion Creek, of the characteristic color, and, as usual, much disintegrated. The exposure amounts to about 1,000 feet in thickness, and is altogether made up of the reddish-colored part of the series. The contact between the uppermost of these beds and the calcareous lower horizon of the Green River is characteristically observed. The structure in the region of Elk Gap is quite complicated, the underlying series considered to represent the upper portion of the Vermilion Creek dipping 10° to the south and being overlaid by a series of the sandstones carrying at their base a prominent bed of reddish shales which dips 29° to the southwest. The overlying series are referred to the Green River, but it seems possible that they may represent the Bridger, which is seen directly to the northwest.

East of the river at Godiva Ridge the top of the Vermilion Creek series is well shown by its contact with the characteristic cherty *Goniobasis* bed at the base of the Green River series.

Around the whole circle formed by the great Green River body in Washakie Basin, the upper limit of the Vermilion Creek, as we have seen, is quite a defined plane, the variegated and banded red series of the upper Vermilion Creek giving way quite suddenly to the calcareous basal members of the Green River series, which are often conformable, but in one or two places show distinct nonconformity with the lower series. The broad plains which surround the Green River exposure offer few satisfactory outcrops and no valuable sections of the lower portion of the Vermilion Creek group. Wherever it approaches the nearly conformable underlying Laramie, the Cretaceous and Eocene possess great petrological similarity.

The deeper members are better shown in the basin of Vermilion Creek, the locality which has given its name to the group. The upper members also are here well shown along the line from Pine Bluffs to Cherokee Trail, and again as forming the lower portion of the Vermilion Bluffs, which bound the basin upon the southeast. Here, as at Washakie Mountain, the uppermost edge of the bluff is formed of unstratified Pliocene conglomerate, below which is a development of 500 or 600 feet of the calcareous Green River series, underlaid by 800 feet of the characteristic Red-beds of the upper Vermilion, which pass downward in the region of Vermilion Creek into gray and drab beds. It is the horizon of these gray and drab basal members, which are elsewhere rich in bones of *Coryphodon*. At the foot of Vermilion Bluffs the dip is only about 2°, but toward Vermilion Creek it gradually reaches an inclination of 12°.

The whole surface of the basin of Vermilion Creek is a region of terrace-like benches, scored and more or less deeply eroded by water-courses, which are now for the most part dry. Throughout the lower part of the basin, especially near the contact with the underlying and nonconformable Laramie Cretaceous, are a series of dark-drab and gray gravelly sandstones, which lie approximately horizontal, rising very gently to the east and north. The underlying Laramie Cretaceous dips to the northeast about 25°, the two being utterly unconformable. Attention is especially called to the fact of an angular nonconformity of 25° between the Laramie and the lowest member of the Eocene, the same groups already noted as conformable at Black Butte and east of Washakie. If the geologists who have asserted the conformable passage from the Cretaceous to the Tertiary by a transition series had not confined their observations in the Green River Basin to the region of Bitter Creek and Washakie Basin, the present unreasonable controversy would never have arisen. The higher members of the Vermilion series, as exposed on the western flanks of Vermilion Creek valley, are coarse gravelly sandstones, the upper portion of which has the characteristic red color of the formation. Directly north of Diamond Mountain these higher Vermilion Creek beds yielded several bird-bones from a coarse, gritty, buff sandstone. Passing southward, the uppermost members of the group come into nonconformable contact with the Carboniferous limestones. Southeast of Diamond Peak, and along Talamantes Creek, the whole series are seen to pass unconformably over the Cretaceous, Jura, Trias, Permian, and upper Carboniferous, coming finally into contact with the Weber quartzite of O-wi-yu-kuts Plateau.

The meridian of Bishop's Mountain, a little northeast of Diamond Peak, marks an anticlinal in the Vermilion Creek series. Eastward the whole strata incline gently to the east, to pass under the Green River and Bridger series of the Washakie Basin, and westward beneath the Green River rocks of Tabor Plateau and Quien Hornet Mountain. The entire thickness of the Vermilion Creek series, as displayed in the basin of Vermilion Creek, cannot be less than 4,000 feet.

Considered as a whole, the Tertiary field lying east of the meridian of Quien Hornet Mountain is a single broad basin, of which the Vermilion Creek forms the lowest member, and upon the east and north lies conformably as to its angle upon the Laramie beds of the Cretaceous, while to the south the discrepancy of angle between those two formations amounts to 25° at Vermilion Creek, and to 3° or 4° near Fortification Peak, in the valley of the Yampa. The greater part of the area is covered by easily eroded earthy beds of the Vermilion Creek series, which are characterized by the presence of a considerable number of fresh-water Tertiary genera — *Melania*, *Goniobasis*, *Viviparus*, and *Unio*, and also by the bones of vertebrates, including *Coryphodon*.

The upper limit is frequently well marked by contact with the lower limy members of the Green River series; but since these two members are nonconformable, the Green River often overlaps and obscures the edges of the Vermilion Creek beds. This is the case between Sunny Point and Vermilion Bluffs, and also through the whole Tertiary exposure from Godiva Ridge to the White River divide. West of the meridian of Bishop's Mountain the Vermilion Creek beds incline very gently to the west, passing beneath the irregularly eroded Green River series.

Along the immediate base of the Uinta Mountains the later strata are eroded off, leaving a narrow strip of the Vermilion Creek beds extending from the head of Willow Creek westward to the slopes of Mount Corson. Along this line is an admirable opportunity of studying the relations of the Vermilion Creek with the Cretaceous. West of the ford of Green River, about four miles north of Flaming Gorge, the upper Cretaceous sandstones of the Laramie group are seen dipping to the north at very high angles, 25° near the river and increasing westward, until at the gap where Henry's Fork enters the Quaternary valley north of Camp Stevenson the Laramie sandstones dip 75° or 80° to the north, while the Vermilion Creek beds, distinctly and nonconformably above them, dip only 25°. Continuing still farther west from the gap north of Dead Man's Springs, the Vermilion Creek beds swing to the south and overlap first the Fox Hill, then the Colorado, and later the Dakota. They are in turn overlaid by the unconformable Bridger series, forming with a Pliocene gravel-cap the mass of Mount Corson. The lowest Vermilion Creek member exposed along Henry's Fork is a coarse conglomerate which underlies some striped red sandstones, the conglomerates dipping 25° to 35° northward.

Along the western side of the Bitter Creek uplift and in the valley of Sage Creek the erosion of the calcareous beds of the Green River series has laid bare a narrow belt of the Vermilion Creek lying between the Green River group and the Laramie Cretaceous. The relation with the Laramie sandstones is obscure, owing to the soft and friable nature of both series.

North of Uinta Range, to the east and west of where Bear River emerges from the mountains, the foot-hills are deeply overlaid with Tertiary sandstones and conglomerates, which, near the mouth of Bear River, have a dip of 8° or 10° from the range. Extending westward along the flank, these conglomerates become more and more important, until directly north of the upper cañon of Weber River the mountain wall is composed of excessively coarse conglomerate between 3,000 and 4,000 feet thick. It is almost structureless, and lines of stratification can rarely be perceived. The blocks of which the conglomerate is chiefly formed range from the size of a pea to masses with a weight of several tons. Here and there a comparatively fine-grained bed gives a clew to the dip, and the formation is seen to incline from 4° to 5° northward away from the foot-hills of the range. The rapidity with which these conglomerates grow finer in advancing from the shore along the Uinta is very conspicuous. Of these coarse conglomerates, perhaps the most remarkable exposure is on a point directly north of the upper Weber Cañon, about ten miles south of the 41st parallel.

This peak is over 11,000 feet high, and marks the greatest altitude which the comparatively undisturbed Tertiaries have been observed to attain. To the north the ridge and peak are scored down by deep cañons which well display the graduation of the material from the coarse conglomerate immediately in contact with the older rocks out toward the north, until, near Wahsatch and Evanston, they have become fine-grained, sandy beds, devoid of pebbles. A section displayed on the 111th meridian, from the high peak to Evanston, estimating from the observed dips, indicates a thickness of about 4,000 feet of strata; while from Evanston to Croydon, on the Union Pacific Railroad, some distance to the west, certainly 2,000 feet of lower beds are displayed. It is entirely within bounds to assign to the Vermilion Creek of this region a total thickness of 5,000 or 5,500 feet, and it should be borne in mind that this nowhere represents the former summit of the Vermilion Creek series. On the contrary, we can but suppose that a considerable portion of the uppermost beds have been removed, and hence that an unknown amount is to be added to the total thickness of the group.

In the region of Aspen Plateau the Vermilion Creek beds are about horizontal, and are, for the most part, alternately of cream-colored and red arenaceous clays, with not infrequently a considerable proportion of marly strata. They have yielded in this vicinity numerous fragments of *Coryphodon*, which add certainty to the assignment of the rocks of this region that had been already made upon structural and stratigraphical grounds. East of Aspen, both the Vermilion Creek group and the small exposure of Green River group pass rapidly under the unconformable Bridger beds, and the eastern flank of Aspen Plateau seems to have been the western limit of deposition of the Bridger beds of the Bridger Basin.

At the mouth of Echo Cañon the Vermilion Creek conglomerates are seen to contain a large number of rounded pebbles, from extremely fine sizes up to six, eight, and even ten inches in diameter. The latter size, however, is very rare. Passing up in the series, the conglomerate beds are capped by Indian-red sandstones, which expose in Echo Cañon fine precipitous fronts, carved down by transverse ravines, which carry off the drainage from the high Tertiary plateau to the north. Between Echo City and the top of this plateau are represented about 3,800 feet of strata, chiefly of these Indian-red sandstones, containing toward the upper limit gray shale-beds, with occasional sheets of fine conglomerate.

Directly west of Coalville the Vermilion Creek rocks are seen to rest unconformably upon the northwesterly dipping Cretaceous. This line of discordant contact may be traced southwestward across Weber River, appearing on the hill-sides north of Silver Creek. From Echo City along this entire line of contact, even past the north side of Parley's Park, there is no single instance in which any close observer could possibly assume a conformity between the Vermilion Creek beds and the underlying Cretaceous. On East Cañon Creek the discrepancy rises to 50° or 60°, gradually growing less toward Echo City, until directly south of the mouth of Echo Cañon the nonconformity is reduced to about 10°. At Croydon low beds of Vermilion Creek are seen resting unconformably upon the Fox Hill sandstones of the Cretaceous, the latter dipping 25°, while the Tertiaries never dip over 5°, and are for the most part nearly horizontal.

East of the great Cambrian anticlinal of the northern end of the Wahsatch, shown on Map III., is a parallel highland, the Bear River Plateau. It is merely an area of elevation that has escaped the extreme erosion which the beds in immediate contact with the Cambrian and Silurian rocks of the older uplift have suffered. It varies from two to five miles in width, and on the east overlooks the valley of Bear River and descends by a series of rudely sloping spurs, which are separated by the cañons of Woodruff, Randolph, and Saleratus creeks. The beds here are inclined from 1° to 2° to the east, and show a thickness of about 2,500 feet. They have the usual characteristic red color, and are made up of prevailingly coarse arenaceous materials, with occasional strata carrying sufficient pebbles to be denominated a loose conglomerate. There are a few beds of nearly pure, white, fine, siliceous sand, which are striped with fine seams of gray argillaceous marl. On the divide between Saleratus and Lost creeks the coarseness of the material increases westward till it shows a perceptible approach to the heavy conglomerates displayed in the Narrows below Croydon and at Echo City. The western edge of Bear River Plateau descends by a rapid declivity, often almost an escarpment, between 2,000 and 3,000 feet deep to the level of the Silurian and Cambrian rocks. This abrupt, precipitous face is cut by deep cañons, the branches of Blacksmith's Fork and Muddy River. These cañons do not cease their cutting action when they reach the harder rocks of the Silurian and Cambrian beds, but have deeply scored through that anticlinal, making gorges 1,800 to 2,000 feet deep in the quartzite. From the peculiar relations of the topography of the Bear River Plateau with the older rocks, it is clear that the Vermilion Creek rocks formerly passed uninterruptedly over the summit of the older anticlinal, that the courses of the streams were determined in the softer Tertiary above, and that upon cutting down to the level of the harder underlying rock they were confined by the Tertiary walls above and obliged to erode in the thus predetermined channel. Afterward, long after the streams had cut deeply into the older rocks, the Tertiaries were in great measure removed.

On the western side of Oyster Ridge and west of Concrete Plateau there is an enormous development of red sandstones and clays, with prominent belts of conglomerate, the whole increasing in coarseness of sediment as it approaches the Uinta on the south and the Wahsatch on the west. Here is an area about sixty miles from north to south by fifty miles from east to west, which is essentially a plateau of Vermilion Creek beds, in general approximately horizontal, but in the vicinity of the Wahsatch rising to 14°. On the south it abuts without change of angle against the Uinta Mountains, and between Upper Bear and Weber rivers forms an elevated plateau which reaches 11,000 feet, a plateau made up of coarse, irregular strata of red gritty conglomerate material, dipping northward at angles of 3° to 4°. On the flanks of the Uinta, cañons have been carved out of these loose, friable strata by the ice action of the glacial period, leaving sharp, deep walls 1,000 to 1,200 feet in height.

Between Weber River and Wahsatch Range there is a lofty plateau culminating in an extremely high point, which reaches nearly 11,000 feet. This plateau is cut through by the valley of East Cañon Creek, and not less than 4,500 or 5,000 feet of horizontal sandy and conglomerate beds of the Vermilion Creek group are displayed. They are here nearly horizontal, but toward Richville, farther down on East Cañon Creek, the red sandstones of the group are seen dipping from the Wahsatch at an angle of about 14°. The railway crosses a point of this plateau through a sharp gorge at the Narrows, where the Tertiary conglomerates and sandstones are nearly horizontal and about 2,000 feet thick.

In the region of Bear River City and Evanston, the Cretaceous, which stands nearly vertical, has its highest members dipping at an angle of 70°. Here, as at Black Butte, the uppermost beds lying above the heavy white sandstones of the Laramie consist of a variety of thin, sandy shales, having many carbonaceous beds, more or less clays, and thin streaks of coal, the whole carrying enormous numbers of *Unio*, *Corbicula*, *Corbula*, *Pyrgulifera*, *Viviparus*, *Melampus*, &c.; and here the rocks of the Vermilion Creek series are horizontal—in other words, there is an angular discrepancy of 70°. They are characterized by the presence of *Melania* and *Goniobasis*, and also by numerous mammalian remains of the typical Eocene genus *Coryphodon*.

At Evanston the highest portions of the Laramie Cretaceous are not exposed, but the sandstones near the summit of the group contain the enormous workable coal-beds of the Rocky Mountain and Wyoming Coal companies. These coal-bearing Laramie beds dip at angles from 16° to 25°, whereas the Vermilion Creek Tertiaries are nearly horizontal over them, and carry remains of the genera *Coryphodon* and *Eohippus*, and fishes.

In the region of Echo Cañon, again, the uppermost members of the Laramie are not displayed, but the distinctive Vermilion Creek beds, which have been traced in absolute continuity from the Coryphodon beds near Evanston, are here seen to overlie unconformably the Cretaceous, the angular discrepancy being 12° to 25°. Near the upper part of the cañon, below Castle Rock, they reach their greatest nonconformity in that immediate region, and near Echo City there is a difference of 11°. The continuous series of Vermilion Creek beds, passing westward, overlaps all the Palæozoic formations, which are conformable with the Cretaceous, and comes directly into contact with the Archæan.

Between Bear River and Oyster Ridge is a further extension of this great Vermilion Creek Plateau, abutting nearly horizontally against the highly inclined Cretaceous of the ridge. The broad upper valley of Bear River is excavated from these strata, which occupy the heights to the west, and extend thence across Bear River Plateau. Along the eastern side of the Wahsatch, east of Farmington and Keysville—indeed, from Huntsville all the way to Parley's Park—the Vermilion Creek beds rise high upon the flanks of the Wahsatch, the highest portions of the Tertiary being frequently higher than the top of the older range. This is true of the whole Bear River Plateau, and true of the Vermilion Creek heights directly north of Parley's Park. The only exposure of these beds west of the summit of the Wahsatch is to be found in a small body of hills lying directly north of Salt Lake City, of which Ensign Peak is a prominent point. This is a mass of sandstone and conglomerate, which has been faulted down into its present position. The entire absence of this great series to the west of the Wahsatch would indicate that the range itself formed approximately the shore of the lake, and it is probable that the small detached mass around Ensign Peak was merely a bay of the Tertiary putting into the land which lay to the west.

From the outcrops thus broadly sketched, it is clear that a single lake extended from longitude 106° 30′ to 112°, stretching northward probably over the greater part of the Green River Basin and southward to an unknown distance. The rocks of this same group which occur in New Mexico represent a southern continuance of the identical lake, characterized by the same fauna. So far as the area of the Fortieth Parallel goes, these rocks have only been definitely studied in the region east of the Wahsatch and north of the Uinta. South of the latter range, from the heights west of Strawberry Valley eastward across Green River, extends a broad area of Tertiary rocks of great thickness. These have not been sufficiently studied to say definitely to what members of the Eocene they belong. In the region of White River some beds have yielded fossils which, although Eocene, have a more recent facies than those of the highest or Bridger member to the north of the Uinta. They are still lower than the Titanotherium beds which form the base of the Miocene east of the Rocky Mountains. It seems most probable that the immense mass of Tertiary south of the western end of the Uinta, which is shown in the valleys of Du Chesne, Red Fork, and upper Uinta rivers belongs to the Vermilion Creek series. In the absence of more definite information, the whole sweep of the Tertiaries south of the Uinta, with the exception of certain little patches of known Pliocene, has been colored as the Uinta group, whose upper members near White River have yielded the highest Eocene forms; but there is no doubt whatever that subsequent study will show that the rocks in the angle between the Uinta and the Wahsatch south of the former range are identical with those in the opposite angle north of the Uinta, and that they should be classed with the Vermilion Creek. And the altitudes to which the level Tertiary strata northeast of Strawberry Valley attain, indicate that the level of their deposition was as high as the rocks north of the Uinta. We may expect a full elucidation of the Tertiaries south of the Uinta from the pens of Powell and Gilbert.

The thickest exposures of the Vermilion Creek series are in the immediate vicinity of the Wahsatch, as shown by the deep valley of East Cañon Creek, where is exposed not less than 4,000 feet. The most characteristic exhibition is in the basin of Vermilion Creek, where a fuller section is displayed. It is made up of a heavy, gritty series at the base, which in the region of Vermilion Creek and north of Evanston is gray, but as displayed at Echo Cañon and East Cañon Creek is characterized by the presence of enough red sandstones and clays to give it more of a brick or in places a deep pinkish color. The middle members are of finer material and are more intercalated with clays, while the upper part of the series, as shown wherever the group comes in contact with the Green River series, is made up of striped and banded sandstones varying from gray to yellow, white, and red, with prevailing red and white tints.

As regards the relations of this with the underlying group, it should be repeated that the evidence has finally accumulated so that there can be no longer a doubt where to draw the line between the Cretaceous and the Tertiary series. I unhesitatingly say that the bottom of the Vermilion Creek is the base of the Tertiary, and that it rests in essential nonconformity (though locally in accidental conformity) upon the Cretaceous.

The Cretaceous members, as we have seen, are *inter se* strictly conformable. The uppermost exposures in the near vicinity of the Vermilion Creek beds are along the Bitter Creek uplift, at Evanston, at the eastern end of the O-wi-yu-kuts Plateau, Red Creek, the northern slopes of the

Uinta, Oyster Ridge, Bear River City, and Echo Cañon. Of all these localities, the only one where there is the slightest appearance of conformity of position is in Washakie Basin, where the inclinations of the two formations are practically identical, and the appearance of nonconformity by erosion is wanting. The Cretaceous, as we have seen, is here characterized lithologically by a variation between beds of heavy sandstone, yellowish shales, finely laminated sandstones, dark clayey shales, ashy, laminated clays, and numerous intercalated beds of coal. The organic remains of these upper Cretaceous, as I have shown when describing that formation, are numerous vegetable remains, including the leaves of palms, and mollusks of the genera *Ostrea*, *Anomia*, *Corbicula*, *Corbula*, *Cyrena*, *Goniobasis*, and *Viviparus;* while above these Meek, Bannister, and Cope exhumed a portion of a skeleton of *Agathaumus sylvestris*, a distinctly Cretaceous Dinosaur. Passing upward, Cope obtained in the immediately overlying series the following list:

Clastes? glaber.
Emys megaulax.
Emys pachylomus.
Emys euthnetus.
Trionyx scutumantiquum.
Alligator heterodon.
Orohippus vasacciensis.

All these types are distinctly Tertiary. The following list, partly from Green River Basin, will give the characteristic features of the vertebrate fauna of the group:

VERMILION CREEK GROUP.

CARNIVORA.

Oxyæna lupina, Cope.
Oxyæna forcipata, Cope.
Pachyæna ossifraga, Cope.

UNGULATA.

Phænacodus primævus, Cope.
Meniscotherium chamense, Cope.
Helaletes singularis, (Cope) Marsh.

Eohippus tapirinus, (Cope) Marsh.
Eohippus angustidens, (Cope) Marsh.
Eohippus cuspidatus, (Cope) Marsh.
Eohippus validus, Marsh.
Eohippus major, Marsh.
Eohippus pernix, Marsh.
Parahyus vagans, Marsh.
Coryphodon hamatus, Marsh.
Coryphodon elephantopus, (Cope) Marsh.
Coryphodon latidens, (Cope) Marsh.
Coryphodon radians, (Cope) Marsh.

TILLODONTIA.

Dryptodon crassus, Marsh.
Esthonyx bisulcatus, Cope.
Ectoganus gliriformis, Cope.
Calamodon simplex, Cope.

REPTILIA.

Diplocynodus stenops, Cope.
Crocodilus grypus, Cope.
Crocodilus heterodon, Cope.
Trionyx leptomitus, Cope.
Trionyx radulus, Cope.
Plastomenus corrugatus, Cope.
Plastomenus communis, Cope.
Dermatemys costilatus, Cope.

It will be seen from these facts that I am fully justified, first, in asserting general nonconformity between the Laramie and the Vermilion Creek; secondly, that the angular conformity in the region of Washakie Basin is exceptional; thirdly, that the Vermilion Creek fauna is distinctly lowest Eocene.

GREEN RIVER GROUP.—Not only is the middle member of the Eocene series, or the Green River group, unconformable with the rocks of the Vermilion Creek group, but from certain occurrences in western Utah and eastern Nevada it is now known that it overlaps to the westward at least 200 miles. Within the area covered by Vermilion Creek rocks the Green River series rests for the most part unconformably upon the horizontal as well as the highly inclined Vermilion Creek beds. It probably somewhat overlapped the Vermilion Creek rocks toward the east, but the area of the lake in which it was deposited expanded westward to certainly twice the east-and-west dimensions of the lake of the Vermilion Creek period.

At first it seemed possible that the exposures of the Green River Eocene, which are observed in western Utah and eastern Nevada from longitude 114° to 116°, might represent a second middle Eocene lake, whose deposits and fauna are identical with the contemporaneous deposits and fauna in the Green River region; but the recent discovery of Tertiary beds near Stockton, west of the Oquirrh Mountains, and the extension from the Oyster Ridge region far to the northwest, or toward the Great Basin country, confirm the general belief that the detached outcrops between the meridians 114° and 116° are really parts of the sediments of one lake.

The way in which the Vermilion Creek beds abut against the eastern flank of the Wahsatch nearly up to its summit, is sufficient warrant for the belief that that range formed the westward barrier for a great amount of the sediments of the early Eocene lake. But when we pass eastward from the immediate neighborhood of Wahsatch Range, it is found that the slightly inclined Vermilion Creek beds rise rapidly in altitude, still maintaining their horizontal position and forming extensive plateaus, which have been more or less eroded, leaving isolated highlands and even mountain peaks, all made of horizontal beds. Such points are the high peak directly northwest of Wanship, and the elevated plateau country north of Croydon, also Bear River Plateau, which lies to the east of the Cambrian anticlinal on the northern portion of our Map III. From an examination of the outcropping edges of these horizontal Vermilion Creek beds, it is clear that if continued westward they would pass over the top of Wahsatch Range; while an examination of the country to the west of the range shows a depressed basin in which, so far, no traces of Vermilion Creek rocks have been discovered. One must therefore believe either that the Vermilion Creek rocks formerly extended over the top of the now exhumed Wahsatch Range and continued to some indefinite distance westward, or else that the Wahsatch formed the barrier to the westward extent of the lake, and that subsequent faults have carried down the region west of the range, while the erosion of the glacial period has degraded the main Wahsatch range, so that it is now below the level of the Eocene plateaus directly to the east. From evidence to be adduced in the chapter which treats of orographical disturbances, it will be seen that unquestionably a series of enormous faults occurred posterior to the deposition of the Vermilion Creek series, which depressed the whole country out as far as middle Nevada, and which permitted the waters of the Eocene lake to flow westward and make a comparatively continuous sheet from the Rawlings uplift at longitude 107° to longitude 116°. Accompanying this great dislocation, the Vermilion Creek rocks east of the Wahsatch were thrown into a series of more or less abrupt folds. Along the northern slope of the Uinta, in the region of Henry's Fork, they were uplifted at an angle of 25°, and in general they sagged downward to form two prominent basins, one of which forms the Bridger Basin, the other the basin of Washakie.

At the beginning of its existence, then, the middle Eocene lake had for its bottom, from its eastern shore as far west as tne Wahsatch, the horizontal or upturned beds of the Vermilion Creek, that covered all but the single mass of Uinta Range, which probably formed a great east-and-west island in the lake. That portion of the lake lying west of the Wahsatch occupied a region in which the Carboniferous were the uppermost rocks, a region which had been a continental land-mass since the close of the Carboniferous, and over which no Mesozoic or lowest Eocene strata had been deposited. It was, indeed, the land area from which the materials of the eastern Mesozoic and the main mass of the Vermilion Creek Eocene beds had been furnished; and it must have been, as we may judge from the relations of the slight exposures of western Eocene beds to the older rocks, a comparatively corrugated region characterized by bold ranges of Palæozoic rock, many of which doubtless projected above the level of the middle Eocene lake, creating a complex archipelago.

From the character of the Eocene deposit west of the Wahsatch, we may assume that the lake in that region during the latter part of its history was comparatively shallow, and that the detritus was largely derived from the islands, partaking of their extremely localized character. On the other hand, the rocks of the Green River Basin of this same period show deeper waters and excessively fine sediments, which might have been transported from a considerable distance, and which doubtless represent material not only from the neighboring Uinta Range, but from a variety of different sources around the whole shore of the lake. The sediments, deposited nonconformably against the sharp, ridgy chains of the archipelago of the west, show always a sharp nonconformity with the immediately underlying rocks. On the other hand, in the region east of the Wahsatch, a large amount of the Vermilion Creek series was left in a nearly horizontal position, and the sediments there sank quietly through deep water upon an approximately level bottom, accumulating in strata nearly conformable with the underlying Vermilion Creek rocks. From the manner in which the rocks of the Green River group abut westward against the Vermilion beds, it is evident that there was in the region included between the Wahsatch and Uinta a highland lifted above the lake of the Green River period.

Exactly the extent and area of all the islands which rose above the surface of the Green River lake, it is at present impossible to tell. The central and higher parts of the Uinta were out of water, but it seems quite clear that the depressed portions of the eastern end of the range were for the most part submerged. The entire Vermilion Creek series, as we have seen, was made up of sandstones and intercalated clays, with more or less conglomerates near the old shores of the lake. This detritus doubtless came partly from the erosion of the siliceous Cretaceous beds which must in great part have formed the shore and islands of Vermilion Lake. But it would seem that about the close of the Vermilion Creek period, erosion must have worked off from the higher summits most of the Mesozoic rocks, and with the beginning of the Green River group have begun its work of degradation upon the calcareous beds of the Carboniferous.

The Green River beds are in sharp contrast with those of the earlier Eocene, first, by the extreme fineness of the material, and, secondly, by their calcareous nature. As a whole, east of Wahsatch this group consists of calcareous sands and slightly siliceous limestones, which are overlaid by remarkably fissile calcareous shales, the former abounding in fresh-water mollusks, the latter in the remains of fishes, plants, and insects. The lower member, the impure limestones, probably reaches about 800 feet in thickness, and the thin, fissile, calcareous shales about 1,200 feet, making a total of 2,000 feet for the entire group. To what height they originally reached along the northern flank of the Uinta, is in a great measure unknown. Where the overlying Bridger group overlaps them and abuts against the Coal Measure limestones of the Uinta, as it does from Mount Corson to Concrete Plateau, there is, of course, a certainty that the Green River beds extended no farther to the south; and likewise directly west of Concrete Plateau, where the Bridger comes into actual contact with the Vermilion Creek, it is clear that the Green River beds did not extend in that direction. But in the region of the present valley of Green River they doubtless extended much higher against the flanks of the range, and east of the Uinta saddled across the divide into the valley of White River. Over the Washakie Basin they occupied the greater part of the area, and were there again deposited as fine calcareous sediments. Detached outliers of the Green River series still exist between the Bitter Creek Cretaceous uplift and the Archæan mass at the head of Red Creek, sufficient to show that the sheet of sediment stretched over all that country and connected the Washakie and Bridger basins.

The chief present outcrops of the Fortieth Parallel region are: First, a narrow strip east of Oyster Ridge, first observed near Piedmont Station, where it overlies unconformably the Vermilion Creek rocks, and is itself overlaid by the Bridger with heavy Quatenary desert deposits to the east. This narrow zone extends in a northeasterly direction as far as the northern limits of our map, and probably over into the Nevada extension of the Green River lake, the exposure gradually widening to the north, where it covers eight or ten miles.

The next, and by far the most characteristic development, is a broad belt extending from the northern edge of the map in a meridional direction down the valley of Green River to the foot-hills of Uinta Range. It is from this typical display in the valley of Green River that the group has derived its name. Farther east the broad area occupying the middle of Washakie

Basin, and extending over the region from O-wi-yu-kuts Plateau to the White River divide and southward, forms decidedly the most important geographical area of this group within our limits.

The most eastern exposures are west of the valley of Little Muddy Creek, in the region of Washakie Mountain, where the variegated upper beds of the Vermilion Creek group, which have a dip of from 4° to 5° westward, are overlaid by the horizontal brown sandstone and blue calcareous shales and clays of the Green River series.

This locality is of special interest as displaying the nonconformity of the two groups at the most eastern exposure of the Green River, and the gradual rise of the Vermilion Creek group passing eastward would indicate that a portion of the earlier group was lifted above the level of the lake of the Green River period, or at least above its plane of deposition. From this point the margin of the Green River formation defines a rude circle through Cathedral Bluffs, Table Rock, Pine Bluffs, Vermilion Bluffs, and Sunny Point, the strata of the series always presenting their edges to the exterior of the area in a more or less important escarpment, but dipping in from every direction, at gentle angles, toward the centre of the basin. In passing from Washakie to Cathedral Bluffs the plane of contact of the Vermilion Creek and Green River series is depressed toward the north until at Barrel Springs it reaches the lowest point, and then rises again.

At Cathedral Bluffs, capping an exposure 600 or 700 feet thick of the upper Vermilion Creek beds, is a layer 100 or 150 feet thick of the impure limestone which forms the base of the Green River group. It is here of concretionary structure, with a dull drab color, carrying more or less siliceous matter, and near the top a prominent seam four or five feet thick of oölitic limestone largely metamorphosed into chalcedony. The round grains are from a thirtieth to a tenth of an inch in diameter. They are of more or less concentric structure, showing a cryptocrystalline calcareous cement. They are probably crystallitic and not organic, and may be related to the calcareous spherical sands, examples of which are now found on the beaches of Great Salt Lake. They here contain 74.81 of silica, the remainder being carbonate of lime. Besides this bed there is a prominent chalcedonic stratum made up of casts of *Goniobasis*. Farther west, at Table Rock, the summit is of calcareous beds with more or less lignite, several of the thin limestone beds being almost entirely composed of *Melania*, *Viviparus*, *Unio*, and other fresh-water shells. The siliceous oölitic bed observed upon Cathedral Bluffs recurs here.

Very characteristic displays of the Green River series are observed at Pine Bluffs, a conspicuous escarpment which offers a commanding view over the valley of South Bitter Creek and the Washakie and Vermilion Creek basins. The upper 400 feet of the escarpment are made up of a highly calcareous buff sandstone, which dips 4° to 5° to the east and strikes a little east of north. Directly beneath the sandstones are white, shaly beds underlaid by thin sandstone, all slightly calcareous.

At the Springs, where Bitter Creek emerges from the Green River area, about ten miles north of Pine Bluffs, are admirable exposures of the characteristic limy beds and shales of remarkably fissile structure, which readily split into flakes almost as thin as a sheet of paper. These are more or less interspersed with carbonaceous and arenaceous beds, the carbonaceous members especially showing a tendency to whiten on exposure to the air. Considerable surfaces of the upper valley of Bitter Creek are covered by white chips of the calcareous and carbonaceous shales, which, by exposure to the air, have acquired this peculiar chalky appearance. The shales at Barrel Springs, another point near the extreme boundary of the Green River area, lying south and east of Cathedral Bluffs, are highly carbonaceous, and, as usual, are intercalated with more or less sandy members. They are rich in leaf-impressions, and among the numerous fresh-water mollusks have been recognized —

Unio.
Tellinides.
Goniobasis tenera.
Goniobasis nodulifera.
Goniobasis Carteri.

In the region of Cherokee Ridge the very slight dip toward the centre of the Washakie Basin, which is observed in all the distinct outcrops of the Green River area, gives way to a local anticlinal where beds of the series are observed dipping 7° northward, the line of Cherokee Ridge marking pretty nearly the axis of the anticlinal. The series here consists of drab laminated sandstones, slightly calcareous and abounding in casts of *Goniobasis*, the sandstones passing into slightly saccharoidal, creamy-brown limestone. The whole northern half of this anticlinal declines at first to 7°, passing unconformably under the overlying Bridger series to the north; but the southern member of the anticlinal, which seems to have been somewhat faulted up, declines to the south at angles of from 25° to 30°, marking the highest slope developed in the Green River group.

The area enclosed between Vermilion Bluffs, Brown's Park, the Escalante Hills, and Snake River, is one in which the relations of the Tertiary are involved in much obscurity. It is a region which has suffered extensive faults and extraordinary erosion, and is for the most part largely covered with deep accumulations of soil. It is certain that at some point in Vermilion Bluffs the Green River strata occupy the surface, and we are unable to observe any break from Vermilion Bluffs southeastward into Brown's Park. The rocks in Brown's Park are also in great measure covered by local accumulations of soil. Throughout the southern part of the valley, wherever exposed, the Tertiaries are seen to be approximately horizontal, and to be composed of soft, friable beds. Along the north wall of the valley there is a sharp break, however, and the Tertiary rocks which come to the surface lie immediately against the quartzitic sandstones of the plateau and dip to the south at an angle of 18° to 25°. They are of a rather coarse, gritty character, containing many sheets of fine pebbles, and are prevailingly calcareous. They are unlike any Tertiary in the region; but from their calcareous nature, the fact of their being upturned at so high an angle, and their apparent connection with the series which sweeps around the eastern end of O-wi-yu-kuts Plateau, they are assigned by Mr. Emmons to the Green River age. There seems to be a decided difference between the strata which were seen uptilted along the south base of the O-wi-yu-kuts Plateau and the soft, white, friable, horizontal beds of the valley itself, which are seen to extend eastward well toward the divide separating the valley of Vermilion Creek from that of Little Snake River. It is not improbable that there are two distinct members here—the Green River, which is seen inclined along the northern edge of the park, and a more recent horizontal member, assigned to a special group by Powell, which overlies the beds we have referred to the Green River age.

The surface of the whole Green River outcrop, both of the Washakie Basin and of the southern area from Vermilion Bluffs southward to the White River divide, is always characterized by a more marly soil, by infrequent outcrops of solid rock, and by the prevalence, among the few actual exposures, of calcareous members, sandy shales, or thin fissile shales, varyingly carbonaceous, and always more or less charged with casts of *Goniobasis*, *Melania*, and *Viviparus*. Along the whole valley of the Little Snake, at Sunny Point, as well as at Godiva Ridge and Elk Gap, the lower horizon of the Green River group is easily recognized, consisting of calcareous sandstones and impure limestones, resting, as usual, upon the brilliantly striped beds of the upper Vermilion Creek. At Sunny Point particularly there is a thickness of about 950 feet of Green River, made up as follows:

	Feet.
1. Coarse brownish sandstone, with intercalated brown calcareous shales	100
2. White calcareous shales, with half-inch seams of gypsum and a four-inch seam of agatized Unios	45
3. Drab, concretionary limestone, with brown sandstone shales	85
4. White and brown argillaceous shales	120
5. Rusty arenaceous shales	100
6. Beds of soft, light-colored, argillaceous and calcareous shales, some of which are impregnated with carbonaceous material and have a light blue color on the weathered surface, containing also small seams of gypsum	400
7. White sandstones and clays	100

The relation of the two series at Elk Gap is somewhat perplexing, from the unusual attitude of the rocks. The lower exposure consists of the upper members of the Vermilion Creek group, which dip to the south at an angle of 10°, but are overlaid by a series of somewhat calcareous sandstone having at the base a prominent red shale, the upper member dipping 29° to the southwest. A short distance down the river both series are found perfectly conformable. In order to account for this position, it is necessary to suppose that, prior to the deposition of the Green River series, a portion of the Vermilion Creek series was faulted up with a considerable northerly dip, and that since the deposition of the Vermilion Creek series nonconformably over this faulted rock, a second disturbance has taken place in this locality which has reversed the dips of both series to south, thus bringing the underlying bed, which formerly had a steeper dip to the north, into the position of a less steep dip to the south. It is noticeable that the line of strike of this steeply southward-dipping Green River series at Elk Gap would carry it directly into the northern edge of Brown's Park, where beds also assigned by us to the Green River series hold the same position, dipping 25° to the south. It would seem, therefore, that a long line of displacement has occurred here, with a downthrow to the south. Provided the upturned beds in Brown's Park are, as we suppose, Green River, there is a vertical displacement of 5,000 feet between them and the series of the same horizon north of the Archæan mass on Red Creek, the Brown's Park being the depressed member.

Around the base of Godiva Ridge, overlying the variegated beds of the Vermilion Creek series, are the sandy and calcareous lower members of the Green River series, capped by white limy rocks, containing silicified beds made up of casts of *Goniobasis*, an occurrence, as we have seen, most frequent in the lower Green River series. There is apparently a slight nonconformity between the two series here, but it is decidedly less marked than at Elk Gap.

Beneath the Wyoming conglomerate on the summit of Vermilion Bluffs is an exposure of 500 or 600 feet of calcareous beds, here largely made up of papery shales of the Green River.

Excellent exposures are obtained on Vermilion Creek, below its cañon, which is cut through the Carboniferous series. Here the beds are composed of a characteristic white, fine-grained, siliceous material, intercalated with coarser, loosely compacted drab sandstones, the latter containing among the siliceous material a great many feldspar and mica particles. Besides these intercalations, certain members of the white silts have a peculiar silky lustre, and pass into fine siliceous limestones and calcareous shales. Moreover, not a few of the limestone beds develop concretionary structure, a peculiarity confined, so far as we have seen, among all the Tertiaries, to the Green River group.

The White River divide, as before mentioned, is formed of the Laramie Cretaceous rocks, which have a sharp northerly pitch of 25°. They are unconformably overlaid by soft calcareous Tertiaries which dip to the north at only 3°, and which stretch uninterruptedly northward, connecting with the calcareous beds of Godiva Ridge. As displayed near the divide, there are about 1,500 feet of these rocks, which are unquestionably but the relic of a wider extension. From the character of the Green River series directly south of the White River divide, where their identification is rendered complete by the recurrence of fossils characteristic of the beds in the region of Green River City, there is no doubt that the Green River beds formerly saddled across the whole divide and formed a continuous sheet of sediment far to the south.

Beneath the Wyoming conglomerate of Bishop Mountain a thin sheet of the Green River calcareous beds extends to the north and west toward Tabor Plateau, overlying the upper beds of the Vermilion Creek series. On the western side of South Bitter Creek, upon Tabor Plateau, and thence for fifteen or twenty miles northward, the Green River series not only overlies the Vermilion Creek, but overlaps the Laramie and Fox Hill Cretaceous beds, the calcareous Eocene beds having a dip of 4° to the north.

From twelve miles above Green River City down to Flaming Gorge, the whole valley of Green River is excavated from the nearly horizontal strata of the Green River series. Between the Cretaceous of the Bitter Creek uplift and the eastward margin of the area of the Green River rocks is a narrow band of the Vermilion Creek rocks, extending from north of the map as far as Sage Creek. Between this series and the Cretaceous rocks, we have described a slight nonconformity; but between them and the overlying Green River calcareous beds just to the west there seems to be no recognizable angular discrepancy, at least as far south as Sage Creek. From that point southward there is a slight and growing discrepancy, which, north of the northern foot-hills of the Uinta, becomes a perfectly distinct nonconformity. North of Big Horn Ridge, and especially where

Green River enters the Quaternary valley north of Camp Stevenson, the discrepancy between the two series is also perfectly clear.

Perhaps the most characteristic development of the Green River series is to be found in the neighborhood of Green River City, where the Union Pacific Railroad crosses the river. Here, on both sides of the stream, the broad valley is walled in by cliffs and hills formed of the calcareous shales and sandstones of the Green River group, which are displayed for a thickness of scarcely less than 2,000 feet. In a railway-cut on the western bank, the extremely fine paper shales that occur on both sides of the river have yielded numerous fossil fishes, of which the more characteristic forms are enumerated later in the section.

Plate XIV. gives an excellent idea of the steep cliff bordering the river immediately north of Green River City. Here the shales are excessively thin and fine-grained. Plate XIII. is a close, detailed view of the same cliff front.

The plateau north of the railway and east of Green River Valley is a gently rolling summit. In the immediate vicinity of the railway, rise isolated, tower-like rocks, which possess all the abruptness and hardness of outline of artificial fortifications. The sculpture of the shales along the river banks is also extremely interesting, displaying vertical cuts 300 or 400 feet high, capped by rounded hill-tops, and these in turn by towers. South of the city, on the eastern side of the river, is a remarkable series of hills stretching back four or five miles from the river, appropriately called by Powell the Alcove Ridges, from their singular mode of erosion. The river cliffs are here cut by transverse ravines, bold headlands projecting against the river bank with almost vertical faces. The exceedingly fine characteristic shaly structure of the upper part of the group is also well shown in Bitter Creek Valley, in a railway cut The plateau to the north of the railway presents to the south and east a bluff from 800 to 1,000 feet high. All these strata dip at gentle, almost imperceptible angles to the west toward a middle line of depression, in the Bridger Basin. At a short distance west of Green River the calcareous shales pass, with apparently a slight unconformity, beneath the softer beds of the overlying group. As exposed by the river-cut and the Alcove Ridges,

there is no less than 2,000 feet of the series displayed, of which the white and brown paper shales occupy the upper 1,200 feet. Throughout this thickness they are more or less intercalated with arenaceous beds, which at the base of the shale-series rapidly increase in proportion and become more and more calcareous, finally appearing either as marly sandstones or as creamy-white, brittle, fine grained, earthy limestones. Capping the shales, and making the uppermost member of the series in the region of Green River, are displayed about 100 feet of brown sandstone of massive structure. It forms the heavy, dark-brown cap upon the bluffs in the region of Green River City, where all traces of the original stratification are lost, and the rock presents an appearance of somewhat peculiar local metamorphism. The physical characteristics, especially the compactness, of this upper rock, vary very greatly, and to this fact may be due the circumstance, that exceptional parts of the bed have resisted erosion and protected the softer underlying shales from wearing down, which has resulted in the remarkable turret and bastion forms that characterize the region.

Although enormous numbers of individual fossil fishes are obtained from these shales, the number of genera is exceedingly small. The types are closely allied to those of Monte Bolca, in Italy. Fresh-water mollusks which are found in the more compact limestones of the lower portion of the group are chiefly *Viviparus* and *Goniobasis*, genera found in both the Vermilion Creek and the overlying Bridger series. There are no brackish-water forms whatever. A considerable amount of the fine calcareous shale-series is heavily charged with bituminous matter, a very large portion of which is volatile.

Throughout the region near the railway the shales possess a characteristic dip of 3° to 4° to the west, which they retain on the western side of the river. Near the summit of the low, flat ridge between Green River and Black's Fork, they pass under the thinly bedded drab sandstone which forms the base of the Bridger group. The latter never possesses a dip of more than 2°. The contact of these rocks is well covered with disintegrated soil; but when last seen the Green River beds, before they pass under the Bridger, still retain their dip of 4°. It is therefore probable that the two formations have here a slight nonconformity, a condition of things which is rendered more probable by the peculiar overlap of the Bridger in the region of Concrete Plateau.

The dip of 4° extends all the way down the river to the lower valley of Henry's Fork. East of the river this group forms broad terraces which ascend toward the east as far as the meridian of Quien Hornet Mountain, while a short distance to the west of the river they invariably pass under the horizontal Bridger series. With the exception of the anticlinal in the Green River group, already described at Cherokee Ridge, the highest observed dips of this series are along the flanks of the Uinta Mountains.

From Quien Hornet Mountain to Green River the calcareous underlying members of the group dip at 5° to the north, with a slight inclination to the west, unconformably overlying the Vermilion Creek group with a discrepancy of angle of 5° to 12°.

Where Green River emerges from its upper valley into the broad, open area above its confluence with Henry's Fork, the limestones which form the base of the Green River series dip 5° to the north, while the underlying sandstones and clayey beds of the upper portion of the Vermilion Creek underlie them at higher angles, usually 8° to 14°. West of Green River the upper shales appear at the bases of the long eastern spurs. From Twin Buttes, and north of Dead Man's Springs, the valley of Henry's Fork passes through the Green River formation for four or five miles. Here is displayed a small lignite bed. The highest inclination recognized in these beds is north of Dead Man's Springs, where the low ridges, made up of yellow sandstone and the creamy-colored brittle limestone, dip northward from 20° to 25°, carrying, as usual, an infinite number of casts of *Goniobasis.*

West of Bridger Basin the display of Green River rocks is very limited. As before mentioned, it at first makes its appearance coming out from under the Bridger beds in the vicinity of Piedmont, and thence northward its exposure increases in width, until at the northeastern edge of our map the belt is about thirty-five miles wide, and probably includes the northern limit of the Bridger Basin. South of Piedmont it seems clear that the Bridger group completely overlaps the Green River, coming directly in contact with the Vermilion Creek, which gradually

rises toward the west, occupying higher and higher positions, till it reaches the elevated plateau made in the angle between Uinta and Wahsatch ranges. This plateau, which received its relative elevation at the close of the Vermilion Creek period, slopes gradually to the east and again gradually to the north, and the Green River formation abuts against the gently inclined beds of this series, describing a curve northward, and swinging around to the west through northern Utah into Nevada. Near Piedmont the white, impure limestones and thin, calcareous shales have yielded a few fishes identical with those found in the shales near Green River City. Northward they pass across the railway west of Carter's Station, and are there represented by light, creamy, calcareous beds.

Down the valley of Bear River, beyond the northern limits of Map III., the rocks of the Green River group have been observed by Dr. Hayden, and north of Oyster Ridge, on Fontanelle Creek, by Professor Cope. The discovery of this group at these two points seems very clearly to warrant the belief that the lake of that period extended westward around the north of Bear River Plateau, connecting with the deposits to the west, which are about to be described.

At the extreme northwestern limits of the Great Salt Lake Desert, at the eastern foot of the prominent group of the Ombe Mountains, outcrops a series of beds which dip at an angle of 45° to the east, with a general north-and-south strike. Their most prominent exposures are about ten miles south of the railway. Although devoid of fossils, they are readily referred by their lithological characteristics to the Green River series, consisting as they do of white and thinly bedded shales, both siliceous and calcareous, equally fissile with those of Green River, and, like them, charged with richly bituminous zones, the latter sometimes reaching the condition of coal and appearing in beds one or two feet in thickness. The material of the coal is a jet black, lustrous mass, which, however, slakes, crumbles, and becomes valueless on exposure to the air. This correlation is not based solely on the resemblance of the beds to those of the distant Green River Basin, but also on identical rocks a little farther west, which are well charged with Green River group fossils.

A few miles farther west, and a short distance from Peoquop Range, there is a break in the continuity of the great Palæozoic bodies. In this depressed basin, as shown on Map IV., where the Quaternary is not present, may be seen the upturned edges of rocks of the Green River period, striking about east-and-west, resting unconformably upon the Palæozoic series on both sides of the gap. They strike a little north of east, and dip both to the north and south, with a varying inclination of from 5° to 20°. They are in general a series of fine carbonaceous shales and marls of a prevailing yellow-brown hue, though occasionally passing into blackish beds, where the carbonaceous matter is highly concentrated. The lowest strata are heavy red shales and marls, with a few indurated gray clays as the basal member. Although no organic remains have been found here, they are referred to the Green River period by their exact resemblance to the beds which occur at Elko, a little farther west.

A further development of these Green River beds is found in Huntington Valley, extending from Dixie Valley southward. The rocks occur here as a low ridge between the Dixie trachyte hills upon the west and a body of Lower Coal Measure limestones on the east. They consist of creamy calcareous rocks, sandy marls, and fine calcareous shales, containing the usual carbonaceous seams, and even thin coal-beds. The calcareous shales yield fragments of fossil fishes evidently identical with those of Elko, but too nearly obliterated for specific determination. The beds have a dip of 30° to the east, and strike about north 20° east. Here is displayed an interesting relation to the trachytes which have broken through them.

A very characteristic member of these Green River shales is found on the eastern base of the River Range, due north of the station of Osino. As in the Dixie group, the characteristic beds are white and creamy brittle limestone, in beds six inches to a foot thick, overlaid by calcareous and arenaceous shales carrying beds of clay from one to two feet thick. The development of carbonaceous material here rises to the importance of coal-beds, of which one is two feet, another five to six feet, another three feet thick, besides which there are many brown beds of carbonaceous material containing a high proportion of volatile hydrocarbons, burning when heated with an intensely bright flame for a short time, and then crumbling into a loose ashy residue. The coals of the true coal-beds are black, lustrous lignites, containing a great many yellow, amber-like grains, and white coatings of sulphate of lime through the cracks and fissures of the coal. Like the Ombe coal, this rapidly slakes and crumbles upon exposure to the air, and has little commercial value. Above the coal-seams in the characteristic bituminous shales, which are here highly calcareous, the true paper shales of the formation, are found great numbers of fishes and insects of the identical species occurring at Green River City.

From all that may be seen at Dixie and on the flanks of River Range, it is probable that there are 2,500 or 3,000 feet of beds in these exposures. At the coal-mine the dip is 45° to the east, while farther down the ravine it rises to 65°. The same series of beds recurs in Elko Range, east of Elko Station. They here have a strike about due north, and dip 35° to the east, and consist of very thin shales, sometimes calcareous, often sandy, and again dark-brown, with bituminous matter. Fragments of an undeterminable fish were the only fossil discovered by us here.

West of Dixie Hills no outcrops of the Eocene have been recognized, and for the present we must consider that Piñon Range was the western boundary of the Green River group.

I ought not to close this subject without remarking again that, although I consider the general tendency of the evidence warrants the belief that these western deposits represent truly the extension of the great lake of the Green River period, yet at the same time the absence of outcrops between Ombe Range and Bear River renders it possible that the western group of occurrences may represent an independent lake.*

Whatever may have been the climate in the region of the western outcrops, there can have been no change between there and the Bridger Basin. The atmospheric condition must have been practically the same; and since both sets of strata are characteristic of still and deep-water deposition, it is not strange that the species should be the same, even if the lakes themselves had no communication. It is only necessary that they should drain into

* Since the above was written, inclined coal-bearing fresh-water Tertiaries have been observed near Stockton, at the base of Oquirrh Range, thus indicating very positively that the group once stretched quite to the base of the Wahsatch.

the same ocean to account for the identity of species, because the only remains of aquatic fauna besides the fresh-water mollusks have been fishes, certain of which, from their nature, once probably migrated annually to the south and were afterward land-locked.

The following are some of the more characteristic fossils of this group:

GREEN RIVER GROUP.

FISHES.

Clupea humilis, Leidy.
Clupea alta, Leidy.
Clupea pusilla, Cope.
Osteoglossum encaustum, Cope.
Asineops squamifrons, Cope.
Asineops viridensis, Cope.
Erismatopterus Rickseckeri, Cope.
Heliobatis radians, Marsh.

INSECTS.

Antherophagus priscus, Scudder.
Endiagogus saxatilis, Scudder.
Trypodendron impressus, Scudder.
Corymbites velatus, Scudder.

Bridger Group.—The belt of Eocene country studied by this Exploration leaves some open questions as to the physical conditions at the close of the period of the Green River rocks. I have shown that at the close of the Vermilion Creek the lake which had formerly extended from the meridian of 107° 30′ to the Wahsatch was rather suddenly allowed to expand itself westward to the meridian of 116°, the expansion being caused by the subsidence of the country between the Wahsatch and the meridian of 117°. So isolated are the present outcrops of the Green River rocks which have accumulated in the western portion of the lake, that we have a very slender basis from which to reason as to its conditions. The fauna was identical with that of the Green River Basin, the rocks show a singular likeness to those in the eastern areas

We are somewhat at a loss when we proceed to examine the areas and character of the Bridger group or next succeeding member of the Eocene; the main difficulty being to determine whether the few isolated bodies of Bridger rocks represent parts of what was formerly a continuous sheet, or whether at the close of the Green River period the lake limits were immensely contracted, and the Bridger series only permitted to accumulate in certain small, detached basins. Much light would be thrown on this were we able to decide finally whether the Green River and Bridger series are conformable with each other; but it so happens that the Bridger beds are usually found in the middle of basins, in nearly horizontal position. These areas of Bridger rocks are surrounded, as a glance at the map will show, by groups of the Green River formation, which pass under the Bridger at angles so slight as to leave it somewhat uncertain whether they are strictly unconformable. On this point, however, all the positive evidence is in favor of a true nonconformity. Whatever may have been the conditions in the basin of Green River, it is clear that the western part of the lake, namely, that west of the Wahsatch, never received any sediments of the Bridger period, since it is inconceivable that if they had accumulated in such a large area as the expanded Green River period lake is known to have covered, some fragments should not have escaped both processes of removal and burial which have been active over this area since Eocene times.

From the relation of the Green River beds with the high, rocky, mountainous ridges near the 116th meridian, it is evident that there were large areas from which detritus must have been removed during the Bridger age, and there is no reason to suppose that very much less material would have been accumulated than in the basin of Green River, for nearly uniform climatic conditions must have obtained over both regions; and while 2,000 feet of the sediment of the Bridger period were accumulating in the restricted basin of Green River, there was land-mass enough, which must have yielded a very large, if not indeed an equal amount of sediment over the area of the western part of the lake. The total absence of any Bridger beds may be considered as a strong indication, amounting almost to proof, that there was a great physical change at the close of the Green River age, which gave to the country west of the Wahsatch, drainage either to the sea or into the Green River Basin; in other words, that it was no longer a lake west of the Wahsatch. That since the Green River period there has been sufficient mechanical disturbance of the area to bring about the new condition, is evident from the extreme dips of the Green River rocks near the River Range of Nevada, where they reach 60°, and at Cherokee Ridge, in Wyoming, where the southern side of the east-and-west anticlinal dips to the south at angles reaching 25°. If this disturbance took place, as the evidence indicates, immediately at the close of the Green River period, it will sufficiently account for the isolation and limitation of the deposits of the Bridger period. If, however, they succeeded the Green River beds without any orographical changes, we can only account for their absence over the region west of the Wahsatch by supposing that the sediments of the Green River had previously filled up that portion of the lake. In either case, there was no lake during Bridger time west of the Wahsatch.

Supposing the Bridger beds of the Washakie and Bridger basins to have been deposited conformably in the same lake which laid down the Green River series, and to have been uplifted together with the Green River in a post-Bridger upheaval, it is not a little remarkable that erosion should have removed the Bridger from all parts save the middle of these two basins. The few observations which bear upon this point in the way of the dips of the two formations combine to indicate that the movement took place at the close of the Green River period, that the western lake was extinguished by this upheaval, and that the waters of the period formed a lake of restricted area altogether within the basin of Green River. Even with this supposition, which I conclude to be the most probable until it may be varied by future evidence, there is left the shadow of a doubt whether the three Bridger bodies which appear upon our map—that of the Bridger Basin, the Washakie Basin, and the region east of Vermilion Creek—were parts of a continuous sheet, or whether they themselves were areas of special lakes in the same general basin, isolated from each other, but characterized by great fauna resemblances.

A glance at the eastern half of Map II. shows that the middle of the Washakie Basin is occupied by an irregular area of beds of the Bridger period. It has an extension of about twenty-five miles from east to west, by sixteen to twenty from north to south. It is completely surrounded, as

already described, by the beds of the Green River period, which dip at gentle angles toward the middle of the basin. The inclination is never over 4°, except on the northern side of the Cherokee anticlinal, where it steepens northwestward to 7° and passes with apparent nonconformity under the Bridger series. The country around the girdle of Green River rocks is largely covered with soil, and the few outcrops are either creamy limestones, calcareous shales, or slightly calcareous sandstones. Immediately in the neighborhood of the junction of the Bridger and Green River groups, the plains are covered with extensive deposits of soil, so that the actual contact of the two deposits is rarely seen.

From twelve to fourteen miles southwest of the head of Bitter Creek are seen exposures of the soft green clays, marls, and whitish-gray sands of which the upper beds of the Bridger group are made. Passing eastward of Pine Bluffs, the country is covered with more or less drifting sand, which forms noticeable trains of dunes. The sand suddenly gives way to the soft Bridger beds which are intricately eroded into branching ravines. This bad-land country extends southeastward to the mouth of a dry valley north of Cherokee Ridge, and from that point a chain of bluff escarpments extends northeasterly for twelve or fourteen miles. The relations of this sharp wall to the Green River country to the south are obscured by deep accumulations of valley soil; but the nearest approach of the two sets of strata shows the Bridger lying nearly or quite horizontal, the other dipping at 7°.

This escarpment is the most remarkable example of the so-called bad-land erosion within the limits of the Fortieth Parallel Exploration. The Bridger beds here rise about 300 feet above the level, dry valley to the south, and present a series of abrupt, nearly vertical faces, worn into innumerable architectural forms, outliers often standing detached from the main wall in bold blocks, which have been wrought into a variety of singular forms by æolian erosion. Plate XV. gives a very fair general view of a portion of the Bad Lands, showing some of the curious buttressed shapes. A few ravines cut their way through the plateau from considerable distances back in the basin. Along the walls of these ravines the same picturesque architectural forms occur, so that a view of the whole front of the escarpment, with its salient and reëntrant angles, reminds one of the ruins of a fortified city. Enormous masses project from the main wall, the stratification-lines of creamy, gray, and green sands and marls are traced across their nearly vertical fronts like courses of immense masonry, and every face is scored by innumerable narrow, sharp cuts, which are worn into the soft material from top to bottom of the cliff, offering narrow galleries which give access for a considerable distance into this labyrinth of natural fortresses. At a little distance, these sharp incisions seem like the spaces between series of pillars, and the whole aspect of the region is that of a line of Egyptian structures. Among the most interesting bodies are those of the detached outliers, points of spurs, or isolated hills, which are mere relics of the beds that formerly covered the whole valley. These blocks, often reaching 100 feet in height, rise out of the smooth surface of a level plain of clay, and are sculptured into the most remarkable forms, surmounted by domes and ornamented by many buttresses and jutting pinnacles. But perhaps the most astonishing single monument here is the isolated column shown in the frontispiece of this volume. It stands upon a plain of gray earth, which supports a scant growth of desert sage, and rises to a height of fully sixty feet. It could hardly be a more perfect specimen of an isolated monumental form if sculptured by the hand of man.

Looking along the perspective of this strange line of escarpments, the uniform buff and gray marls and clays are seen to be interrupted at several elevations by beds of peculiar green earth, which add to the architectural forms the element of variegated courses. Not the least remarkable feature is the fact that the plains skirting the base of these Bad Lands are quite level, there being little or no talus at the bottom of the abrupt slopes of the cliffs. It is easy to see that these exceedingly fine materials, when dislodged from their original positions in the beds, would be rapidly carried away by the waters which are concentrated by the ravines and angles of the Bad Lands. The present clay floor at the foot of the cliffs has almost the appearance of the accumulation of a lake, but it is in reality only the detritus levelled by flowing water, a task which the exceedingly fine nature of the material renders comparatively easy, and which is permitted here by the slope of the underlying Green River beds toward the Bad-Land escarpment.

These bluffs are extremely rich in the remains of vertebrate fossils. At the base of almost every cliff were observed the bones of *Mammalia*, and frequent shells of *Testudinata*.

It is not altogether easy to account for the peculiar character of this erosion, resulting as it does in such singular vertical faces and spire-like forms. A glance at the front of these Bad Lands shows at once that very much of the resultant forms must be the effect of rain and wind storms. The small streams which cut down across the escarpment from the interior of the plateau do the work of severing the front into detached blocks; but the final forms of these blocks themselves are probably in great measure given by the effect of rain and æolian erosion. The material is so excessively fine that under the influence of trickling waters it cuts down most easily in vertical lines. A semi-detached block, separated by two lateral ravines, becomes quickly carved into spires and domes, which soon crumble down to the level of the plain. Outlying hills or buttes are carved away, leaving narrow, isolated spires, which finally disappear by the same process of erosion. It seems probable that some of the most interesting forms are brought out by a slightly harder stratum near the top of the cliffs, which acts in a measure as a protector of the softer materials, and prevents them from taking the mound-forms that occur when the beds are of equal hardness. As to the thickness of the Bridger series in the Washakie Basin, no precise figure can be arrived at. It probably amounts to less than a thousand feet.

A little west of south from Washakie Basin, between Vermilion Bluffs and Elk Gap, is a detached area of soft, easily eroded clays and sands, which, from their position overlying the paper shales of Green River, have been assigned to the Bridger. No organic remains were found here, and the occurrences are of very slight importance.

The chief exposure of the Bridger beds is to be found in Bridger Basin, between the meridians of 109° 30′ and 110° 45′, extending from the foot-hills of the Uinta, on the south, northward beyond the limits of our map. As displayed along the base of the Uinta Mountains, it consists of a series of soft, sandy, and clayey beds, for the most part covered with soil, or obscured beneath unconformable deposits of Pliocene conglomerates, and wherever distinctly seen it is found to dip at gentle angles to the north, angles never exceeding 2°, and hence within the probable limit of the original deposition. Thus exposed, there is a body of 50 to 60 miles from east to west, the main axis trending a little east of the meridian. It is bounded on the east, in the region of the meridian of 109° 30′, by the shales of the Green River series, which come upon the surface from a position beneath the Bridger. On the west, also, it is margined by a narrow line of Green River beds, separating it from the still lower Vermilion Creek group.

Throughout the middle of the Bridger Basin it rests in positions of complete horizontality, and throughout its whole extent shows no evidence of orographical disturbance, such as could be registered in local changes of angle. The aggregate thickness of the beds of this group is estimated as between 2,200 and 2,500 feet. The material is almost wholly made up of fine sand and clay, arranged in varying proportions, and occasionally slightly changed by calcareous admixtures.

As between this series, however, and that of the Green River, the notable difference is, that the Bridger is a prominent sand-and-clay formation, while the other, from bottom to top, is essentially characterized by the presence of abundant lime. The strata of the Bridger are also exceedingly soft, and are eroded with almost the facility of beds of Quaternary earth. The upper 1,000 feet are nothing more than a soft, sandy clay sediment, varying from drab to pale olive, carrying a few beds of slightly indurated sandstone and occasional stripes of grayish and greenish marls, and at one or two horizons beds of inconspicuous limestone, which closely resembles the arenaceous limes of the Green River group.

One of the noticeable features of this group is the vitrification of certain beds. It is not uncommon to observe, along the steep escarpments of the eroded clays and sands, the edge of a hard bed standing out like a shelf, which upon examination proves to be chert or hornstone, sometimes inclining to semi-transparence, in which case they represent chalcedony, or more nearly hyalite. Such sheets are of not infrequent occurrence, but are usually of no great lateral extension. They rarely exceed three or four feet in thickness, and but for their lithological peculiarities would be an entirely unimportant member of the series. There are also calcitic and selenitic intercalations, from which erosion removes the superincumbent clays, leaving the surface covered with the rubbish of crystals. In the siliceous hyalitoid strata, innumerable dendritic infiltrations of iron and manganese are observed, whose most highly developed form is the well known moss-agate of the region.

On the northern limit of the map only the lower members of the Bridger are seen resting upon the Green River beds; but in passing south the country gradually rises, and each successive topographical elevation marks a higher stratigraphical horizon, the formation rising in broad, irregular terraces, bounded by more or less abrupt slopes, and sometimes by bold escarpments of Bad Lands. North of the railway, and for a considerable distance to the south, is an undulating desert almost devoid of vegetation, its surface desolate stretches of arid, ashen-colored sand or clay, without any conspicuous hills.

In the region of Church Buttes outliers of the Bridger group constitute detached bodies rising above the Plains in the most picturesque forms, eroded in the characteristic bad-land shapes; domed mounds and buttressed blocks remind one of a variety of architectural designs. The color here is grayish drab, with numerous stripes of greenish argillaceous sandstone characteristic of the lower part of the series.

Farther to the south a second broad, irregular terrace is seen, whose front, under the name of Grizzly Buttes, presents an escarpment not unlike that already described in Washakie Basin. The forms here are usually soft, rounded outlines, deeply scored with sharp, parallel ravines cut down at short intervals. The extremely steep slopes are weathered into absolute smoothness. The colors are here light-gray and drab, with white and greenish bands; and the perspective of the front of Grizzly Buttes is certainly one of the most remarkable geological views of the region; not so architectural as the Bad Lands of Washakie Basin, but singularly impressive by the infinite variety of peculiar shapes.

The deepest exposures of the Bridger series are laid bare in the valley of Henry's Fork, where, as south of Turtle Bluffs, a thickness of 1,800 to 2,000 feet is exposed. If we are right in assigning to the Wyoming conglomerate a Pliocene age, it is probable that a very large amount of the upper strata of the Bridger series was eroded prior to the laying down of the Wyoming conglomerate. On the southern slope of Turtle Bluffs, and on the north as well, have been found innumerable fossil vertebrates, together with a considerable number of *Unio* and *Planorbis spectabilis*. By far the larger amounts of the beds are gray sands and clays, but here and there are prominent calcareous strata. The chemical constitution of a green calcareous marl upon the southern face of these bluffs will be found in the tables of analyses of sedimentary rocks. A second analysis was made of the light-green band taken from Grizzly Butte, and it was seen under the microscope to consist of fine grains of quartz and black mica and some feldspar, with a permeating cement of green clay.

At Mount Corson and Concrete Plateau, and along the prominent conglomerate spur which forms the divide between Henry's and Smith's forks, the Bridger series is overlaid by great thicknesses of conglomerate, ranging from 200 to 600 feet in thickness, which may be an upper shore member of the group.

With the exception of the Planorbis and Unio beds in the upper members, the greater part of the molluscan remains of the Bridger series is found in the lower strata. The chief forms are:

Unio Haydenii.
Planorbis spectabilis.
Physa Bridgerensis.
Goniobasis tenera.
Viviparus paludinæformis.
Viviparus Wyomingensis.
Pupa Leidyi.

The chief interest of this formation arises from its remarkable fertility in vertebrate remains of true Eocene type. The following list, though by no means exhaustive, will serve to indicate the character of the Bridger fauna:

BRIDGER BEDS.

PRIMATES.

Lemuravus distans, Marsh.
Hyopsodus minusculus, Leidy.
Hyopsodus paulus, Leidy.
Limnotherium tyrannus, Marsh.
Limnotherium elegans, Marsh.

CARNIVORA.

Limnofelis ferox, Marsh.
Limnocyon riparius, Marsh.
Vulpavus palustris, Marsh.
Uintacyon edax, Leidy.
Sinopa rapax, Leidy.
Orocyon latidens, Marsh.
Dromocyon vorax, Marsh.

INSECTIVORA.

Talpavus nitidus, Marsh.
Centetodon pulcher, Marsh.
Entomacodon angustidens, Marsh.
Palæacodon vagus, Marsh.
Passalacodon littoralis, Marsh.
Palæacodon verus, Leidy.

CHENOPTERA.

Nyctitherium velox, Marsh.
Nyctitherium priscus, Marsh.
Nyctilestes serotinus, Marsh.

DINOCERATA.

Uintatherium robustum, Leidy.
Tinoceras anceps, Marsh.
Dinoceras mirabile, Marsh.
Dinoceras lacustris, Marsh.
Dinoceras lucaris, Marsh.
Dinoceras laticeps, Marsh.

UNGULATA.

Palæosyops paludosus, Leidy.
Hyrachyus agrarius, Leidy.
Orohippus agilis, Marsh.
Helaletes boops, Marsh.
Hyrachyus Bairdianus, Marsh.
Homacodon vagans, Marsh.
Helohyus lentus, Marsh.

RODENTIA.

Paramys delicatus, Leidy.
Mysops minimus, Leidy.
Sciuravus nitidus, Marsh.
Tillomys senex, Marsh.
Tachymys lucaris, Marsh.
Apatemys bellus, Marsh.

TILLODONTIA.

Anchippodus minor, Marsh.
Tillotherium hyracoides, Marsh.
Tillotherium fodiens, Marsh.
Stylinodon mirus, Marsh.

AVES.

Bubo leptosteus, Marsh.
Aletornis nobilis, Marsh.
Aletornis pernix, Marsh.
Aletornis venustus, Marsh.
Aletornis gracilis, Marsh.
Aletornis bellus, Marsh.
Unitornis lucaris, Marsh.

CHELONIA.

Hybemys arenarius, Leidy.
Baptemys Wyomingensis, Leidy
Bæna arenosa, Leidy.
Anosteira ornata, Leidy.
Trionyx guttatus, Leidy.

SAURIA.

Glyptosaurus princeps, Marsh.
Thinosaurus leptodus, Marsh.
Oreosaurus lentus, Marsh.
Iguanavus exilis, Marsh.
Saniva ensidens, Leidy.
Crocodilus Elliotti, Leidy.
Crocodilus brevicollis, Marsh.
Limnosaurus ziphodon, Marsh.

OPHIDIA.

Boavus occidentalis, Marsh.
Boavus agilis, Marsh.
Boavus brevis, Marsh.
Lithophis Sargentii, Marsh.
Limnophis crassus, Marsh.

PISCES.

Amia Newberrianus, Marsh.
Amia depressus, Marsh.
Amia Uintensis, Leidy.
Amia media, Leidy.
Lepidosteus glaber, Marsh.
Lepidosteus Whitneyi, Marsh.
Hypamia elegans, Leidy.
Phareodus acutus, Leidy.
Pappichthys plicatus, Cope.
Rhineastes radulus, Cope.

UINTA GROUP.—Of the Tertiaries immediately south of Uinta Range, comparatively little is distinctly known. Flanking all the alluvial valleys of the streams are bluffs and ridges formed of Tertiary strata, the lower members being chiefly rough, gritty conglomerate, passing up into finer-grained sandstones, and at certain points developing creamy, calcareous beds. The strata apparently form an unbroken line from the region of the Wahsatch eastward throughout the length of Uinta Valley, and across Green River into the valley of White River. Near the lower lands of Uinta Valley the upper beds are wanting, and on the flanks of the Uinta Mountains, where the upper series is present it is in great measure overlaid by glacial débris and moraines, which generally obscure its occurrence. The vertebrate remains which have been found in the continuation of these beds in White River Valley belong to a period higher than the Bridger series. They even contain some forms closely approaching the lowest Miocene types. But exactly what relation these White River beds bear to the more western members of the Uinta group does not at present appear.

There is little doubt that the main western portions around the head of Uinta Valley, the Du Chesne, and the region of Strawberry Valley belong, as before indicated, to the Vermilion Creek group, and it is not at all impossible that the upper calcareous beds seen along the middle and eastern Uinta may represent fragmentary portions of the Green River series, which have thus far succeeded in resisting erosion. Some of the lowest exposed beds of the region are seen at Wansits Ridge, near the southeastern point, where they repose unconformably upon the Fox Hill sandstones, dipping at angles of from 8° to 10° to the southeast. In passing southward, this comparatively steep dip declines to a nearly horizontal position. These beds consist of earthy sands and conglomerates containing many coarsely rounded pebbles of the older rocks of Uinta Range. These pass up into greenish and reddish sandy beds, having many coarse, chocolate-colored sandstone members. A still higher dip is observed in these same rocks along the upper branches of Ute Fork, where an inclination of 25° is sometimes seen. But in approaching the flanks of the mountains the sandstones are completely overwhelmed by the rubbish of the Glacial Period, and by moraines eight or ten miles long. The same coarse, red sandstones appear near the mouth of Antero's Creek.

A locality of some petrographical interest was noticed between the upper east and west branches of Lake Fork, near the slopes of the older rocks along Uinta Range. Here is displayed a very thick series of yellow sandstones, rather coarse in texture, developing a concretionary structure, and yielding by erosion peculiar spire-like forms. At the foot of these cliffs the lower members are heavy, reddish beds, the whole exposure of about 600 feet dipping 4° or 5° to the south. Westward from the creek the Tertiary beds are seen occupying the cliffs at a height apparently of 2,000 feet above its bed, the upper members made of coarse conglomerate, resembling those of Pliocene age. In the region of Strawberry Valley the outcrops are still further obscured by an enormous amount of overlying disintegrated soil and a thick growth of forest. Some outcrops of sandstone along the eastern slope of the Wahsatch, of very high dips, were referred to the Cretaceous, but from stratigraphical reasons only. As north of the Uinta, the Tertiary series seem to thicken greatly on approaching the Wahsatch, which is unquestionably to be accounted for by the fact that that range marks the shore of the land-mass against which the earlier Eocene lake was traced; and the lake being very deep near its own shore, the detrital material accumulated more thickly there than to the east. When the Tertiaries south of Uinta Range are carefully unravelled, as they doubtless will be by Powell and Gilbert, it will probably be found that the most recent Eocene group, as developed in White River Valley, is unconformable with all the earlier Eocene groups. It is a shallow deposit, of which not over four hundred feet are seen, and in all probability is the sediment of a very restricted post-Bridger lake, wholly south of Uinta Range, and the last member of that remarkable series of Eocene lakes whose great deposits are piled unconformably over one another in the region. To this group alone should the term Uinta be applied. As provisionally used on the Fortieth Parallel Atlas, Uinta group was a term stretched for convenience to cover all the Tertiaries south of Uinta Range, of whose true subdivisions we were ignorant.

The following list comprises some of the more important vertebrates of the true Uinta series:

UINTA GROUP.

Hyopsodus gracilis, Marsh.
Diplacodon elatus, Marsh.
Epihippus Uintensis, Marsh.
Epihippus gracilis, Marsh.
Agriochœrus pumilus, Marsh.
Amynodon advenum, Marsh.

SECTION II.

MIOCENE TERTIARY.

WHITE RIVER GROUP.—Over a vast portion of its area the geological province of the Great Plains has a covering of Pliocene Tertiary beds, varying in thickness from 2,000 feet down to a few hundreds. The streams, which flow from the front of the Rocky Mountains and join the various affluents of the Missouri, have not infrequently cut through this covering of Pliocene and exposed the underlying rocks. In several places it is found that the Pliocene rests unconformably upon beds of upper Cretaceous, which lie either horizontal or in slight undulations. At other points, notably the valleys of Platte River and White River, the wide-spread Pliocene has been found to be directly underlaid by beds of Miocene age, characterized by an ample and typical fauna. Along the 41st parallel, at the extreme eastern end of the belt of Fortieth Parallel work, the Pliocene strata have been eroded away, leaving a rudely terraced escarpment, which faces the south, overlooking a nearly level plain composed of the beds of the Fox Hill and Laramie Cretaceous. East of the Denver Pacific Railroad and south of the 41st parallel a small development of Miocene beds is seen to be interposed between the Cretaceous and the Pliocene; being in fact an eroded edge of the sheet of Miocene which, over a considerable area of the Plains, underlies the Pliocene.

The precise area and boundaries of this Miocene lake cannot yet be definitely assigned. It is clear that the beds brought to light upon North Platte and White rivers, and at the locality just mentioned at Chalk Bluffs, near the Denver Pacific Railroad, belong to the same lake. Messrs. E. S. Dana and G. B. Grinnell, in their valuable geological reconnoissance from Carroll, Montana, to the Yellowstone National Park,* have brought to light in the vicinity of Camp Baker, Montana, a further development of Miocene beds, here as elsewhere on the Plains capped by Pliocene, both series containing characteristic fossils. The altitude at which these beds were observed by them, 5,000 feet, induced them to suppose that the rocks they

* Reconnoissance of Capt. William Ludlow, 1875.

examined belonged to an independent lake, shut off from the great Miocene lake of the Plains, the elevation being 2,000 feet greater than that of the beds exposed on White River. But since the small exposure falling within the limits of the Fortieth Parallel Exploration has an altitude of nearly 6,000 feet, and since there is no known barrier which could have separated it from the Miocene rocks upon Platte River, as well as those displayed upon White River, I have felt bound to assume that the Chalk Bluff beds, as well as those displayed farther east, near the northern boundary of Kansas, are a part of a general Miocene lake, the beds of the region having undergone broad changes of level since the Pliocene period. These Miocene beds evidently pass southward as far as the northern boundary of Kansas, and continue northward into Montana.

At the somewhat ambiguous locality of Fort Union, on the Upper Missouri, occur beds bearing molluscan and vertebrate faunæ, which correlate directly with the higher horizons of the Laramie Cretaceous. From later beds at the same place has been collected a rich flora corresponding with great exactness to the Miocene beds of Manitoba, of Greenland, and of northern Europe. It has never been announced whether these two series of beds were conformable. Both horizons have been embraced in the Fort Union group, whereas there is every probability that the rocks at that locality bearing Dinosaurians are Laramie, while the upper distinctly Miocene series is with equal probability to be correlated with the known Miocene of the Plains. At Chalk Bluffs the Laramie Cretaceous and White River Miocene are observed in immediate contact, with but slight angular unconformity. Cretaceous and Miocene fossils occur in close proximity, and in the absence of a clear understanding of the stratigraphy this locality might easily appear as paradoxical as Fort Union.

In the Fortieth Parallel Exploration we have, therefore, only a very limited exposure near the edge of the Miocene lake, where it washed the foot-hills of Colorado Range. That the beds extended south over the Cretaceous area of the Plains, forming the southeast corner of Map I., is unquestionable from the Miocene escarpment. The strata of which the Chalk Bluff escarpment is composed rest unconformably upon the gently dipping sandstones and shales of the Laramie or uppermost group of the Cretaceous.

The latter group are here nearly horizontal, but if examined over considerable areas are found to be thrown into very slight undulations, and toward the western limit of the outcrop to have a perceptible dip to the east.

Prior to the deposition of the Miocene beds, the Cretaceous had undergone a great deal of deep erosion, which left the surface in soft undulations of very gentle grade, the details of the surface rarely showing any abrupt topographical forms. The entire escarpment, including the Miocene and Pliocene beds, reaches a height of 700 feet above the Cretaceous plains. The small streams of the Plains have worn numerous narrow ravines down the escarpment, cutting back to a considerable distance, and offering admirable sections in which to observe the character of the beds.

Following the escarpment westward, it becomes evident that the Miocene deposits abut against the very lowest base of the foot-hills, always limited by the upper Cretaceous rocks, whereas the overlying Pliocene overlaps to the westward, and formerly rose high against the range, as is shown from Box Elder Creek northward to the Chugwater. In other words, the Miocene lake was of much lower level, covered, as far as we now know, a smaller area, and was limited in this region along the east by the gently upturned upper Cretaceous beds.

In the limited exposure from Carr Station eastward along the tributaries of Owl and Crow creeks, the Miocene shows a thickness of about 300 feet, the altitude of the uppermost strata being here about 5,800 feet, or fully 2,200 feet higher than the contact between the same beds upon White River. At this locality the separation between the two series is not at all one of angle or of any abrupt change of material. The conglomerate mentioned by Dana and Grinnell to the north as the dividing-line between the stratigraphically conformable Miocene and the Pliocene, is here wanting, and the division is established solely on palæontological ground. The beds consist of constantly varying thin layers of gray and creamy clays, fine sands, and marls. The latter, in broad white beds, presents so chalky an appearance as to have suggested the name of the region, Chalk Bluffs. There are numerous ferruginous layers where the sandy material is cemented by brown earthy iron oxyds, whose more compact outcrop may be traced along the varied forms of the escarpment for several miles

The lower 300 feet are characteristic Miocene, and have yielded numerous typical Miocene vertebrate fossils. The following list is made up largely from this locality, but partly from other points of the same horizon, also on the Great Plains:

MIOCENE OF THE PLAINS.

Laopithecus robustus, Marsh.
Drepanodon intrepidus, Leidy.
Drepanodon primævus, Leidy.
Dinictis felina, Leidy.
Amphicyon vetus, Leidy.
Amphicyon angustidens, Marsh
Hyænodon horridus, Leidy.
Hyænodon cruentus, Leidy.
Hyænodon crucians, Leidy.
Oreodon Culbertsoni, Leidy.
Oreodon gracilis, Leidy.
Eporeodon major, (Leidy) Marsh.
Eporeodon bullatus, (Leidy) Marsh.
Merycochœrus proprius, Leidy.
Agriochœrus antiquus, Leidy.
Perchœrus probus, Leidy.
Leptochœrus spectabilis, Leidy.
Protomeryx Hallii, Leidy.
Leptomeryx Evansii, Leidy.
Leptauchenia major, Leidy.
Poebrotherium Wilsoni, Leidy.
Hyopotamus Americanus, Leidy.
Elotherium Mortoni, Leidy.
Elotherium superbum, Leidy.
Elotherium bathrodon, Marsh.
Elotherium crassum, Marsh.
Menodus giganteus, Pomel.
Brontotherium ingens, Marsh.

Brontotherium gigas, Marsh.
Diconodon montanus, Marsh.
Rhinoceros Nebrascensis, Leidy.
Rhinoceros occidentalis, Leidy.
Mesohippus Bairdi, (Leidy) Marsh.
Mesohippus celer, Marsh.
Mastodon mirificus, Leidy.
Palæolagus Haydeni, Leidy.
Ischyromys typus, Leidy.
Palæocastor Nebrascensis, Leidy.
Eumys elegans, Leidy.
Leptictis Haydeni, Leidy.
Ictops Dakotensis, Leidy.
Meleagris antiquus, Marsh.

TRUCKEE GROUP.—Passing westwardly from Colorado Range, the entire country, as far west as the western base of Wahsatch Range, is altogether free from deposits of the Miocene. The broad area of Tertiary which occupies North Park and the upper valley of the North Platte is mainly posterior to the period of basaltic eruptions; and from its analogy with deposits in connection with the great basaltic outflows of Idaho, Oregon, and Nevada, it is assumed that these Tertiaries are Pliocene. The Pliocenes of the Great Plains also bear the same relation to the basalt north of the limits of our work, and there are further strong lithological grounds for referring the limited lacustrine Tertiaries of North Park and the Platte to the Pliocene.

The basin of Salt Lake, unlike the country between it and the Great Plains, is at present low enough to have been the receptacle of Miocene beds; but there is every reason to suppose, as will be seen hereafter, that the depression of the Utah Basin took place at a date posterior to the close of the Miocene age, and that during the Miocene period it was, like the country to the east, a land area without considerable lakes The same is true of middle and eastern Nevada, and it is not till we arrive at the meridian of 117° that we again reach strata which may be referred with any degree of probability to the Miocene age. This longitude marks approximatively the division between the higher plateau country of Nevada and the western Nevada Basin. The valleys of the latter area sink to an altitude of 3,700 feet, while those of the plateau country to the east are 5,000 and 6,000 feet.

A line of great geological change has been indicated as existing immediately west of the Battle Mountain group and Toyabe Range. The main feature of this change has been already indicated as the complete cessation of Palæozoic strata, which have continued from far to the east up to this meridian, and the sudden coming in of ranges made of Triassic and Jurassic rocks which continue westward into California. Besides the occurrence of these rocks of the middle age, there appears with equal suddenness, cropping through the immense Quaternary deposits of the valley, and in some instances in the eroded ravines of the rhyolite ranges, a series of upturned sedimentary beds displaying a very great total thickness, probably not less than 4,000 feet, the series being older than the rhyolites, partly older and partly contemporaneous with the trachytes. A large portion of the material of the group is made of trachytic muds, which carry, especially in Oregon, enormous numbers of Miocene fossil mammals.

The rocks of the group are limited on the east, within the boundaries of our Exploration, by the 117th meridian, and on the west by the abrupt wall of the Sierra Nevada. Northward they extend through Oregon and pass into Washington Territory, having their greatest development on Crooked River, the John Day, and the Malheur. South of our work they are well known in the valley of Walker River, but beyond that southward I am not aware of their having been observed.

An immense upturned series of fresh-water Tertiaries is displayed on a grand scale in the region of Cajon Pass, in southern California. Thus far I am not aware of these having yielded more than uncharacteristic fresh-water mollusks and a few unidentifiable fragments of mammalian bones. In future this is likely to be correlated with the lacustrine Miocene of the north.

The rocks of this series, within the limits of Map V., are always found upturned from 10° to 25°, and wherever observed in connection with basaltic eruptions they are cut through and overflowed by the basalt. The rhyolites also break through and overflow them, while the sub-lacustrine eruptions of the trachytic period are intercalated in the Miocene series.

On the eastern half of Map V. the Miocene first appears upon Silver Creek, at the western base of Toyabe Range, in latitude 39° 95′. Here and at Boone Creek, surrounded and overflowed by enormous masses of rhyolites, are some beds inclining from 15° to 20°, composed of light buff and ashy strata, very thinly bedded in some places, and in others made up of broad belts of uniform sediment 30 or 40 feet thick. They are characterized here and there by passages of chalcedonic material, which are local silicifications *in situ*, and in the softer passages by the presence of rolled specimens of fossil vertebrate bones, which are always too imperfect for identification. Under the microscope it is evident that this material is of volcanic origin, consisting of particles of crystalline grains of sanidin, with more or less magnetic iron, hornblende, mica, and a little quartz. There is no direct proof of their Miocene age, but they are referred to the Truckee group from their evident recent nature, and the fact that they immediately antedate the massive rhyolites.

Similar rocks, even more conspicuously made up of volcanic materials, are seen in the valley of Reese River to the north and west of Silver Creek, and also around the flanks of Lone Hill Valley, between the Shoshone and Augusta Mountains. Here the middle of the broad depression is occupied by heavy accumulations of Quaternary, which conceal all but a belt of Tertiary rocks, that line the edge of the valley and are immediately overlaid by the massive eruptions of rhyolite which form the greater part of the two bounding ranges. A similar inclined mass of volcanic and sandy sediments lies to the west of the Augusta Mountains, in like relations to the Quaternary valley and overlying rhyolites.

This group again appears near the southern end of Havallah Range, where a broad mass of basaltic rock has outpoured along the eastern face of the range, burying the greater part of the Miocene beds. Similar uncharacteristic exposures are seen directly south of Buffalo Peak and east of Lovelock's Station on the foot-hills of West Humboldt Range. The sediments are here less characteristically volcanic, and seem to be made up partly of volcanic material, but largely of coarse sands and gravels, and from their immediate contact with the Triassic rocks it is fair to assume that these exposures represent the lower limits of the series, while the soft volcanic beds displayed in the Shoshone and Augusta Mountains are without suggestion as to their position in the series.

I have merely mentioned these outcrops, because they are of some local importance, and in general their lithological resemblance and their relative position to the other rocks refer them to the one group. Future work may add the necessary proof of age to these scattered exposures.

The most important and characteristic development of this series within our limits is at the Kawsoh Mountains and along the southern extremity of Montezuma Range. The northern and eastern portion of the Kawsoh Mountains and the valley which lies north of them, separating their broken detached group of hills from the end of Montezuma Range, together offer a section of about 2,300 feet of Miocene beds, noting from the top as follows:

1. The upper 1,200 feet consist entirely of drab, mauve, gray, pale-buff, and white stratified trachytic tuff, intermixed with more or less detrital material. The beds are characterized by rapid changes of color and texture, are of very variable coarseness, and have a prevailing amount of glassy fragments, as if an enormous amount of the material were the glassy scoria and rapilli of violent and long-continued trachytic eruption. At intervals are beds of pure gray sand with a few seams of slightly marly clay. The microscope shows that this entire series is made up of angular and sub-angular fragments, many of them excessively small. There are some singular chalcedonic strata, one to two feet thick, of which the lower stratum-plane is exceedingly rough, resting upon the trachytic tuff and including a great many minute fragments of the volcanic material, the upper surfaces being rudely botryoidal, the protuberances reaching the size of an egg. Toward the lower edge of this great series of trachytic tuffs, the upper limits of which are nowhere seen, the proportion of true detrital material—quartz and feldspar sand—becomes rapidly greater until the tuff is underlaid by—

	Feet.
2. Coarse, sandy grits, gray and yellow fragments, partially rounded, partially angular, with a slight proportion of calcitic material..	250

		Feet.
3.	Saccharoidal limestone, rich in fresh-water mollusks	60
4.	Marly grits, yellow and drab, rather coarse	40
5.	Fine-grained, friable, buff and gray sandstone, having a peculiarly sharp, gritty feel	70
6.	Variable gray sandstones	100
7.	A marly grit	50 or 60
8.	White and yellow infusorial silica	200 to 250
9.	Palagonite tuff, base never seen, 250 feet being maximum exposure.	

No lower members than the bed of palagonite tuff are observed in the Kawsoh Mountains, or in the southern end of the Montezuma; but in Warm Spring Valley, a small depression in the basaltic hills a few miles north of Hawes's Station, on Carson River, the palagonites, there remarkably well developed, are seen to be underlaid by a light siliceous clayey bed made up of fine silt and comminuted infusoria. It is always far less pure than the white infusorial beds above the palagonites. Here, as everywhere, the series has an inclined position, dipping 15° to 20°.

Miocene palagonite has only been observed by us in this little Warm Spring Valley, at the northeast corner of the Kawsoh, and at the southern point of Montezuma Range. We have nowhere over 250 feet exposed.

In the Kawsoh exposure it is rather uniform, made up of yellowish-brown, decomposed-looking material, varyingly mixed with sand, and northwest of Mirage Station, in a little ravine at the foot of the rhyolitic hills, it is a rather coarse breccia, containing decomposed fragments of a somewhat vesicular augitic rock, the binding material in this case being pretty pure palagonite. Microscopic sections of the enclosed fragments of rock show a richly augitic material, in which a considerable glassy base has suffered extreme devitrification. Not only plagioclase but orthoclase is present. In passing from the outside inward, the section of these fragments shows a progressive palagonitic decomposition of the augite.

In the region of Hawes's Station, on Carson River, it is finer-grained, more uniformly yellowish-brown, and consists of a purer palagonitic material. In this case it is free from carbonate of lime. The palagonite of Fossil Hill, at the northern end of Kawsoh Range, when treated with acids, shows a very feeble effervescence. Our purest type of palagonite, that of Hawes's Station, has been subjected to analysis, with the following result:

Silica	50.87	50.88
Alumina	14.86	14.37
Ferric oxyd	13.02	13.30
Lime	6.08	6.18
Magnesia	4.08	4.14
Soda	1.76	1.86
Potassa	0.85	0.93
Water	8.48	8.34
	100.00	100.00

For the optical character of this palagonite and its microscopical behavior the reader is referred to Vol. VI. of this series. For purposes of comparison with other distant occurrences of palagonite, I give here three analyses. No. 1 is a palagonite from Iceland, collected between Thingvellir Lake and the Geyser (Bunsen *). No. 2 is from James Island, Galapagos (Bunsen). No. 3 is from Dyampang-Kulon, Java (Prölss†).

	No. 1.	No. 2.	No. 3.
Silica	41.28	36.93	37.57
Alumina	11.03	11.56	15.18
Ferric oxyd	13.82	10.71	13.07
Lime	8.75	7.95	6.02
Magnesia	6.49	6.28	5.58
Soda	0.62	0.55	0.79
Potassa	0.65	0.78	2.17
Water	17.36	25.24	19.61
	100.00	100.00	100.00

The Javan occurrence, described by Junghuhn, like our own, forms stratified deposits in a series of upturned Tertiary rocks. Comparing our

* Poggendorff Annalen, 1857, p. 219.

† Neues Jahrbuch fur Mineralogie, 1869, p. 434.

palagonites with all these others, a remarkable difference may be observed between the silica equivalents, the Nevada specimens carrying about 10 pen cent. more than the others. The Icelandic and Galapagos palagonites, as well as those described by Sartorius von Waltershausen from Etna, are clearly derivable from doleritic eruptions, whereas our Miocene palagonites most certainly antedate all the basaltic period.

In the stratified series overlying the palagonite, as before indicated, is a great thickness of purely trachytic tuffs, and from fissures through this stratified series after its complete deposition have outpoured the entire rhyolite series, and again, still later, the basalts, which are generally unaltered and directly overlie the upturned edges of the palagonite beds, the latter having suffered no inconsiderable erosion prior to the basaltic period. The reference of the palagonite and the accompanying stratified rocks to the Miocene will be accounted for later. For the present it is sufficient to assert that we have no knowledge of any basaltic eruptions until long after the consolidation and subsequent upheaval of the Miocene palagonites. Throughout Nevada, it is true, the basalts precede the visible Pliocene beds, which in many cases rest horizontally against the somewhat eroded flanks of the basaltic hills. A little north of our work, however, in the basin of Snake River, it is seen that there were basaltic eruptions in the middle of the Pliocene period, which overflowed the earlier lacustrine beds of the period, and in turn are themselves overlaid, as in Nevada, by the main later Pliocene series.

As a matter of geological date, it is perhaps unsafe to say that the basalts are entirely within the Pliocene. The evidence of the Pliocene river system of the Sierra Nevada would go to show that the basalts of that country were in part at least post-Pliocene. This evidence coincides with the relations in Idaho. Thus far, however, in western Nevada, it would seem that there were no Pliocene deposits earlier than the basalts, whence we infer that Nevada possessed during the pre-basaltic part of the Pliocene age a free drainage to the sea. As between the trachytes, rhyolites, and basalts, the order established by Von Richthofen has been found to hold with remarkable persistency over the Fortieth Parallel. It was, then, with no small surprise that we discovered palagonitic tuffs in early Miocene strata overlaid by enormous thicknesses of trachytic mud, and subsequently disturbed and overflowed by rhyolites and basalts.

This brief sketch of the relations of the beds to the subsequently erupted rocks shows at once that the palagonites are not derivable from the products of the basaltic period. In looking back to the pre-trachytic augitic rocks for a source for these palagonites, we have only the diabases of the middle age, whose period of ejection is assigned to the close of the Jurassic, and the rare augitic propylites and augitic andesites, which are clearly within the Tertiary period. A comparison of the analyses of our augitic andesites with the true basalts demonstrates a constant difference in silica, amounting on an average to 8 or 10 per cent. Since the andesites, both hornblendic and augitic, clearly came to the surface before the period of the trachytes, and since this basin of the Miocene lake was the scene of considerable activity at the period of the augite-andesites, it seems not an unwarrantable assumption that the palagonites were derived from the augite-andesites. With this the date of their appearance as preceding the trachyte, their high silica-tenure as compared with the palagonites derived from dolerites, and the presence of orthoclase in the included fragments of the palagonitic breccias, would thoroughly coincide. In the impure parts of the palagonite tuff the microscope shows occasional but rare shields of infusoria. This is especially true at the upper limits of the palagonite beds, where they pass rapidly into the pure-white infusorial silica.

Among the basaltic tuffs and decomposed basaltic materials in the vicinity of Black Rock, near the northern edge of the western half of Map V., among many curious basaltic products was observed a certain bed of soft, brown breccia, of which the cementing material is palagonitic. There is no doubt in this case that, like the deposits of Iceland and Etna, it is simply a local dependent of the basaltic eruptions.

The infusorial silica overlying the palagonite has its most important outcrops at Fossil Hill and along the whole northeastern edge of the Kawsoh Hills, and skirting their northern base nearly as far west as Warm Spring Valley; also near the site of Sam's Station, northwest of Mirage Station, and on the banks of Little Truckee River, between Pyramid and Winnemucca lakes; also west of Reno Station, on the Central Pacific

Railroad, near the boundary of California. The deposits of Warm Spring Valley and of Carson Valley are obscure, and show no very great thickness of beds. That near Hunter's Station, west of Reno, is an extensive exposure on the right of the railway-cut in approaching California, and consists of several hundred feet (certainly as many as 300) of pure-white, pale-buff, and canary-yellow beds of remarkably pure infusorial earth.

At Fossil Hill, on the northeast point of the Kawsoh Mountains, it appears overlying the palagonite tuff, and is succeeded above by marly grits. All along the northeast slopes of the mountains the cliffs and hills of infusorial silica appear in an uptilted position, their summits deeply eroded and overwhelmed by caps of basaltic rock. The bedding is here for the most part very thin, but certain of the strata reach eight or ten feet in thickness, of comparatively uniform material, without bedding-planes. Occasional fragments of willow leaves are observed. The lower members are pure-white, the upper show some interstratification of earthy impurities, and in the neighborhood of the overlying grits they are often pale-yellow. The white beds are remarkably light, cut easily with the knife, and have the earthy feel of chalk. They are almost entirely free from carbonate of lime, except in the uppermost yellow members immediately underlying the grits and sands, where there is a varying but always small proportion of carbonates. An analysis of the pure-white product is given in the table of analyses of stratified rocks.

Specimens of these white strata were subjected to microscopic analysis by Dr. C. E. Ehrenberg, of Berlin, who found forty-six distinct species of diatomes. Twenty-eight of these forms have been classed as *Polygastera*, and eighteen as *Phytolitharia*, the most abundant species being—

Gallionella granulata.
Gallionella sculpta.
Spongolithis acicularis.

In a lavender-colored bed far up in the series above the acidic tuffs, further sandy beds are observed in the same section, containing more or less infusoria, in which the following species were recognized by Mr. Charles E. Wright:

Gallionella?
Spongolithis acicularis.
Pinnubaria inæqualis.
Cascidoniscus radiatus.

Near White Plains Station the palagonitic tuffs, with the overlying infusorial earths, are directly broken through by a dike of pearlitic rhyolite, and afterward, after considerable erosion, overpoured by basaltic flows.

On Little Truckee River, a few miles above its mouth, the right bank, which is here quite a considerable cliff, displays a front of soft, white, infusorial rocks, dipping about 30° away from the river, or to the southeast. The white cliffs overhang the river, and large blocks, which are easily detached from the irregular, rough, chalk-like surface, roll down the abrupt slope into the river, and by their extreme lightness float on the surface, shooting quickly out of sight on the rapid current. It was not the least curious of our geological experiences to dislodge hundreds of these large blocks from the face of the cliff and see them drift away on the river surface in a tossing flotilla. Stems and leaves of plants of the willow family are not unfrequently found in the infusorial beds; but so far as we have observed they contain no molluscan remains or vertebrates. The upper members are rather more impure, are very finely stratified, and in some instances approach a quartzitic texture. They have apparently been metamorphosed, possibly by the contact of some lava-flow, resulting in an interesting series of colors—buff, lavender, gray, and bright brick-red. In these upper beds the surface of the slope is covered with thinly laminated chips. Under the microscope, though often showing traces of infusorial structure, the indurated strata are for the most part of a cryptocrystalline texture.

The sections of these rocks exposed are so exceedingly limited, in all cases nearly covered by Quaternary deposits, or the horizontal Pliocenes, or flows of rhyolite and basalt, that, with the exception of the Fossil Hill locality, we are unable to determine the limits of these infusorial beds. There, in passing up, the main mass of 250 feet is overlaid by marly grits, which occupy about 150 feet. These are all more or less infusorial, as the microscope shows, and carry, besides the remains of diatomes, not a little carbonate of lime.

They are succeeded above by the saccharoidal limestone, which is best shown on Fossil Hill, but also appears again west of White Plains Station, and in the hills in the neighborhood of Valley Wells. This limestone is usually cream-colored, and is cryptocrystalline in texture. At Fossil Hill it carries a great number of fresh-water mollusks, of which the following are the most important species:

Carnifex Binneyi.
Carnifex Troyoni.
Ancylus undulatus.
Melania sculptilis.
Melania subsculptilis.
Sphærum rugosum.
Sphærum Idahoense.

And the similar occurrence at Valley Wells gave a partial repetition of this list of species.

Where the parallel of 43° 30′ crosses Montezuma Range, there is a peculiar northeast-and-southwest break, which severs the range into two parts. This depression is occupied, as Map V. well illustrates, by a series 700 or 800 feet thick of the upper portion of the Truckee Miocene, inclined at very gentle angles, usually not over 2°, resting on the south unconformably upon the granite, to the east and west concealed by Quaternary deposits, and over a long stretch of country northwest of Indian Pass overlaid by sheets of more modern basalt. All the strata are excessively soft, and have suffered much from erosion, the resulting forms being soft, gentle slopes, for the most part débris-covered, but here and there showing the edges and surfaces of the Miocene beds. They are altogether volcanic materials of the period of trachytic eruptions. A few layers are compacted, but for the most part they are friable pale-gray, ashy, and lavender pumices and hyaline sands, varied with beds of orange, red, yellow, and purple, with some nearly pure white. There is the utmost variety in the texture of these beds, some being excessively fine, others rather coarse, containing a good deal of quartz sand. They no doubt represent the upper portion of the series already described above the grits and limestone of the Fossil

Hill section. So far they have not been seen to contain any organic remains, and are referred to the Miocene by their position under the basalt, and from lithological resemblance to the pumice and tuff beds which outcrop so characteristically between Kawsoh and Montezuma ranges. Unimportant outcrops are seen on the eastern slope of the Sahwave Mountains, and on the western slope of Truckee Range, north of Luxor Peak.

There is but one other locality of any importance falling within the limits of our observation, and that is the débris-covered slopes south of the Daney Mine, in the Washoe mining district. There the excavations for mining-shafts in the soft upper rocks have brought to light a series of volcanic tuffs belonging to the age of the propylites, being, in fact, made up of rapilli and sand of propylitic eruptions. They contain numerous leaves of Tertiary plants, chiefly willows, and are overlaid by gritty sands and some fine, white, clayey beds, the latter appearing in very small amount. It is conjectured that these are the earliest of the Miocene deposits, and if we could obtain a full section anywhere they would probably be found underlying the palagonite tuff, which we conceive to represent the age of the augite-andesites. The hornblende-andesite sands themselves would doubtless be represented in the sequence of sediments.

No vertebrate remains have been found upon the area of Map V., except a single rhinoceros tooth from the grits of the Kawsoh Mountains, a species which has been pronounced to be probably Miocene. The fresh-water mollusca of the saccharoidal limestone of Fossil Hill would not alone afford sufficient data for referring this series to the Miocene, although Professor Meek, independently of any other reason, made this assignment. The main reason for classing the whole group as Miocene is, that farther north in Oregon, upon John Day, Des Chutes, and Crooked rivers, Professor Marsh's researches have brought to light an immense formation, computed by him to be 3,000 or 4,000 feet thick, containing numerous vertebrate remains of clearly Miocene type. These Oregon beds are all in inclined positions, earlier than basaltic eruptions, and the main material of his whole series, as I have determined by microscopic studies, is of stratified trachytic pumices, tuffs, and hyaline sands. The Oregon Miocene is apparently the direct northward continuation of the Nevada formation. Besides the parallelism between the two series, is the fact of an overlying unconformable Pliocene in each case. The mollusks from Fossil Hill, and the rhinoceros tooth, distinctly refer the Nevada strata to the Miocene. The overlying Pliocenes and basalts are similar and of identical position in each case; and this, together with the identity of material and similarity of disturbed position, has led us finally to refer our Truckee group to the Miocene.

The following list of fossils, characteristic of the series, will serve to convey a general idea of the fauna of the Miocene lake of Oregon:

OREGON MIOCENE.

Eporeodon occidentalis, Marsh.
Eporeodon superbus, (Leidy) Marsh.
Thinohyus lentus, Marsh.
Thinohyus socialis, Marsh.
Rhinoceros Pacificus, Leidy.
Diceratherium annectens, Marsh.
Diceratherium crassum, (Leidy) Marsh.
Diceratherium armatum, Marsh.
Diceratherium nanum, Marsh.
Miohippus annectens, Marsh.
Miohippus Condoni, (Leidy) Marsh.
Miohippus anceps, Marsh.
Allomys nitens, Marsh.
Moropus distans, Marsh.
Moropus senex, Marsh.

SECTION III.

PLIOCENE TERTIARY.

Niobrara Group.—The Pliocene occurrences of the Fortieth Parallel are altogether lacustrine. Contemporaneous marine deposits are found west of the Sierra Nevada, and form important members of the upturned sedimentary series of the Coast Ranges of the Pacific. But east of the Sierra Nevada, all the way to the valley of the Mississippi, there are no very broad intervals, except the basin of Green River, which are not characterized by deposits of Pliocene lakes.

East of Colorado Range, in the geological province of the Great Plains, there is no single formation of more geographical importance than the deposits of the great Pliocene lake, a sheet of water which stretched from the base of the Rocky Mountain system eastward well toward the Mississippi Valley, and extended in a north-and-south line from the lowlands of Texas to an unknown distance into British America. It is the latest considerable geological formation of all this vast area of Plains, and is continuous over a great portion of its surface. Where the Rocky Mountains, against which it abuts, are particularly high and form powerful condensers of moisture, the resultant streams have carried away from the neighborhood of the front of the range considerable areas of Pliocene, with their underlying Miocene beds, leaving the still underlying Cretaceous formation as the surface-member of the plains. It is very interesting in the area of Map V. to notice the presence of the Tertiary strata against the eastern base of the hills, where the mountain-mass is low and relatively deficient in strong streams, and its absence abreast of the loftier parts of the range, where powerful streams are frequent enough to have completely eroded away the soft Tertiaries.

The most conspicuous topographical fact in Colorado Range, as shown upon the limits of Map I., is the great and sudden rise of the range south of the 41st parallel. From the northern edge of the map down to the heads of Cache la Poudre River, the average mountain-mass is low, its forms are comparatively soft and rounded, it never attracts any very great amount of moisture, the streams which flow from it are small, and in consequence the sheet of Pliocene beds lies uneroded upon its eastern base. The Cache la Poudre itself forms the first of the powerful streams which derive their abundant waters from the melting snows of the lofty ridge. It is interesting to observe that abreast of this sudden elevation the Tertiaries along the eastern base of the mountain have been entirely eroded away, leaving broad, low plains of Cretaceous, the escarpment of the southern edge of the Tertiary exposures clearly showing that their absence to the south is due to erosion.

As exposed upon Chalk Bluffs, the plane of demarkation between the Pliocene and Miocene, as before stated, is drawn on palæontological evidence alone, the upper 300 or 400 feet being of Pliocene beds, which from that latitude northward completely cover the whole of that portion of the Plains which falls within the limits of Map I. Over this extent of country, the position of the Pliocene strata is exceedingly important, as illustrating certain changes which have taken place since their deposition. The altitude of the contact-plane between the Pliocene and the Miocene is in the region of 6,000 feet upon the surface of Chalk Bluffs. The Pliocene strata rise in altitude along the base of the mountains in the region of Shelter Bluffs, on parallel 41° 30′, to over 7,000 feet. Northward, on the northeast corner of the map, the country is depressed to about 4,500 feet, yet the Pliocene beds occupy the entire area. As the Miocene and Pliocene are conformable, so far as angle goes, the absence of the Miocene in the northeast corner of the map is evidence of a depression in that region since the deposition of the Pliocene.

When examined on a north-and-south line, the surface of the Plains is a series of gentle undulations, rising to the greatest height between streams. Each stream which is traced from west to east across the plain occupies a sharp valley, usually walled in upon either side by abrupt bluffs, the top of the bluffs representing a general depression considerably lower than the table-lands between the streams. In other words, the present sharp, cañon-like valleys are eroded in the bottom of a previously carved broad, gentle valley. The average grade of these streams, from the mountain base to the eastern edge of our map, is from twenty to thirty feet to the mile. The Pliocene strata, it is evident, incline eastward at about the angle of the surface of the plain.

Far to the east and north in the valley of White River, and also upon Loup Fork, in Nebraska, the contact-plane of the Miocene and Pliocene is found at an altitude of about 3,000 feet above sea-level, the strata there, as well as upon our area, being apparently horizontal. Their deflection from the horizontal is not to be measured by any angular observations, but only by observing a given datum-plane over considerable east-and-west areas. If the Pliocene strata were truly horizontal in our area, and continued so over the whole plains, we should be at a loss for the eastward barrier which formerly retained the waters of the lake; but the gradual sinking to the east of the contact-plane between the conformable Miocene and the Pliocene series offers strong evidence of the depression of the entire country into an inclined plane since the deposition of the Pliocene beds. This is fully confirmed by the dying out of the Pliocene strata in Nebraska and Dakota upon the Cretaceous, where the Tertiary beds overlap them unconformably at altitudes 4,000 feet below the highest Tertiary limits upon our Map I. The conclusion seems irresistible that the Pliocene was deposited in a broad lake when the country between the meridian of 98° and that of 105° constituted a level area; and that altogether subsequently to the deposition of the entire Pliocene series, the whole region has been either elevated or depressed into the position of a great inclined plane, with a difference of 4,000 feet between the eastern and western limits of the lake.

I gladly credit this remarkable discovery to General G. K. Warren, who announced it in 1858. Never having seen his statement, I arrived at the same conclusion independently. When I verbally communicated to General Warren what I supposed to be an original discovery of my own, he referred me to the identical conclusion already published by him in the annual report of General (then Captain) A. A. Humphreys for the year 1858. Warren's interesting paper, entitled "Preliminary Report of Explorations in Nebraska and Dakota, in the years 1855–'56–'57," was reprinted in 1875.

From the position of the fresh-water Pliocene beds in Texas, and their fauna, there is little doubt that they are an extension of this same lake into lowlands of Texas, where they are now observed at sea-level. If I am right in assuming the probability of these beds constituting a portion of one Great Plains Pliocene lake, the depression in a southerly direction has been even greater than that along the eastern edge of the lake; and the difference of level between our highest observed Pliocene altitude and the fresh-water Pliocene of the Texan seaboard would indicate a change of level of 7,000 feet.

The character of these changes of level presents some curious orographical considerations. Over this whole area there is nowhere the slightest evidence of either faults of importance or noticeable folds in the Pliocene sediments. Wherever observed, they have the character of horizontal beds. We must therefore suppose that either the country to the west and north was gradually lifted without fold or fracture, or that the eastern and southern margins of the lakes were depressed from 4,000 to 7,000 feet without any noticeable local displacements or crumplings within the entire area of the lake. This will be particularly alluded to in a subsequent chapter on mechanical geology. Our small Fortieth Parallel portion of this Pliocene lake, therefore, is to be considered as an area of beds on the western elevated edge of an inclined plane.

Westward of Carr's Station, along the southern limits of the Pliocene, that formation is seen to rest directly upon the Cretaceous, having overlapped the otherwise conformable Miocene. North and west it is seen overlapping all the sedimentary series of Mesozoic and Palæozoic age, in places coming directly in contact with the Archæan core of the range.

As nearly as we can estimate, about 1,500 feet of beds are exposed in the series. It will be remembered that the Miocene of Chalk Bluffs was described as characterized by beds of marly clay and ferruginous sandy clays, the whole remarkably fine-grained and devoid of all broad zones of coarse material. The Pliocene, on the other hand, is to be distinguished by prevailing sandy formations of great vertical thickness; the predominant sandy character of the series being locally interrupted by marls, clays, gritty sandstones, some sheets of rather fine conglomerate, and peculiar brittle limestones, the latter apparently of no very great geographical extension.

The more important beds are rather coarse yellowish creamy sandstones, whose material is seen to grow coarser in approaching the mountain base, until in direct contact with the foot-hills of the range it is decidedly a conglomerate, consisting of pebbles, masses of quartz and feldspar, and chips and fragments of all the Archæan rocks represented in the crystalline body, varying in size from a pea to a pumpkin. These conglomerates form the uppermost beds, and when eroded by the mountain streams show finer materials immediately underlying them, a peculiarity of erosion along the upper waters of the stream being overhanging eaves of harder rocks on the bluff edges, under which the softer material has been worn away. Close by the mountains these beds dip $1\frac{1}{2}°$ away from the hills. The conglomerates are in several different layers, the coarsest being in the last bed. In passing eastward from the mountains, the pebbles become finer and finer, until they are little more than fine, grayish grits. Wherever seen, they are underlaid by calcareous grits and fine, whitish marls.

South of the Union Pacific Railroad, especially south of Otto and Hazard stations, the Pliocene beds are eroded in a series of rough terraces, with angular bastions and sharp escarpments, forms which have given rise to the name of "Natural Forts."

The surface of the plateau, a few miles south of Cheyenne, and thence for a considerable distance eastward, is made up of a bed of light, creamy limestone, with a brittle sherdy fracture, and a good many small veins of chalcedonic material. An analysis of this limestone will be found in the table of stratified rocks

East of the meridian of Cheyenne, over the broad plains to the north, the beds are altogether fine-grained, chiefly arenaceous, but interlaminated with a few beds of clay and marl, the prevailing color being pale olive-gray. The valleys of Crow, Lodge-Pole, and Horse creeks show a slight tendency to bluff formations on their banks, while the Chugwater is bordered for forty miles with a more continuous line of abrupt cliffs. These sharply escarped bluffs are cut at right angles by lateral ravines. As in the soft Bridger beds, so among the fine, marly members along the Chugwater and other northern valleys, are observed thin lenticular masses of jaspery rock, which sometimes carry dendritic infiltrations, resulting in moss-agate. Molluscan remains were not found. Fragments of silicified branches and trunks of trees abound, but the most important fossil remains are those of vertebrates, of which large numbers were obtained from Chalk Bluffs. The most important forms from this lake are—

PLIOCENE OF THE PLAINS.

Canis sævus, Leidy.
Canis temerarius, Leidy.
Leptarchis primus, Leidy.
Cervus Warreni, Leidy.
Merychyus elegans, Leidy.
Procamelus robustus, Leidy.
Megalomeryx Niobrarensis, Leidy.
Merycodus necatus, Leidy.
Cosoryx furcatus, Leidy.
Platygonus striatus, Marsh.
Bison Alleni, Marsh.
Bison ferox, Marsh.
Tapiravus rarus, Marsh.
Protohippus parvulus, Marsh.
Protohippus perditus, Leidy.
Protohippus placidus, Leidy.
Protohippus supremus, Leidy.
Pliohippus pernix, Marsh.
Pliohippus robustus, Marsh.
Merychippus insignis, Leidy.
Merychippus mirabilis, Leidy.
Hystrix venustus, Leidy.
Arctomys vitus, Marsh.
Geomys bisulcatus, Marsh.
Moropus elatus, Marsh.
Grus Haydeni, Marsh.
Aquila Dananus, Marsh.

At three places along the eastern base of Colorado Range are developments of coarse, semi-stratified gravels and conglomerates. Along the northern line of the map, on the branches of the Sybille, these gravels distinctly overlie the Niobrara Pliocene, abutting against the Archæan core of the range, from which their material is derived. The same is true of the region at the head of Chugwater and Pebble creeks. Apparently the same formation recurs in the valley of the Big Thompson, near the southern edge of the map, where similar conglomerate table-lands rest upon the Colorado and Fox Hill Cretaceous. Along the northern part of the map are 200 or 300 feet of these gravels, which descend toward the north and east in rude terraces. They are made up of coarse bowlders and pebbles and rough siliceous sand, composed altogether of granitic materials. At Big Thompson Creek they form benches or terraces 200 feet above the level of the stream, leaving to the east of the main body a few isolated outliers, which have successfully resisted erosion. At the latter locality, bowlders of Triassic sandstone mingle with the Archæan material of the conglomerates.

These southern bodies, taken by themselves, might possibly be considered as relics of the age of the great Pliocene beds which abut against the foot-hills, since they rest directly on the Cretaceous. But taken in connection with the developments to the north, it is most probable that they post-date the Niobrara Pliocene. I have placed this group as the closing member of the Tertiary series for the following reasons: It clearly overlies the Niobrara Pliocene, and it is absolutely certain that it antedates the Glacial Period, and consequently the gravel deposits of the Quaternary. While the Pliocene formations of the Plains abut directly against Colorado Range, the other side, flanked by the broad Cretaceous depression of the Laramie Plains, is altogether free from the Tertiary. Its altitude is about 7,000 feet, which represents the highest limits to which the Pliocene reached on the eastern side of the range. It is therefore probable that the range itself formed in these latitudes the westward barrier of the Pliocene lake.

North Park Group.—West of the western base of Medicine Bow Range the depression of the North Park, surrounded by bold Archæan masses on the north, east, and west, and separated from the similar depression of Middle Park by upheaved Cretaceous rocks and high ridges of volcanic material, was occupied by a lake which we have every reason to believe was of Pliocene date. The entire valley of North Park, except where the Cretaceous and volcanic rocks rise above its surface, is occupied by a nearly horizontal set of lacustrine strata, which in places overlap the secondary beds and come directly in contact with the Archæan bodies. The materials near the contact are composed of detritus of Archæan schists, and granitoid rocks of comparatively coarse sizes. Where it overlaps the softer shales of the Cretaceous, however, it is made up of the rearranged débris of those rocks. In general, therefore, the exterior boundaries of this oval basin of Tertiaries are varied in coarseness and texture. The entire middle portion of the park, however, is covered with horizontal beds of extremely white, fine, marly and sandy deposits. The various affluents of Platte River have eroded shallow valleys through these soft beds, displaying along their banks many excellent sections. There seem to be not over 300 feet of these materials.

Made up as they are of local débris from the surrounding hills, and devoid, so far as our observations go, of fossils, it is difficult to correlate these beds with other formations. They appear to occupy, nevertheless, positions entirely similar to the Niobrara Pliocene to the east, and may hereafter be proved by fossil remains to be the equivalent of those beds. In the absence of proper evidence, we have simply made of them a special group, calling it, after the locality of the basin, the North Park group. That they are Tertiary, is clear from their position unconformably over the Cretaceous. That they are Pliocene is rendered highly probable by their abutting horizontally against the post-Cretaceous basaltic hills which line the park at the southwest. In these so-called Pliocene North Park beds we find no basaltic tuffs, such as are intercalated in a lacustrine series in the Middle Park.

Among the loose, friable sandstones are soft whitish and grayish-white and buff marls, which cannot be distinguished from the Niobrara Pliocene of Horse Creek. Not a small portion of the material of the beds has been derived from trachytic and rhyolitic rocks which, in enormous masses, bound these Tertiaries to the south and east.

A continuation of this lacustrine Pliocene occupies the whole valley of the North Platte, up to the latitude of 41° 30′. Throughout that distance it rests directly upon the Archæan rocks on both sides of the valley, wrapping around the northern end of the Grand Encampment Mountains, and extending out unconformably upon the Laramie Cretaceous to the west of Savory Plateau. Here are exposed in all about 1,000 feet of rocks, which on the south of Bruin Peak reach an altitude of not less than 8,800 feet above sea-level, and again at Savory Plateau about 8,500 feet. The highest of the Pliocene deposits within the valley of North Park cannot fall far short of these figures, which probably represent the upper limit of the lake.

As developed in the valley of the North Platte, the group is composed chiefly of sandstones of varying coarseness, capped by about 300 feet of drab, marly limestone, which near the Archæan shore of the lake contains small pebbles. The lower beds, as displayed upon Jack's Creek, include strata of indurated clay, containing fine pebbles and some plates of brown and white mica. West of Savory Plateau and south of Little Muddy Creek, the limits of this Tertiary are not definitely known, since the area is covered with much soil and dunes of sand, the latter urged eastward by the prevalent west winds of the region. It was therefore impossible to determine the relation between the North Park group and the Vermilion Creek group west of the belt of Laramie Cretaceous.

It has sometimes seemed possible that this great thickness of North Park Tertiary might possibly be an eastward extension of the Eocene basin, whose limits approach it so nearly in the region of Savory Plateau; but if, as we have supposed, the basalts of the southern end of North Park are coeval with those of the Elk Head Mountains, it is clear that the two Tertiaries sustain different relations to their eruption. The wonderful dike which rises above the Vermilion Creek strata west of the Elk Head Mountains, to which Mr. Emmons has given the name of the Rampart, clearly cuts through the soft Eocene beds, while it is equally certain that the Tertiaries of the northwest corner of North Park abut unconformably upon the flanks of the basaltic hills.

There are some slight indications, especially near the three forks of the Platte, at the north end of the depression of North Park, of a disturbed

Tertiary, which is possibly unconformable beneath the light beds that cover the main surface of the Park.

The peculiar northern termination of this series of Tertiary rocks in the region of Savory Plateau and the Platte valley has left their former extension as a difficult problem. There seems to have been no barrier which should have prevented the northward continuation of these Tertiaries. Nor do the Cretaceous rocks west of Savory Plateau at present afford a sufficient topographical altitude to wall in a Pliocene lake in that direction. These difficulties have sometimes suggested that possibly the main Tertiary of the North Platte valley might in some way be an eastward extension of the Eocene itself, and the calcareous upper rocks which are seen within the Platte valley might be correlated with the calcareous lower Green River beds. We did not, however, detect any break between the rocks of the Platte valley and those of North Park which are unconformably above the basalt, and hence the whole series are provisionally referred as one group and placed within the Pliocene, and I shall be quite ready to welcome any additional evidence on the subject.

The angular discrepancy with the Cretaceous rocks west and south of Savory Plateau is very slight, but north, where it overlooks the valley of Sage Creek, the discrepancy is undoubted. There the uppermost member is a hard, siliceous shale, underlaid by white, limy sandstones.

Much of the valley of the Platte is covered by accumulations of Quaternary material, but the Tertiary beds may be followed nearly uninterruptedly along the northern flanks of Grand Encampment Mountain and Pelham Peak. The overlying Wyoming conglomerate of Savory Plateau offers no proof as to the age of these Tertiaries, since it sustains the same position as has been observed over the Eocene beds to the west, and over the Niobrara Pliocene along the eastern base of Colorado Range.

Humboldt Group.—The whole subject of the Tertiaries of the basin of Utah is surrounded with unusual difficulty. Along the western base of the Wahsatch, a portion of the Terrace country, rising to 700 or 800 feet above the level of the lake, is composed of loose, friable Tertiaries, carrying very recent fresh-water mollusks, the genera at least being chiefly the equivalents of existing types. These beds along the western base of the

Wahsatch are approximately horizontal. Three considerable depressions east of the main ridge of the Wahsatch—Morgan, Cache, and Ogden valleys—which unquestionably represent bays formerly connected with the main Pliocene lake west of the Wahsatch, have been the receptacles of Pliocene sediments very similar to the fragments of horizontal Pliocene terraces on the west base of the Wahsatch. They are all characterized by recent genera of fresh-water mollusks. The height of the Tertiary in all these valleys reaches a full thousand feet above the level of Salt Lake.

With the exception of terrace-masses along the western base of the Wahsatch, which for the most part are deeply covered by Quaternary deposits, the valley of Salt Lake carries a sheet of Quaternary, through which rise masses of Palæozoic and volcanic rocks. The northern boundary of this great basin is beyond the limits of our map, but has been crossed by us in several places, and the members of the Exploration have been unanimous in referring to the Pliocene period a considerable series of horizontal rocks which occupy a divide between the waters of the Utah Basin and those of Snake Valley. These rocks are composed chiefly of friable gray, white, and drab sandstones and marly limestones, for the most part horizontal, but in places uplifted at low angles. At the northwest boundary of the Salt Lake Basin, near the 114th meridian, at latitude 40°, are further exposures of horizontal Pliocene rocks, which rise to altitudes of 1,000 to 1,800 feet above the level of the Basin.

The question naturally presents itself, Why are not these beds continuous over the whole Salt Lake Basin? If eroded away, by what channel could the enormous amount of material have been conducted beyond the limits of the enclosed basin? It is unquestionably to-day a restricted basin, from which no water escapes. Its boundaries are nowhere less, so far as we know, than 600 feet above the present level of the lake; and since the Tertiaries to the north form a barrier, how is it possible that 1,000 or 2,000 feet of Tertiary material can have been removed from the whole area of the basin, there being no channel through which it could have been transported? There is one hypothesis which accounts for these curious facts. If after the deposition of the Pliocene lacustrine beds the old fault which had been previously defined along the whole west base of Wahsatch Range were again to become the theatre of displacement, and what is now the valley of Salt Lake were to suffer depression, a basin might be formed of sufficient depth to act as a receptacle for the detritus derived from the surrounding Tertiaries. That this has actually occurred, there can be no doubt. The horizontal beds which are now reposing against the western flank of the Raft River Mountains, the similar body lying west of Deep Creek Valley being supposed to represent a comparatively undisturbed portion of the series, have their easternmost correlatives in Cache Valley, Ogden Valley, and Morgan Valley, while the intermediate area has suffered a depression greatest along the actual western base of the Wahsatch.

The Tertiary beds of Cache Valley consist of grayish sandstone and marly limestone, presenting a great variety of size of grain, some of the beds being excessively coarse, porous sandstones. Among the limy beds, some are essentially oölitic; others are made up almost entirely of late Pliocene fossil shells, among which Meek recognized a new *Lymnæa.*

The Quaternary terraces of Bonneville Lake, which will be described in the succeeding section, cover and obscure much of the Cache Valley Pliocene, but enough is laid bare to indicate positively about 400 feet of beds, and probably as much as 700. Near the northern end of the valley, not far from the town of Mendon, they are considerably disturbed, showing angles of 10°, and even 15°. Along the whole flanks of the valley these Pliocene rocks rest nonconformably upon the immense masses of limestone of the surrounding mountains, and at the contact are usually obscured by mountain débris. A few of the beds are compact enough to have been used for building-stone.

Along the southern part of the valley a prominent red sandstone is observed, underlaid by lavender calcareous sandstones. Near Mendon, *Lymnæa* and *Helix* abound in the sandstone.

Ogden Valley, a depressed area walled in by high mountains and discharging its drainage through the cañon of Ogden River into the valley of Salt Lake, was also an enclosed bay in the Pliocene lake. Wherever the important surface-accumulations of Quaternary gravels and earth have been washed away, sandstones similar to those of Cache Valley are seen.

The Pliocenes are here obscured by the same Bonneville Lake terraces as in Cache Valley.

Morgan Valley is the third of these interior Pliocene bays, whose deposits do not greatly differ from those of Ogden Valley, except in being rather finer and whiter. No molluscan remains were observed here.

The limestone mass of Terrace Mountain, on the northwestern margin of the Utah Basin, is divided by a northwest-and-southeast depression, which severs the range into two equal portions. Upon the eastern and western sides the depressions of this pass form bays in the limestone which are occupied up to a thousand feet above the lake-level by horizontal Pliocene, consisting of fine yellowish and whitish sands, reddish gravels, and marly sands, all very loosely compacted, but nevertheless unmistakably a Tertiary formation, and in nowise to be confounded with the Quaternary marls of the desert. These fragmentary remains are of no little importance, since they present their escarped and bevelled edges horizontally, and attract marked attention to the absence of the extensions of the beds in the surrounding country

A similar but geographically much more important area is exposed along the western side of the Raft River Mountains, in the northwestern corner of Map III. Here the entire western base of the high limestone range is buried under soft, white, friable sandstones, conglomerates, and pumiceous tuffs, which rest in complete horizontality, and are exposed for a thickness of probably 1,000 feet. This is only another of the detached relics which have escaped depression and erosion.

In the southeastern corner of Map IV. the broad Quaternary valley of Deep Creek is flanked upon the west by low, softly sloping hills, which rise about 1,000 feet above the valley. The exposure for a distance of twenty-five miles north-and-south by six or seven miles transversely is entirely of fine white sands and marls, with a few rather fine gravelly conglomerates unquestionably referable to the Pliocene age. One particular bed is conspicuous for its very rough texture; it is a rearranged volcanic ash, similar to those found in the region of Toano.

There is a particularly large development of undisturbed Pliocene, not less than 500 or 600 feet in thickness, on the divide between Thousand

Spring Valley and Holmes Creek. The upper bed of this exposure is a drab, earthy limestone, full of siliceous and muddy impurities, and peculiar from the number of ferruginous dendritic infiltrations. The greater part of the Holmes Creek beds are originally due to volcanic eruptions. Geognostically they do not very greatly differ from the trachyte lacustrine tuffs of the western Miocene beds, and, like these, they are formed of the sands and rapilli of a direct ejection. They are, however, the tuffs of Pliocene rhyolite eruptions. The escarpment of these pumiceous Pliocenes results in interesting castellated forms; a fine sample on the eastern side of the valley has received the name of Citadel Cliff, from its bold architectural form. Here are exposed over 100 feet of evenly bedded white sands, containing many small, transparent glass particles.

Among the beds of volcanic derivation is a noticeable stratum, having a thickness of about five feet, formed of closely compacted fragments of brown, glassy material. The microscope shows it to be made up of crystals of feldspar and quartz in a groundmass of red and black volcanic ash, the red particles being a rhyolitic glass, and the black particles a pure, true black obsidian. The upper bed of the surface of Citadel Cliff is made up of cream-colored conglomerate, in which lime is a large element. Between Thousand Spring and Gosiute valleys, and throughout the entire western slope of Toano Pass, similar horizontal beds of rearranged sand and volcanic material occupy the rolling country. They overlie the upturned Eocene of Peoquop Pass with clear nonconformity. Near the town of Toano a peculiar solid white pumiceous bed is found to be admirably adapted to building-purposes, since it is very easily quarried, and hardens upon exposure.

West of Humboldt and Tucubits ranges there is a long valley drained by Humboldt River and Huntington Creek. Throughout the length of this depression, over 100 miles, there is a nearly continuous exposure of horizontal Pliocene beds. It is difficult to decide what thickness of beds is exposed, since they are often buried by Quaternary, but there cannot be less than 600 or 800 feet. In the middle of this valley the beds are horizontal, but on either side there is a dip of from 2° to 3°, which is probably the inclination of deposition. The foot-hills of the ranges on both sides are skirted by continuous belts of Tertiary, which are bevelled off to the central valley. Streams have excavated broad depressions down these plains, and the intervening spurs have been graded off so that the whole valley country presents few abrupt exposures, and those only along certain exceptionally sharp stream-cuts. The most important of these are seen in the valley of the South Fork of the Humboldt, where 100 to 150 feet of sandstone cliffs flank the valley on either side. Here are found sands, that are at times quite marly, associated with more or less coarse beds of grit, which nearer the mountains are entitled to be named conglomerate. There are a few calcareous clays and some limited beds of true marly limestone. It is not surprising that this whole Pliocene exposure should have more or less calcareous material within its mass, since so large a portion of the surrounding mountain-sides from which the material has been derived is of Palæozoic limestones.

A little north of Piñon Pass, on the western side of Piñon Range, is an exposure of about 80 or 100 feet of highly calcareous horizontal beds. The spurs and hills resemble white chalk, or white, infusorial silica. Certain of the porous beds are impregnated with alkaline carbonates, as if the lake in which they were formed had been saline, or, as is possibly though not probably the case, they had suffered alkaline infiltrations in more modern times. Similar deposits fill the valley north and south of the Humboldt as far west as the meridian of 116° 45′.

There is little doubt that all these exposures of Pliocene represent the deposits of one lake, out of which the numerous lofty mountain masses were lifted in a complicated system of islands. Fossil remains are excessively rare, for the reason that the greater part of the area which is colored as Tertiary is overlaid by more or less Quaternary débris. At Bone Valley, which is drained by the waters of the North Fork of the Humboldt, a few vertebrate remains were found, including a jaw of *Protohippus perditus*, also a jaw of *Merychippus mirabilis*, and fragments of *Cosoryx*. These forms are of exceeding importance as proving the identity of the beds in which they were found with those of the Niobrara Pliocene east of the Rocky Mountains.

A similar proof has been obtained by Professor Marsh as to the Pliocene beds of Oregon, and but one reason has restrained us from coloring all the Tertiaries west of the Wahsatch as Niobrara. It is, that in the great Boise Basin, which is drained by Snake River, and which lies directly north of the region that has just been described, there are two sets of Pliocene strata, separated by basaltic eruptions. Sections obtained along the plains between the Owyhee Mountains and Snake River show that a considerable portion of the beds of the valley, which consist chiefly of white sands and marls carrying numerous well defined Pliocene forms, were overlaid by large accumulations of basaltic flow, and that subsequently a second period of lacustrine deposition took place, likewise characterized by Pliocene forms, the latter representing a more advanced stage of development and more recent type than those beneath the basalt. The Nevada and Utah Pliocenes carry few organic remains. Later, it will be evident that either basaltic outflows lingered later in Idaho or else the greater part of the western Nevada Pliocene is the equivalent of the post-basaltic Idaho series.

It is unnecessary for our present purposes to follow the details of the Pliocene outcrops over the remaining part of Map IV. and those which occur on Map V. Their character is that of soft, partially compacted, locally derived material, laid down in a series of intricate valleys, winding among what at the time of deposition were islands of the most complicated geological structure. The beds which are seen along Humboldt River show a maximum exposure of about 300 feet, of which white and creamy varying sands, a few beds of pale-yellowish clay, and a little conglomerate are all that appears. The Humboldt Valley south of its bend at Lassen's Meadows cuts a cañon through these Pliocene strata for about twenty-five miles, exposing cliffs upon either river bank from 150 to 300 feet high. No fossils were obtained, except near the northern end of Havallah Range, where portions of the skeleton of a Pliocene equine animal were exhumed; and near Mill City, in the excavation of a mining canal, numerous Pliocene *Unionidæ* were obtained.

Similar to the exposures along the valley of the Humboldt are those exposed in the cañon of the Truckee, south of Wadsworth. This river, after traversing its sinuous cañon across Virginia Range, suddenly turns to a northwest direction and enters a cañon from 100 to 200 feet deep through horizontal beds of soft, white, marly sands, and fine arenaceous and clayey beds, mingled with coarse, almost conglomeratic grits.

By far the most important question connected with these western Pliocene beds is that which has already been discussed in the department of the Plains and in the basin of Salt Lake, namely, the orographic movements which their position proves.

One cannot fail to ask, What has been the probable connection, over this whole area of middle and western Nevada, of the Pliocene beds? Wherever the Quaternary has by any accident failed to cover valley areas, we immediately come upon strata of Humboldt Pliocene. There is little doubt that if the entire Quaternary were removed from the region it would be seen to be blanketed with a stretch of Pliocene beds, uninterrupted except by the mass of the older mountains. Passing westward from the region of Toano, where the altitude of these horizontal beds is about 6,000 feet, they may be traced with no interruption, at least with no barriers to prevent their continuation, westward down the valley of the Humboldt and throughout all the complicated net-work of valleys which communicate with the level of the Pliocene beds, gradually sinking as we progress, until in the region of Pyramid and Winnemucca lakes they are at an altitude of about 3,800 feet above the sea.

We are forced to admit either that there was a series of communicating lakes which drained to the west, the lowest member of the chain being along the depressed western edge of Nevada, or else that all these Pliocene beds represent the deposits of one intricate lake which subsequent to Pliocene time has been depressed westward, making a difference of elevation of 2,000 feet between its eastern and western edges. The problem reduced to that form, if answered by the hypothesis of a series of different Pliocene lakes, varying from 4,000 to 6,000 feet above sea-level, resolves itself into a still more difficult one. We to-day find the horizontal Pliocene beds along Truckee River lying at altitudes above Pyramid Lake, into which the waters of the Truckee flow. All the modern drainage of a wide area flows into the depressed region occupied by Pyramid, Winnemucca, Carson, and Walker's lakes, the present levels of these lakes being all under 4,000 feet.

The Quaternary detritus, therefore, from the Pliocene beds which we find within this drainage-area at an elevation of 6,000 feet along the upper Humboldt Valley, must be and must have been delivered into the lowest part of the basin; and if that were the case, it is inconceivable that the Pliocene beds of Truckee River should have remained unburied by modern detritus. Pyramid Lake itself has its bed several hundred feet below the neighboring Pliocene beds, and it is over 2,000 feet below the apparently horizontal beds in the upper valley of the Humboldt. The only possible way of accounting for this relation is to suppose that the whole country from about the meridian of 114° 30′ was depressed to the west, the western edge of the lake settling 2,000 feet. If, as we believe, there is no proof whatever against the continuity of the Pliocene sediments from Thousand Spring Valley westward to Pyramid Lake, the same is true from that point eastward to the deposits of Cache Valley. I believe that the entire section of Utah and Nevada studied by us was covered by one Pliocene lake, in which the series of parallel ranges was an archipelago, and that in post-Pliocene times a very great orographical movement has taken place, the maximum displacements being upon two lines: one upon the eastern base of the Sierra Nevada, a region of long previously defined fault, the other upon the western base of the Wahsatch, also a region of recurrent faults.

There is, according to this view of the case, a comparatively undisturbed region in the neighborhood of Thousand Spring Valley, from which the Tertiaries to the east have sunk in an inclined plane as far as the base of the Wahsatch, where they were carried to a considerable depth below the present surface, making a displacement of over 1,000 feet. Westward they have sunk in another inclined plane to the base of the Sierra Nevada, where the displacement was certainly 2,000 feet. The throwing of the horizontal deposits of this broad lake into two inclined planes has been of the same gentle character as that already described upon the Great Plains. In the case of the displacement which occurred along the base of the Wahsatch, we have corroborative evidence in the upturned position of the Tertiaries along the divide between the basin of Salt Lake and that of Snake River; also at the northern end of Cache Valley, a region which must have been closely contiguous to the plane of displacement. In both these places the Pliocene beds are upturned at angles from 10° to 20°, a phenomenon not elsewhere observed by us, but one which finds its counterpart in the post-Pliocene coast rocks of California, where a series of intense, recent orographical disturbances has been brought to light by Professor Whitney. As horizontal Pliocenes occur upon the divide between the basin of Utah and that of Idaho, it becomes quite certain that during the Pliocene the two areas were regularly connected as one and the same lake.

As between the basin of Idaho and that of eastern Oregon, the connection is not so clear; but between western Nevada and Oregon it is evident that the Pliocene beds carry over from one to the other, and it will not be at all surprising if future work demonstrates that in Pliocene times Utah, Nevada, Idaho, and Oregon were in part covered by one and the same great Pliocene lake, studded with numerous mountainous islands. I consider it proved that the displacement at the Sierra Nevada base and the Wahsatch base were at the close of the Pliocene, and thus broke the one broad lacustrine basin into two new lake basins—one at the foot of the Sierras, the other under the shadow of the Wahsatch Range—which were to receive the waters of the Quaternary age, and form lakes whose existence will be discussed in the next section. The following are the more important fossils described by Prof. O. C. Marsh from the Pliocene beds of the western lake:

Platygonus Condoni, Marsh.
Dicotyles hesperius, Marsh.
Anchippus brevidens, Marsh.
Protohippus avus, Marsh.
Morotherium gigas, Marsh.
Morotherium leptonyx, Marsh.
Graculus Idahoensis, Marsh.
Rhinoceros Oregonensis, Marsh.

SECTION IV.

RECAPITULATION OF TERTIARY LAKES.

The relations which subsist between the Laramie Cretaceous and the Vermilion Creek or lowest Eocene group have been stated in a general way in the Mesozoic chapter, and the fuller evidence of the nonconformity there asserted was presented when discussing Eocene geology. I shall now, by way of recapitulation, outline as succinctly as I am able the remarkable sequence of lacustrine Tertiary basins which since the close of the Laramie period have played so important a part in the geology of the middle Cordilleras.

I have shown that in the region east of the Wahsatch the great series of conformable strata was a periodically subsiding series, having the greatest amount of post-Carboniferous sinking near the Wahsatch or western shore. The sediments which overlay the depressed parts of the Rocky Mountain chain and encircled its rugged islands were thinner than at the Wahsatch region, but at the close of the Cretaceous were equally near the ocean surface, as is indicated by the abundant series of coal-beds in the upper Laramie. I may anticipate an important observation from a subsequent chapter on the mechanical disturbances of the middle Cordilleras by saying that, in very many instances, the subjacent Archæan topography has exerted a marked influence on subsequent disturbance; indeed, it has evidently determined the loci of most modern ranges.

An important instance is the post-Cretaceous tilting of all the conformable post-Archæan beds up to the top of the Laramie, over and around the Rocky Mountain islands and submerged ranges.

At the close of Cretaceous time the relative upheaval of the whole Rocky Mountain chain and the west shore of the Cretaceous sea, including the system of the Wahsatch and its northerly extension, resulted in the walling in of the system of the Colorado River, which then for the first time became an area from which the sea was quite excluded. The Wahsatch and Rocky Mountain systems, passing northward, trended together, meeting near the present head waters of Green River; southward they diverged more and more, until in New Mexico and southern Colorado the two walls of the basin are five hundred miles apart.

Over a considerable portion of this enclosed area, the then latest rocks, the Laramie, were left either horizontal or in gentle folds. Exceptions to this in the area of the Fortieth Parallel were Uinta Range and its easterly dependencies, Oyster Ridge, Bitter Creek quaquaversal, and other lesser folds. As a whole, it was an enclosed basin, secluded from any marine invasion.

Littoral and estuarial faunæ, together with the Dinosaurians, perished with the revolution which created this basin.

Fresh water from the surrounding and inwardly draining area rapidly converted the basin into a sweet lake, having a drainage southward to the sea. Whatever ocean waters may have been caught in the hollow land were at once diluted and flooded out, as is evidenced by characteristic fresh-water fauna entombed in the sediments of the lake.

For this body of water I propose the name of UTE LAKE, taking the name of an Indian tribe whose roaming-ground covers a large part of the lake area. It has fallen to our corps to study only that portion of the lake lying north of the 40th parallel.

Above that latitude it filled the entire Green River Basin for a distance of one hundred and fifty miles north, with an east-and-west exposure of about the same distance on the parallel. It is expected that the labors of Hayden, Powell, and Gilbert will outline its southward continuation and complete its ancient shore line. Already, from a locality in New Mexico over two hundred miles south of our work, Marsh has reported representatives of the fauna of this lake, and it only remains to be proved, as will be easily done, whether Ute Lake actually extended so far south, or whether, as is at present wholly improbable, it was succeeded in that direction by another lake of the same age and faunal characteristics.

The deposits of Ute Lake are the beds of the Vermilion Creek group, already shown to be of basal Eocene horizon, a series having in our field a maximum thickness of about 5,000 feet, and carrying, besides abundant fresh-water *mollusca* and a few fishes, the characteristic vertebrate fauna of the lowest Eocene.

The entire group of beds is made up of predominant sandstones, which carry conglomerates along the shores and hold minor clay intercalations. The prevailing color is red, the clays which give character to the color being frequently almost vermilion. A few beds of earthy semi-lignite give evidence of temporary land-surfaces. The prevailing type of sediments is coarse. By far the greater bulk of the material in the Fortieth Parallel region came from the land lying west of the lake and the lofty Uinta Range, which during the Ute Lake period was an island but little detached at its western extremity from the western mainland.

After the accumulation of the Vermilion Creek series was complete, the greater supply having come from the high land west of the lake, a period of orographic disturbance ensued by which a portion of the western land suffered subsidence, and the lake immediately enlarged itself by overflowing the newly depressed area, thus fully doubling the east-and-west dimensions. Judging by the sediments of the enlarged lake, the eastern boundary was also somewhat depressed and the area of the basin somewhat increased in that direction. This eastward growth does not show in the Fortieth Parallel area, unless the obscure lower Tertiaries of North Park and North Platte valleys shall finally appear to be an eastward extension of Eocene beds; but it is shown in the beds of Green River Eocene discovered by Hayden's survey of the Middle Park. Westward the new lake extended to longitude 116°.

The Uinta was still a great island, and the highland of the Wahsatch and its adjoining plateau of lately elevated Vermilion Creek rocks formed a peninsula.

For this new body of water I propose the name of GOSIUTE LAKE.

In the orographic movements which thus defined a new lacustrine basin, the Vermilion Creek rocks over the Fortieth Parallel area were very generally disturbed. Along the east base of the Wahsatch they were tilted to 14°, and on the Uinta western flank to much higher angles. Consequently the sediments of Gosiute Lake—the Green River group—were laid down unconformable to the preceding Vermilion Creek group, as is abundantly proven in preceding pages of this chapter.

As developed at characteristic localities in the neighborhood of Green River, this group embraces about 2,000 feet of conformable, fine-grained rocks, giving general evidence of accumulation in still, rather deep water. The lower 1,200 feet are made up of finely fissile shales and calcareous clays, with some quite fine limestone. Many of the upper shales are strongly bituminous. This member carries numerous fishes (already mentioned), many insects, and abundance of fresh-water mollusks of the genera *Viviparus*, *Goniobasis*, and *Unio*, besides a few beds of lignite.

In the Green River Basin the position of these beds is either nearly horizontal or locally upturned to angles up to 25°. In Utah and Nevada the outcrops are all isolated exposures which the general Quaternary and wide-spread volcanic formations have failed to cover. The rocks are generally fine shales, clayey or calcareous, with abundance of carbonaceous shale and beds of lignite. The fossil fish, insects, and mollusks are identical with those of the Green River Basin.

Overlying the shales in both the Green River Basin and Nevada are heavy beds of ferruginous sandstone, at least 500 feet thick in Wyoming and probably much more in Nevada.

On the mode of extinction of the middle Eocene Gosiute Lake our Exploration throws but little light. The only facts in evidence are the slight nonconformity in Wyoming between the Green River and the overlying Bridger group, and the entire absence of the latter group over the Eocene area of western Utah and Nevada. The nonconformity, although slight, is sufficient to prove orographical movement at the close of the Green River age; and the absence of Bridger beds west of Bear River is very good negative proof that the disturbances lifted that region above the Gosiute Lake level. In this connection it is of interest to note that the third basin thus formed was in the Fortieth Parallel area, wholly within the boundaries of the earliest Eocene (Ute) lake.

For this third Eocene sheet of water I propose the name of WASHAKIE LAKE.

Of the geographical extent of Washakie Lake very little is certainly known. North of Uinta Range the group of Bridger beds, the sediment of this lake, extends from the meridian of 107° 45′ to 110° 45′, about one hundred and fifty miles. The northward extension is not definitely known, but the beds have been recognized one hundred and fifty miles farther north on the low land lying west of Wind River Range. The continuation of these beds still farther south will doubtless be described in the reports of Major J. W. Powell, for whose southward tracing of the various Eocene members we look with interest.

On the eastern margin of the Bridger exposure, in the Washakie Basin, the fragment of Bridger which has been left by the general erosion of the region is bounded in every direction by the underlying and next adjoining member, the Green River series. The Bridger beds undoubtedly extended far east of their present boundaries, and on the west side of the lake, in the region of Bear River, there is little doubt that they also extended some miles farther westward. It is true, also, that the uppermost members of this group, as represented in the Bridger Basin and the Washakie Basin, do not extend up to as high geological horizons as certain beds south of the Uinta in the White River valley. Between Bear River and Black's Fork, on the north side of the Uinta, the Bridger beds overlap the Green River and come directly into contact with the strata of the Vermilion Creek group. At the eastern end of the Uinta, where the O-wi-yu-kuts Plateau breaks down and sinks beneath the rolling Tertiary plains, a fragment of the Bridger beds caps the Green River at such an altitude that its southward continuation can hardly be doubted.

These three Eocene lakes, whose sediments are superposed in the order that I have described, buried the flanks of the Uinta island deeper and deeper. Yet in passing westward the two upper members give out unconformably against the Vermilion Creek ridge. It is therefore evident that, during the successive depositions of the three lakes, the eastern end of Uinta Range suffered a more considerable subsidence than occurred at the western end.

As described in a former section, the rocks of the Bridger group consist of a conformable series about 2,500 feet in thickness, the lower portion being of drab and gray sandstone with some admixture of clay, the upper 1,500 feet of a peculiar clay sandstone of olive and drab colors, banded with olive-green stripes. From bottom to top they are well charged with vertebrate and molluscan remains; the former distinctly characteristic of the middle Eocene age.

Entirely south of Uinta Range, in altitudes considerably lower than the Tertiary Plains north of the range, there is displayed, chiefly in the valleys of Green and White rivers, a rather thin group of fine clayey and sandy strata, which are apparently unconformable with all other Tertiary groups.

Stratigraphically they are of little interest; their chief importance is in the vertebrate fossils, which they yield most abundantly. Professor Marsh, who brought this fauna to light, declares positively that it is of higher palæontological horizon than the Bridger group and represents the summit of the Eocene. Marsh, and Emmons who worked out what we of the Exploration know of the stratigraphy of this region, by accident gave the same name—Uinta—to the group.

I therefore propose for the limited body of water within whose area the group accumulated, the name of Uinta Lake.

Evidence of orographical disturbance since the period of Uinta Lake is to be found in the drainage of the entire area. It is true that this might have been accomplished by the slow wearing down at the point of overflow, where a river as yet unproved delivered the surplus water of the lake. There is also some evidence of post-Bridger disturbances at the eastern end of Uinta Range, where a line of fault has thrown down the beds of the Bridger group into contact with the edges of the underlying Green River series. The precise mode of the extinction of Uinta Lake remains at present problematical; but in the great disturbances which elsewhere throughout the Cordilleras are demonstrable as immediately preceding the Miocene, there was ample change of level to account for the drainage of this lake. That it was extinguished, is rendered certain by the entire absence of the Miocene strata over its area; and we are probably within the bounds of safety, therefore, in assuming the disappearance of the last of the four lakes at the dawn of the Miocene epoch.

With the exceptions of some peculiar conglomerates, which are believed to be of Pliocene age, and the Pliocene reference of the Brown's Park beds by Powell, we have no evidence of Tertiaries subsequent to the deposits of the latest Eocene lake within the Fortieth Parallel area between the Wahsatch and the Rocky Mountains.

The faunal equivalents of the four divisions of the Eocene are entirely unknown east of the Rocky Mountains, in the great geological province of the Plains. There, whenever the covering of Pliocene and Miocene rocks which form the main surface of the great inclined plateau is removed by the accidents of erosion, they are seen to rest unconformably upon the level or gently undulating surface of the Cretaceous strata. There is to-day no evidence of the existence of an Eocene lake in the province of the Plains.

It seems, therefore, altogether certain that during the entire Eocene age the province of the Plains was a land area having a free drainage to the sea. Passing westward from our most western Eocene exposure near Elko, Nevada, quite to the west base of the Sierra Nevada, there is also no evidence of deposits of Eocene age. Over those portions of western Montana, Idaho, and eastern Oregon which have been explored by Whitney, Brewer, Gabb, Marsh, and myself, in like manner, no other fresh-water Eocene has been observed. It is therefore evident that throughout the middle Cordilleras the four lakes described were the only considerable regions of Eocene accumulation, and that otherwise during Eocene time, from the western base of the Sierra Nevada to the valley of the Mississippi, stretched a continuous land area.

In the orographical disturbance which marked the close of the Eocene, two new lacustrine basins of very great extent were created by local subsidences. The province of the Plains, from somewhere about the north middle of Kansas northward far into British Columbia, had its surface at that period altogether made up of the eroded level strata of the Cretaceous formation.

At the close of the Eocene a large part of the plains area, from middle Kansas indefinitely northward, became depressed and received the drainage which now forms the western affluents of the Mississippi, Missouri, Red River, and other of the British Columbia rivers, forming a wide sheet of water.

For this I propose the name of SIOUX LAKE.

Unfortunately the Fortieth Parallel area only covers a very slight exposure of the series of Miocene beds which accumulated in Sioux Lake, to which, long since, Hayden gave the name of White River group. As already shown, it is characterized by typical Miocene fauna.

The beds, as exposed in our area, are composed of fine clay, sand, and marl. On the latitude of 41°, where the Miocene exposures occur with us, they rest directly on the gently undulating strata of the Laramie Cretaceous series; and it is there evident that the lake did not extend westward quite to the present foot-hills of Colorado Range, but had its western shore against a low fold of the Laramie Cretaceous. As displayed on the front of the Chalk Bluffs, the White River Miocene deposits are about 300 feet thick, and are overlaid with entire conformity by the coarser sediments of the Niobrara Pliocene. The Miocene is never found south of the northern part of Kansas, below which point the overlapping sheets of the Pliocene strata come in contact with the Cretaceous and prove that Sioux Lake did not extend in that direction. The recurrence of the Miocene beds in Manitoba indicates a very wide extension of the lake area in that direction. In Montana it extended far west of the Black Hills; and, in all probability, its deposits form a continuous sheet from latitude 40° and 41° over the whole province of the northern Plains.

The chain of occurrences which ended in the development of a great Miocene lake west of the 117th meridian and east of the Sierra Nevada and Cascade Range is more obscure than that which brought about Sioux Lake. The absence of fresh-water Eocene west of the meridian of 115°, and of Cretaceous strata east of the Sierra Nevada, would indicate that the western border of the continent, from longitude 115° to the then shore of the Pacific, remained a land area, free from considerable lakes, from the time of its upheaval at the close of the Jurassic age.

In the modern configuration of the country the most notable feature is the great mountain barrier of the Sierra Nevada and Cascade Range which defines the western limit of the fresh-water Miocene and Pliocene basins of

Oregon and Nevada. North of the latitude of the northern boundary of California the Sierra Nevada was not a barrier to the eastward extension of the Cretaceous. The marine strata of this period, which abut unconformably against the western face of the Sierra Nevada, in continuing northward continually pass farther and farther inland, until in eastern Oregon they abut against the western face of Blue Mountain Range. The shore during Cretaceous time, therefore, had a northwest trend along the Sierra Nevada, and then turned an angle with a slightly northeast trend, reaching the base of the Blue Mountains, which, like the Sierra Nevada, were uplifted at the close of the Jurassic age.

So far as at present known, the highest of the marine series east of the present Cascade Range is the upper Cretaceous. It is not impossible that future search may develop the presence of overlying, conformable marine Eocenes. However that may be, prior to the Miocene age the line of upheavals defining Cascade Range took place, isolating the basin of eastern Oregon from the sea. This chain of elevations, connecting southward with the Sierra Nevada, had also the effect of extending the depressed basin of eastern Oregon southward along the east base of the Sierra Nevada, through Nevada and into California, to an indefinite distance.

The latest beds which were first upheaved to form Cascade Range, so far as now known, consist of marine Cretaceous. Unconformably, beneath the Cretaceous, are sparingly seen the highly altered metamorphic rocks of the Sierra Nevada system, presumably of Triassic and Jurassic age, as upon the flanks of Cascade Range, where the east-and-west upheaval of Siskiyou Range joins it. Thus far in the exposures of the Oregon basin, east of the Cascades, so far as I know, marine Tertiaries have not been observed. In their absence, the natural inference is, that the Cascades were first outlined at the close of the Cretaceous.

The only other reasonable hypothesis of the isolation of the eastern Oregon basin prior to the Miocene is, that the Cascades and the basin of Oregon were defined at the close of Eocene time, and that the marine Tertiaries seen upon the west side of the range will yet be found under the fresh-water Miocenes upon the east side of the range. There is nothing to render this probable; and the former hypothesis, that the marine Tertiaries to the west are both Eocene and Miocene, and that Cascade Range was elevated at the close of Cretaceous time, is by far the more probable. On either hypothesis, the elevation was prior to Miocene time.

The enormous thickness of the fresh-water Miocene beds in the basin of eastern Oregon is for the most part made up of the sands, tuffs, and rapilli of Miocene eruptions which found their vent beneath the lake itself, or along the crest of Cascade Range, and buried the sedimentary hills in deluges of lavas, ending in the erection of important volcanic cones. East of the Cascades, in the fresh-water basin, there are fully 4,000 feet made up for the most part of fine volcanic ejecta, while on the immediate west side the marine Tertiaries are chiefly detrital. Since the period of volcanic eruption covered the whole range of Miocene time, it would seem necessary that a considerable portion of the marine Tertiaries lying west of Cascade Range should have been characterized by the presence of volcanic material. It is true that the prevalent wind is a west-to-east current in these latitudes, and that the fine volcanic dust and sand blown from innumerable vents along these Cascades would for the most part have drifted eastward and been accumulated in the inland lake. But enormous amounts of mud-flows and sands would necessarily have been carried away by the drainage westward. Farther south, in California, the marine Miocenes of the Coast Range are, as they should be, liberally intercalated with beds of volcanic origin. It is possible that the marine Tertiary along the western base of Cascade Range, when further explored, will prove to contain beds of volcanic origin; but until it does, and in the absence of characteristic fossils, it would seem that these beds might be considered as Eocene.

To put the geological alternatives briefly: Either, first, Cascade Range was first lifted at the close of the Cretaceous, in which case there is an unconformity between Cretaceous and Tertiary not observed in California nor in Siskyou Range; or, secondly, the uplift took place at the close of Eocene time, in which case we should expect to find marine Eocene conformably over the Cretaceous in eastern Oregon. Until evidence shall accumulate to the contrary, it is most probable that marine strata were deposited over the greater part of Oregon until the close of the Cretaceous; that immediately thereafter Cascade Range was first upheaved; and that the basin of Eastern Oregon during the Eocene was a land area having free outward drainage.

Whatever may have been the history of the region during the Eocene—whether eastern Oregon was dry-land area or a region of marine sedimentation—at the close of that age occurred a subsidence defining the long basin which, during Miocene time, was occupied by a lake from Washington Territory far south into Nevada and California.

From the Cascades and Sierra Nevada volcanic eruptions began with and continued through the entire Miocene age, pouring down upon the upheaved sandstones on the western side as lava-flows, and delivering a vast amount of material into the newly outlined fresh-water basin east of the Cascades. The great volcanic rock formation of the summit and west side of the Cascades, and the great Miocene fresh-water formation on the east, are a result of the same series of eruptions.

For the fresh-water Miocene lake which extended from the region of Columbia River, and perhaps still farther north, far south through Oregon and Nevada into California, I propose the name of PAH-UTE LAKE, since that Indian tribe with its various sub-families covers so large a portion of its area.

The beds of this lake, to which, in the Fortieth Parallel area, I have given the name of Truckee Miocene, are made up of, first, detrital rocks and gritty sandstones, with more or less conglomerate, never over 150 feet. Over this lie about 250 feet of palagonite tuff, which, for reasons already described, is referred to the age of the augite-andesites; over this, 250 to 300 feet in Nevada, with a greater thickness in Oregon, of infusorial silica, followed by 120 feet of sandy, gritty rocks, purely detrital, but containing always a considerable amount of infusorial silica, succeeded by a fresh-water limestone of about 60 feet, in its turn succeeded upward by 250 feet more of detrital grits, which give way to an enormous formation of volcanic tuffs of the trachytic period. The thickness of these trachyte muds in Nevada cannot be less than 2,000 or 3,000 feet; in Oregon, according to the observation of Professor Marsh, they are even more fully developed. It is in these volcanic muds that the enormously abundant Miocene fauna of this lake is mostly entombed. Out of the grits overlying the limestone in Nevada have been obtained teeth of a rhinoceros, probably *R. Pacificus.*

It was seen that at the close of Sioux Lake the White River Miocene beds, which represent a full equivalent, in time, of the Truckee series, were subjected to but slight mechanical disturbances. As described by E. S. Dana and G. B. Grinnell, the only physical break in the conformable series, where in Montana the Miocene are succeeded by the great Niobrara Pliocene of the Plains, is a narrow zone of conglomerate. In the Fortieth Parallel exposures on the Plains, the Miocene and Pliocene are absolutely conformable, the line being simply arrived at by the characteristic skeletons of vertebrate animals.

The condition of things at the close of the Miocene in the area of Pah-Ute Lake was entirely different. The beds of the Truckee Miocene series were thrown into bold folds, their dips reaching angles of 30°. The disturbances, therefore, which marked the close of the Miocene, were of a general gentle type in the Plains region, but show great intensity throughout the area of Pah-Ute Lake. The result of these disturbances was to enlarge enormously the lake areas in both provinces. I will first describe the outlining and development of the Pliocene lake and formations east of the Rocky Mountains.

Without any considerable local folding, the general basin of Sioux Lake was enlarged, it is probable, by gentle, wide-spread subsidence, until the new-formed lake overlapped Sioux Lake in every direction. Westward, it flowed to the very foot-hills of the Rocky Mountains; southward, from the margin of Sioux Lake in the region of northern Kansas, the lake extended itself through Indian Territory and Texas, and even into the present area of the Gulf; while northward it stretched over the whole surface of the Plains into British Columbia.

For this new and enlarged lake of the Pliocene age I propose the name of CHEYENNE LAKE.

The Miocene beds which formed the main bottom of this lake were generally in an undisturbed condition, and the deposition of Pliocene which then began, has resulted in a sheet of fresh-water rocks, having a maximum thickness of about 2,000 feet against the foot-hills of the Rocky Mountains—in other words, close to the main influx of material—thinning out eastward to a shallow group along its eastern margin in Kansas, Nebraska, and Dakota. The materials of this series are coarsest next to the Rocky Mountains, and at a distance of about 200 miles east are of extraordinary fineness. They are composed of sandstones, conglomerates, and a few marly strata next to the Rocky Mountains, with unimportant chalky limestones, and over the middle area of the Plains, far removed from the source of supply, are chiefly calcareous clays and sands of marvellously fine grain.

For the general production of this lake within the United States there was required only a gentle, uniform subsidence of the bottom of the Miocene lake, and there is no reason whatever to suppose that a period of dry land intervened over the whole province of the Plains between the deposition of the Miocene and Pliocene beds. Cheyenne Lake, in other words, was simply a wide, gentle extension of Sioux Lake.

On the other side of the continent, in the region of Pah-Ute Lake, the conditions were totally different. Severe crumpling, as already mentioned, took place, and the mountainous country east from the eastern boundary of Pah-Ute Lake, which must have been on the meridian of 117°, became depressed, so that the lake, at the beginning of the Pliocene deposition, stretched from the base of the Sierra Nevada to the base of the Wahsatch, making a surface of eight degrees of longitude. The northward extension of this lake must have been far up the upper Columbia River, while its southward extent is at present unknown.

For this lake, occupying the whole breadth of the present Great Basin, and parts of Idaho and Oregon, I propose the name of SHOSHONE LAKE.

Under the description of various Nevada localities, I have shown that the ejections of the trachytic period have furnished a large amount of the Truckee Miocene beds of Pah-Ute Lake.

It was also shown, when describing under the Miocene section a locality at the west end of Montezuma Range, that at the period of the folding up of the Miocene beds the fissures then made gave vent to rhyolitic material. The rhyolites having, as is well known, always succeeded the trachytes in their period of eruption, it would seem that their ejection marked the beginning of the Pliocene. When we come to correlate the basalts, which were the last of the sequence of volcanic rocks, with the sedimentary series, it is found that over the great Shoshone Lake a large part of the group, especially in Nevada and Utah, is subsequent to the basaltic outflows. But in the middle of the present basin of Snake River, basalts are intercalated between distinctly Pliocene strata. It is therefore evident that the rhyolites were characteristic of disturbances which separated the Miocene from the Pliocene, continuing into the Pliocene, as is shown by Niobrara fossils in stratified rhyolitic tuffs, and that the basalts are wholly within the Pliocene period, but, as regards the main massive eruptions, prior to the greater development of Pliocene strata.

Within the field of the Fortieth Parallel Exploration, in the beds of the Humboldt Pliocene, which were the deposits of Shoshone Lake, organic remains are uncommon. A few fossils discovered in the rhyolitic tuffs of Bone Valley are of species identical with those of the Niobrara beds, the deposits of the Cheyenne Lake of the Plains. There is little doubt that, with the faunal differences to be expected from regions so widely separated as those of the Great Basin and the Great Plains, fossils of Shoshone and Cheyenne lakes will be found to be strictly coeval. The same is true of the Pah-Ute Miocene lake and the Sioux Miocene lake; and the recognition of their absolute contemporaneity cannot long be delayed. For the purposes of our map, and in advance of any such detailed correlation, I have chosen to represent the four formations by different colors. It is my belief that the two Miocene and two Pliocene series are eastern and western representatives of precisely the same intervals of time.

Tertiary time in the region of the Fortieth Parallel is therefore represented by nine lakes: four Eocene lakes which occupied the middle Cordilleras in the region already described; two Miocene lakes, one in the province of the Plains, the other in eastern Oregon and western Nevada; and, lastly, the three Pliocene lakes, one of which was coextensive with a large part of the Great Basin and the drainage-system of the Columbia, and another covered the wide expanse of the geological province of the Plains from the Gulf far into British Columbia, and the third a much less important area in North Park and Platte Valley.

The following is a statement of the proposed names, ages, and sequence of these Tertiary lakes:

TERTIARY LAKES.

EOCENE.

Middle Province.

UTE LAKE (Vermilion Creek Group, King; Wahsatch Group, Hayden).
GOSIUTE LAKE (Green River Group, Hayden; Elko Group, King).
WASHAKIE LAKE (Bridger Group).
UINTA LAKE (Uinta Group, Emmons and Marsh).

MIOCENE.

Contemporaneous.

Province of Nevada and Oregon.	Province of the Great Plains.
PAH-UTE LAKE (Truckee Group, King; John Day Group, Marsh).	SIOUX LAKE (White River Group, Hayden).

PLIOCENE.

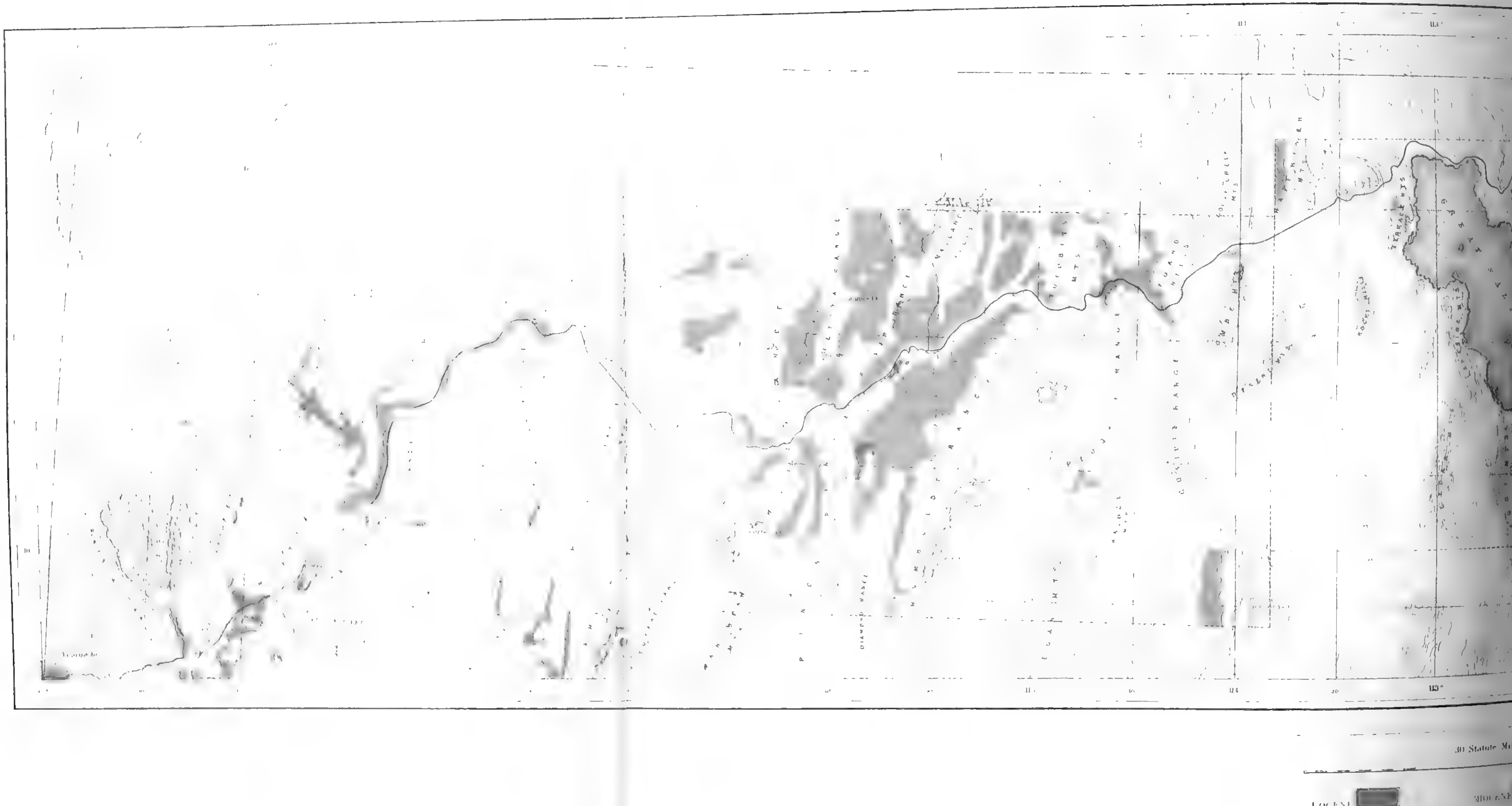
Contemporaneous.

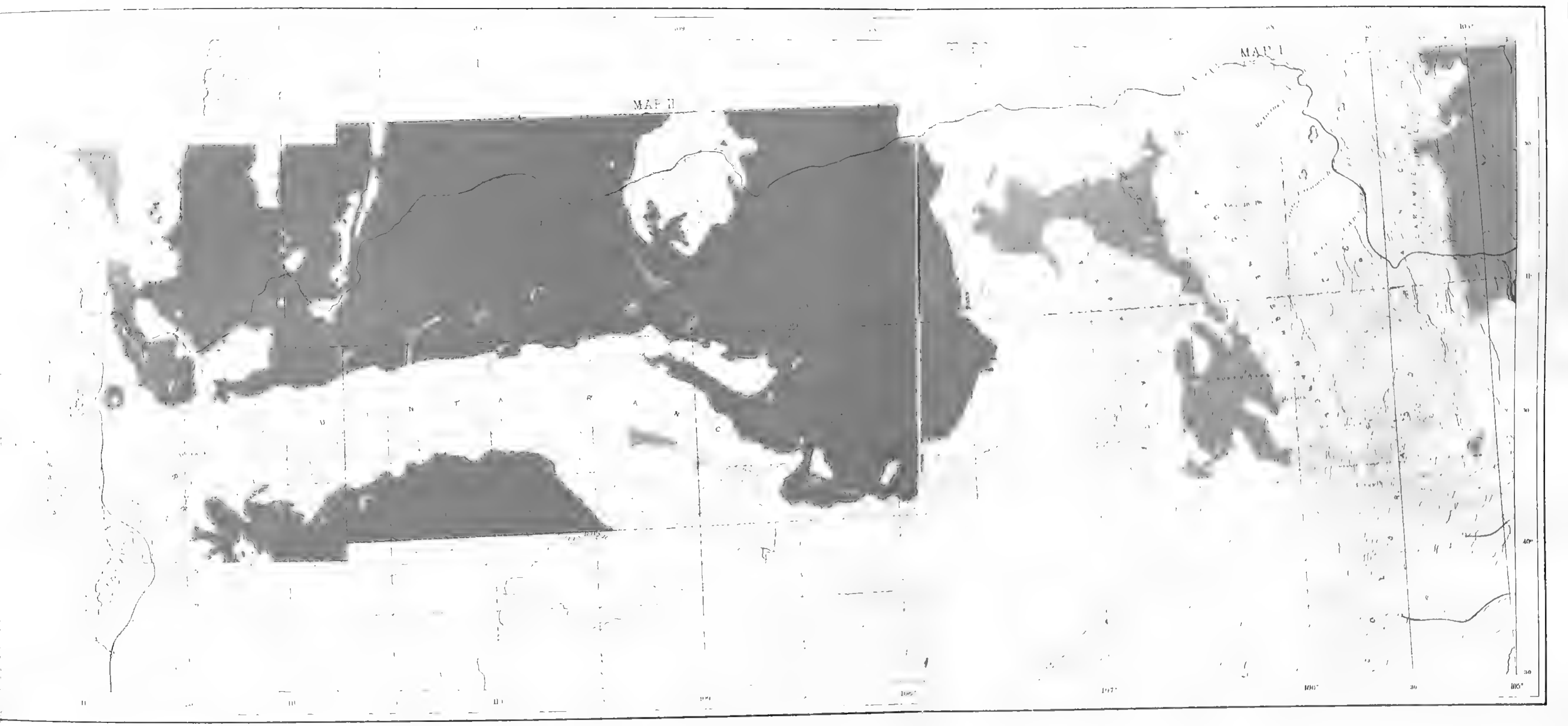
Province of the Great Basin.	Middle Province.	Province of the Great Plains.
SHOSHONE LAKE (Humboldt Group, King).	NORTH PARK LAKE (North Park Group, Hague and Hayden).	CHEYENNE LAKE (Niobrara Group, Marsh).

The value of recognizing and naming these distinct lakes is evident from the historical point of view. Within one lake of the immense area of these sheets of water, surrounded as they often were by a widely varied topographical environment, the sedimentary accumulations might, and certainly do, change from region to region. A geological explorer, finding a distinct group of rocks at one place within the area of a lake, is justified in giving it a local name. Another investigator, in a remote region of the same lake, perhaps a thousand miles away, finds a group of rocks totally distinct, but belonging to the same horizon. He gives them a new local name. For the natural and satisfactory correlation of all these integral parts of the single series of sediments of one lake, it is positively necessary to have for each lake and its conformable deposits a distinctive appellation. In the interest of this precision I have sketched and named the leading Tertiary lakes touched by the Exploration of the Fortieth Parallel. So far as my own area is concerned, the boundaries of the lakes are approximately shown by the geological colors of the maps. My hope is, that fellow explorers of this interesting field will adopt the names I have given, and interpolate in the series such other lakes as do not enter my field, and that we shall soon be able to show in historic series the complete development of Tertiary lakes.

GEOLOGICAL MAP OF THE AREA OF

TERTIARY E




MAP II
MAP I

SECTION V.

QUATERNARY.

General Remarks.—In eastern America, as set forth by Professor Dana, the Quaternary age consists of three divisions—the Glacial or Drift period, the Champlain or Depression period, and the Recent period; the last being characterized in Europe by the reappearance of glaciers. It may otherwise be considered as a glacial period interrupted by an era of subsidence and of climate less favorable for the formation of ice, in which the northern ice-field and the local glaciers retired. In the Mississippi Basin, evidence of an interglacial era, as shown by Newberry,* is found in the presence of organic beds in the Drift. Lately, in his paper on the superficial geology of British Columbia, G. M. Dawson† has divided the Quaternary age of that region into, first, a greater Glacial period, in which, over a large part of British Columbia, moved from north to south a general ice-mass, which has left its traces in scorings and groovings, in the modifications of valleys, and a Bowlder-clay; secondly, a period equivalent to the Champlain, in which the country was depressed and the Drift rearranged; thirdly, a second Glacial period, in which, however, the great southward-moving ice-mass did not reappear, but which was characterized by glaciers radiant to the local mountain systems. The northwestern phenomena, as set forth by Dawson, when compared with those of Europe, show a marked coincidence in the chain of events of the Quaternary period. It is equally evident in Europe and British Columbia that the first glacial period was the greater; that the second was limited, and its ice local. The Champlain was a period of depression and floods, and the Reindeer period a moderate second glacial period, not comparable with the first in magnitude or extent.

In the field of the United States Cordilleras, we have so far failed to find any evidence whatever of a southward-moving continental ice-mass. As far north as the upper Columbia River, and southward to the Mexican

* Report of Geological Survey of Ohio. Geology, Vol. I.

† Quarterly Journal of the Geological Society, Vol. XXXIV, part 1.

boundary, there is neither any Bowlder-clay nor scorings indicative of a general southward-moving ice-mass. On the contrary, the great areas of Quaternary material are evidently sub-aerial, not sub-glacial. The rocks outside the limit of local mountain glaciers show no traces either of the rounding, scoring, or polishing which are so conspicuously preserved in the regions overridden by the northern glacier. Everything confirms the generalization of Whitney* as to the absence of general glaciation.

Wherever in the Fortieth Parallel area a considerable mountain mass reached a high altitude, especially when placed where the Pacific moisture-laden wind could bathe its heights, there are ample evidences of former glacial action, but the type is that of the true mountain glacier, which can always be traced to its local source. In extreme instances, in the Sierra Nevada and Uinta ranges, glaciers reached 40 miles in length, and, in the case of the Sierra Nevada, descended to an altitude of 2,000 or 2,500 feet above sea-level Over the drier interior parts of the Cordilleras, the ancient glaciers usually extended down to between 7,000 and 8,000 feet above the sea. In the case of the Cottonwood glacier of the Wahsatch, a decided exception, the ice came down to an altitude of 5,000 feet.

The interior valleys of the Cordilleras, from California eastward to Wahsatch Range, are all filled to a varying depth with subaerial Quaternary accumulations. Within the system of the Great Basin, from near the Mexican boundary northward to the region of the Columbia, the general configuration is that of parallel mountain ridges, alternating with trough-like valleys. In each one of these depressions is a considerable covering of angular and sub-rounded Quaternary gravel, always of an evidently local character, directly to be traced to the flanking mountain ranges. Its coarseness varies from large bowlders, weighing many tons, to fine gravel, sands, and clay. Except where it has been rearranged in the now extinct Quaternary lakes, it is altogether an unstratified deposit, brought down by the rush of floods from the flanks and cañons of the mountains. It not infrequently banks up against the foot-hills of the range from which it was derived, making a fringing deposit of from 1,000 to 2,000 feet in height, skirting the range for many miles with an inclined talus-slope. The most modern

* Proceedings of the Academy of Natural Sciences of California, 1868.

erosion has not infrequently cut the mountain cañons sharply down below the old talus-profile, wearing a narrow cut through the top of the Quaternary slope, exposing sections of gravel from 50 to 200 feet in depth

Wherever these talus-slopes are opened, they are found to be made of a confused pile of sands, gravels, and bowlders, in which angular chips are the predominating ingredient. Where, as is common over a large part of Utah and Nevada, the flanking hills are made up of limestone, the harder fragments of siliceous or granitoid rocks are closely cemented by a calcareous tufa-like formation, which unites the whole into a sort of breccia.

Not more than a thirtieth part of the entire surface of the Fortieth Parallel area was ever covered by glacial ice. Analytical Map V. accompanying this section shows the actually glaciated areas in blue spots. It is characteristic of the cañons of these extinct glaciers that they give evidence of a gradual recession of the ice from its greatest extension until it entirely melted. This retiring from its greatest bulk was not a continuous retrogression, but was marked by pauses at certain places long enough to permit the accumulation of considerable terminal moraines. In ascending one of the larger cañons, as of the southern Uinta, there is observed a series of successive terminal moraines, and in passing to the upper heights of the ranges it is found that in the great snow amphitheatres, glacial markings, rock-polishing, and the arrangement of morainal matter are evidently fresher than in the lower levels or points of greatest extension.

Since there was no northern Drift, if glaciers existed both in the first Glacial and in the second or Reindeer period, it is evident they must have occupied the same valleys; in other words, that the perpetual snows which hung about the crests of the *névés* after the disappearance of the main glaciers, during the Recent period encroached downward and pushed their ice-streams part way down the channel of the earlier glaciers. Furthermore, since the whole interior has been during the Quaternary period free from Drift and wholly isolated from the sea, proof of the two ice periods must be sought in other evidence than that displayed over the actual glacier-beds. As will be seen later in this section, the evidence of two periods of precipitation, with a drier interval, is found in an entirely distinct set of facts.

The present distribution of perpetual snow indicates islands of climate whose temperature and moisture combine to conserve permanent snow-banks. These present snow-fields, which in all cases are seen to linger about the amphitheatral sources of extinct glaciers, fail to prove that the relative glaciation, or rather the relative annual accumulations of snow, occurred in exactly the same quantitative distribution as at present. The traces of existing glaciers, their extent and thickness, and the low altitude to which they descend, are not found to be exactly proportional to the amount of snow now preserved.

In March, 1871,* I announced the discovery of actual glaciers now existing on the mountains of the Pacific slope; meaning true glaciers, not moving masses of *névé* upon the steep slopes of the upper mountain flanks, but actual trunk bodies whose motion was not wholly the result of steepness of slope. The southernmost point at which living glaciers are now found is about latitude 41° 21′, at Mount Shasta, in the Sierra Nevada. Mounts Hood, Adams, St. Helens, Rainier, and Baker also bear true glaciers, which descend into the subjacent country to lower altitudes according as they are supplied from more or less extensive *névés*, or occupy mountain slopes successively farther to the north.

Altitude alone, or northing alone, is not enough to produce a glacier descending far into the lowlands, since a steeper slope and a wider *névé* will converge more ice and force it farther down into the lowlands, upon a more southern peak, than a more gentle slope and a smaller amphitheatral source farther to the north.

The existing glaciers represent the relics of the former great system; and if the present climatic distribution were relatively the same as during the Glacial period, the few regions which now bear existing glaciers should represent the points of greatest glaciation during the ice period. If the comparison of the existing glaciers with old ice-tracks proves that the greatest former glaciation did not coincide with the points where glaciers now exist, then in the former distribution of temperature and moisture other conditions must have interfered. Perhaps observations have not been carried far enough to make my conclusion final, but I am now of the opinion

* American Journal of Science and Arts, third series, Vol. I.

that present points of actual glaciation were not points of maximum glaciation during the ice age.

For instance, valleys of the Uinta and Sierra Nevada show extinct ice streams thirty or forty miles in length and from 1,000 to 3,000 feet in depth, and although the peaks are among the most elevated in the West, there are no existing glaciers. On the other hand, the now glaciated flanks of Mount Shasta, while they show a former extension of glaciers greater than the existing ones, do not give evidence of a system comparable in magnitude with that of the southern Sierras.

It is not proposed here to discuss the cause of the great climatic change which ushered in the Glacial period. Beyond the great change of level immediately preceding glaciation, and the sudden diminution of Pliocene water-surface, there is nothing observed within the Fortieth Parallel area which throws the slightest light on this difficult question. Certain it is that no change in the relative expansion of land and water could have had any considerable effect in producing the extra precipitation necessary to bring about the glaciers. On the contrary, between the Pliocene and the Quaternary, all the actual features of the country seem to favor greater precipitation during the Pliocene, for the general climate was warm enough to tolerate palms, while at the same time the enormous water-surface must have given place to far greater evaporation than during the Quaternary. Although extremely restricted and absolutely local, the Cordilleran glaciers of our latitudes were undoubtedly the local expression of the general changes of climate which elsewhere produced the great ice-fields.

The first and most interesting question which appeals to a student of this region is, why the northern ice-cap described by Dawson failed to override the mountains of the middle Cordilleras and reach a latitude where the average annual condition of temperature is equivalent to that of the southern margin of the glaciated region of the eastern States. Why, in other words, were the eastern and western halves of the continent so dissimilarly glaciated?

Since Dawson's observations of a general southward moving ice-field in British Columbia, there are no new facts showing the source of that glacial sheet, or establishing any connection between it and the Drift-covered ground in the Mississippi Basin. Until both these questions are solved, generalizations as to the points of similarity and difference between the two sides of the continent during the Glacial age cannot be safely made.

Regarded from the mere point of view of temperature, it is natural enough that the non-Drift-covered region should extend farther north on the western than on the eastern border of the continent, as do the isotherms. Opposed to this is the enormous amount of moisture which the eastward moving Pacific winds must have gathered from the evaporation of the warm floods of the Japan Current, and constantly poured over the elevated continental border, but which in the period of glaciers did no more south of latitude 48° than to maintain the system of local ice-streams. If the eastern Mississippian and Atlantic border ice-sheet was, as I believe, of Greenlandic origin, it is difficult to explain why such vast accumulations of snow should have occurred, as compared with the west coast of Alaska, where the altitudes are great and the amount of moisture furnished by the Japan Current must have been far greater than the Gulf Stream could have thrown upon Greenland. The colder latitude of the latter place is the probable cause of the difference.

Whatever the greater causes may have been, the Cordilleran surface south of Washington Territory was free from an ice-sheet, and the only ice-masses were small areas of local glaciers which did not cover two per cent. of the mountain country.

Supposing the Arctic land configuration to be as now, and a new oscillation of climate to bring on the conditions of a glacial period, it is certain that the present ice-masses would form the nuclei of new northern ice-fields, and Greenland would probably be the point from which the glaciers would move southward to cover eastern America, and the absolute distance from such a centre would have something to do with the failure of the ice to override the Cordilleras. Dawson's suggestion of a great centre of dispersion in Alaska, where an elevated and broad highland fronts the moisture-laden ocean wind, has, it seems to me, a high degree of probability in accounting for the southerly moving ice of British Columbia without recourse to that refuge of pure imagination, a polar cap.

Supposing a low country like that of the average Mississippi Basin to extend westward to the Pacific during general glaciation, the southern boundary of the continental glacier would be determined by isothermal lines and direct distance from the source of supply. The heat-lines would curve northward very much as they do now, only in the absence of high mountains a given line would swing farther to the north on approaching the Pacific Ocean. The effect of the high portions of the Cordilleras is, of course, to bring a cooler climate farther south; in other words, to deflect the isotherm to the south of what its position would be in the absence of the extreme heights. The peculiar condition of the Cordilleras in the United States is such that, while the lower altitudes possess a comparatively warm climate, owing to the general thermal condition of the Pacific slope, the detached, elevated ridges and high, isolated peaks are islands of cold altitude-climate. Generally, then, it is a comparatively warm region, interspersed with islands of high-altitude cold. But for these elevations, therefore, there would have been no glaciers whatever below the parallel of 48° over a great region whose equivalent latitudes in New England, Canada, and parts of the Mississippi Basin were covered with a general ice-sheet thousands of feet in thickness.

Between the phenomena of the Champlain period in the East and West there are equally characteristic differences. Owing to the average profile of river grades in the East, the gravels, sands, and pebbles which were washed down from the surrounding country accumulated in the valleys, filling them full of deposits often hundreds of feet thick. There, too, at the close of the Champlain came a single great flood, and the phenomena of continental subsidence are distinctly observable.

In the Fortieth Parallel area the general abruptness of mountain masses gave to the stream-beds such steep slopes that, instead of being areas of deposition, they were regions of terrific torrents, whose carrying power was sufficient to prevent accumulation, and whose freight of moving rock was enough to erode the great system of cañons. There was no single final flood, such as Dana in his treatment of the New Haven Quaternary has demonstrated, and no *moraine profonde* left by the melting of a general ice-cover to furnish a ready-made source of detrital material. Lastly, excepting the slender evidence of Quaternary depression, adduced by Gilbert in his Lake Bonneville description,* the middle Cordilleras as yet afford no proof of Champlain subsidence.

So, too, the Recent period has failed to record itself in the Fortieth Parallel region in a well defined system of river terraces, as in the East or in British Columbia.

Since in the West the Champlain-period rivers cut cañons and threw their detritus into valley basins instead of filling river valleys, there are only in the cases of rare topographical exceptions those great fluviatile accumulations of gravels and sands in which the shrinking streams of the Recent period could record their recession in terraces.

In the East the floods of the Champlain were due in great measure to the melting of the northern ice-field, not wholly or in prominent part to the rain or snow of local water-sheds.

Over the Cordilleras, there being no ice-cap, the Champlain floods were derived from the local glaciers and the summer melting of mountain snows.

In the East the glacial, Champlain, and Recent periods have ceased. Over the Cordilleras the work of all three periods is still progressing, albeit at a greatly reduced rate.

In the latitude of this Exploration, owing to the absence of a great south-moving ice-field, the later local glaciers of the Reindeer period, if they existed at all, could not record themselves as the only system radiant to the local mountain groups, and thus distinguish themselves from the ice-streams of the earlier and greater Glacial period. Since in this region both must have occupied the same mountain valleys, we are yet without satisfactory grounds for separating the work of the two systems.

It is therefore not practicable to treat the Quaternary age, as a whole, after the manner of writers on the phenomena of this interval of time in eastern America.

The features of Fortieth Parallel Quaternary are—

1. Glacial phenomena.
2. Erosion and cañon-cutting.
3. The sheet of subaerial unstratified gravel and sand, which is a wide-

* United States Geographical Surveys West of the One Hundredth Meridian, Vol. III.

spread deposit covering all regions of interior drainage except the areas of Quaternary lakes.

4. Quaternary lakes and their horizontal deposits now exposed by the desiccation of their areas.

5. The chemical reactions, and deposits due to lacustrine desiccation and pseudomorphism.

6. Modern and now forming débris of high mountains.

7. Æolian erosion, still continuing.

These are often so interdependent in time and in operation that it is best to treat them somewhat in combination, rather than categorically.

Extinct Glaciers and Cañons.—Upon Analytical Map V. accompanying this section are seen in blue, indicated in a general way, the areas formerly occupied by glaciers. The high part of Colorado Range, which enters the map a little south of the parallel of 40° 30′, gives evidence of having been covered with glaciers for a breadth of about sixteen miles. From the forms of the peaks it is clear that large accumulations of *névé* snow covered all the spurs and ridges, while the valleys themselves are clearly modified by the abrading effect of the glaciers. As far north as the high group continues, namely, up to a point abreast of North Park, a distance of about twenty-five miles from the southern limit of our map, the whole summit was clad with glaciers.

Large trunk streams descended the cañons of both branches of the Cache la Poudre as low as 6,500 feet in altitude. Down the Big Thompson from Hague's Peak they descended to the same level, if not a little lower, and along a branch of the Big Thompson from Long's Peak and in the region of Estes' Park to about the same level. West of Long's Peak, with an important tributary from Mount Richthofen, the upper glacier of Grand River reached to the foot-hills of Middle Park.

The depressed region of Colorado Range included within the Laramie Hills was evidently at too low an altitude to act as a powerful condenser, and is absolutely free from glacial traces. That it had prominent snow-banks, and that much of the erosion is due to the influence of the cracking power of frost and the dislocation of blocks by the sudden expansion of the waters filling the minute surface-fissures, is doubtless true, but there were no glaciers.

So, too, the depression along Medicine Bow Range, north of Mount Clark, shows only the most superficial effect of snow-work. Medicine Bow Range is entirely devoid of true glaciation, except in the immediate vicinity of Medicine Bow Peak, where the single high crest formed a centre of moisture-condensation, giving rise to rather limited local glaciers, which descended each of the valleys to an altitude of probably 8,000 feet.

From a little north of Clark's Peak southward to the divide between North and Middle parks the foot-hills of North Park are covered with the terminal-moraine material of the system of glaciers which poured down the western slope of Colorado Range and actually pushed out upon the comparatively level floor of the Park.

Park Range, as indicated by the map, shows a glaciated region about sixty miles in length, with an average width of ten miles. On the eastern flank the ice descended to the level of North Park, and the whole foot-hills for a distance of fifteen or twenty miles are composed of accumulations of terminal moraine, which are built out in some instances two miles beyond the true rocky foot-hills, and 1,000 feet high. The average elevation to which the glaciers pushed down was about 8,000 feet. In the case of Park Range, there was neither a broad exposure of the elevated mass, nor the actual altitudes of Colorado Range in the same latitude. In consequence, the glaciers never descended to a lower altitude than 8,000 feet, or, at the lowest, 7,600 feet; while from the superior dimensions and altitude of the *névés* of Colorado Range, the trunk glaciers were pushed down in particular cases to 6,500 feet, more than 1,000 feet lower than those of Park Range.

The three bodies—the Colorado, Park, and Medicine Bow—present very similar phenomena of glacial erosion. The amphitheatres are all deeply sculptured in characteristic, round forms, the upland-valley bottoms are entirely occupied by smoothly abraded surfaces or *roches moutonnées*, and both main and lateral cañons have the ship-like section characteristic of glaciated regions. Owing to the narrowness of the ranges, the lateral cañons are exceedingly short, but they make up for their limited extension by an imposing depth. The Medicine Bow cañons are somewhat the shallowest, never exceeding 2,500 feet. Those in Colorado Range, in the region of Long's Peak and Mount Hague, reach in extreme cases 3,500 feet.

Considerable portions of the Archæan cores of these ranges have remained as islands above the limits of the sedimentation since pre-Cambrian time. The masses have therefore been subjected from that ancient date to degradation, either by surrounding oceans or by subaerial erosion, where lifted above the ocean limits. It becomes a question of great interest how much of the deep-cañon sculpture which now exists was due to the erosion of the Glacial and Champlain periods, and how much to preëxisting effects. Whatever of the Archæan islands were lifted above the general level of the Mesozoic sea must have risen to a considerably higher level than at present. If erosion had had the effect of producing cañons prior to the Glacial period, it would seem as if these cañons must have left some traces. That there were no great cañons in the Archæan hills prior to the deposition of the Palæozoic and Mesozoic, is shown by the contact-planes of the various members of the stratified series, which display smooth, broad slopes of the original Archæan. The few irregularities of contact are due rather to gentle round projections of the Archæan than to such sharp reëntrant angles as would indicate cañons.

In the region of our portion of the Rocky Mountains, volcanic outbursts are of such infrequent occurrence and limited extent that the evidence of continuity of cañons down the Archæan slope and across the volcanic masses is wanting. In the Sierra Nevada and Cascade Range, where many of the highest peaks are altogether formed of lavas, and where the older mass of the range has been frequently deluged with broad, volcanic sheets, evidence is abundantly conclusive that the period of cañon erosion has been in great measure since the basaltic epoch, and that, as we have abundant proof, was within the limits of the Pliocene age. As Whitney has shown, deposits of Pliocene, themselves buried by basalts, have been cut through by the great cañons of the Sierra Nevada, and left on the tops of the modern cañon walls 3,000 feet above the present river-level. The pre-Pliocene drainage-lines seem never to have been other than broad, comparatively shallow river-valleys, in nowise approaching deep, abrupt cañon forms.

In passing westward from the Rocky Mountains, the next and by far the greatest accumulation of glaciers in our area is indicated as covering the whole lofty part of Uinta Range, from longitude 109° 30′ to 111° 15′, and extending north and south with an extreme limit of 50 miles. Upon the great plateau-like summit of the Uinta, which, at the time of the coming on of the Glacial period, cannot have been less than 15,000 to 17,000 feet high, immense masses of snow accumulated, which have produced upon the nearly horizontal summit-region of the range very peculiar topographical effects. On the north side the glaciers descended to an extreme level of a little above 8,000 feet. Bear River and Smith's and Black's forks show well defined glaciation and moraine material down to between 8,000 and 9,000 feet. Since the actual topographical summit of Uinta Range was along the northern edge of the broad, plateau-like upland, a greater glacier-shed was exposed to the south. In consequence, the glaciers on that side descended on Ute, Lake, and Du Chesne forks to elevations varying from 6,500 to 7,200 feet. As is roughly indicated by the blue color upon the accompanying map, several of the trunk glaciers projected beyond the general *névé* region, both on the north and south sides of the range, from ten to twenty miles.

The Uinta field was therefore comparable with the present Alpine system, but decidedly grander in its accumulation of snow and ice. Over the greater part of the upland the quartzite and sandstone series, which form the summit of the Uinta, are inclined at no greater angles than 5° to 6°. In this comparatively horizontal position the glacial erosion has cut almost vertically down through the beds, carving immense amphitheatres, with basin bottoms, containing numerous alpine lakes. The whole appearance of these broad, smooth-curved cañons is as if a glacier had melted out very recently. The minutest striations and polishings are well preserved. The final débris which was dropped when the glacier melted, rests where it fell on the bare and polished rock surfaces; accumulations of lateral moraine are observed in points of topographical shelter; and but for the forest and late accumulations of meadow-land, the whole region would wear the aspect of having been just dispossessed of its glaciers.

Here, as in the cañons of the Rocky Mountains, the post-Glacial erosion has done an absolutely trivial work. Modern streams which occupy the beds of these old glaciers have worn insignificant shallow troughs in the smooth valley-bottoms; but, owing to the average gentleness of the inclination of these cañons, these extremely rare cuts never exceed 10 or 20 feet, and amount to nothing as topographical features. Compared with the work of the real cañon-cutting age, the erosive force of existing streams is as nothing.

Along the lower course of the cañons terminal-moraine material is observed, but never in such remarkably thick, conspicuous accumulation as in the parks of Colorado. On the contrary, lateral moraines are far more developed here than in our section of the Rocky Mountains. On the south side of the Uinta are trains of moraines extending many miles in length, and flanking valleys whose bottoms are from 2,000 to 3,000 feet below the top of the moraine. In the horizontal Uinta strata the walls of the upper amphitheatres occupied by the former *névés* are steeper than the corresponding walls of granitic regions. The ridges separating amphitheatres are much thinner, and erosion, while it seems to be no deeper, acted more vertically. The narrow intermediate ridges which separate the present amphitheatres show upon their walls the distinct horizontal bedding of the sandstone and quartzite.

While post-Glacial stream erosion has done little or nothing in this country in the way of cutting cañons, the frost and ice work of the summit has been immense. The whole peak region is seen to be riven with innumerable cracks, which are evidently not the result of fault or of fissure at the time of upheaval, but belong to that class of shallow, interlacing cracks which are due to unequal superficial expansion and contraction in a region alternately chilled by radiation and warmed by the sun.

Upon the steep slopes and sharp, blade-like ridges, the results of such fissuring, together with the leverage of expanding ice, have the effect to dislodge large fragments of rock and produce immense slopes of débris. The shapes of this débris are altogether angular, showing in no case any of the effects of attrition seen upon the bowlders which have been embedded in the bottom of a moving glacier, even for a short distance, or such as have been grated together in the motion of lateral moraines. That this débris is altogether since the last Glacial period, is evident from its angular and unstriated character and from the essential difference which it displays from the true Glacial débris to be seen everywhere in the middle of amphitheatres resting upon the *roches moutonnées.*

This shattering action is evidently quite analogous to that which takes place in exposed rock at high altitudes in countries now glaciated, and which is the source of all morainal materials. The arrêts of the Alps, and in general all the exposed portions of rocks in glaciated countries, are subjected in like manner to the disintegrating forces of extremes of temperature and ice. That this action is now progressing, is proved by the constant dislocation of blocks through the high mountain regions of the Cordilleras at all hours of the day, but especially when a sudden chill (as during the hour after sunset) has the effect of congealing the percolating waters.

Upon the summits of the Rocky Mountains, the Uinta, and Wahsatch, and at very many points of the ranges near the Pacific coast, I have heard during the day thousands of blocks dislodge themselves and bound down the slopes. It is evident that such accumulations of débris during the occupancy of the glaciers would either work down and be embedded in the under surface, or, if escaping fissures, would be disposed along the sides and surfaces in the form of transported rocks and lateral moraines. Hence these enormous accumulations must be considered altogether post-Glacial; and throughout the Cordilleras, in all the high mountain ranges, they form a very conspicuous feature. In many instances they must amount to fully 1,000 feet in thickness. In the Sierra Nevada, where all these phenomena are on a grander scale, I have seen débris-slopes measuring 4,000 feet from top to bottom.

The transportation of material by the modern rivers of the Uinta is comparatively slight. Decay of rock material is also extremely slow, and its products, gathered in the various alpine meadows, represent a comparatively insignificant total. But the gradually increasing débris-slopes are telling seriously on the mountain forms. Already many of the dividing ridges in the Uinta upland are nothing more than blades of rock, with débris-trains on both flanks covering the whole mass of the solid rock. It is easy to see that this disintegration and tumbling down of detritus will continue until the solid ridges are shattered and made over into débris-piles, and the whole summit will be nothing more than ridge-like piles of débris separated by broad basins, in whose unencumbered medial portions the old glaciated surfaces of rock will be shown. Of course the rapidity of this action would altogether depend upon the texture and structure of the rock upon which these forces are exerted. The loose, quartzitic sandstones of which the Uinta highlands are formed, offer exceptionally easy conditions; but in the more solid and less jointed bodies of Sierra Nevada granite the action is quite as intense, owing probably to the greater extremes of temperature to which that region is exposed.

Accumulations of terminal moraines in the Rocky Mountains, although found at successively higher positions upon the bed of the old glacier, thus indicating a gradual recession of the ice-mass toward the summit region, do not display the same well marked paraboloidal forms and sharp crests which are shown in the successive cross-ridges of the glacier-beds of the Sierra Nevada.

In passing down ice-fed streams, the fine material which is the result of abrasion by the bottom of a glacier must have distributed itself either in Quaternary lakes or else passed onward to the sea.

In every great glacier-bottom of the Uinta there are the characteristic glacier lakes and meadows, hollows scooped by the extinct glacier, which, upon the final melting of the ice, were rock basins filled to the brim with the waters of the melting perpetual snow, and which have subsequently been more or less silted up with the fine sand of the region, filling the lake and resulting in those open bits of verdant meadow which are such a characteristic and beautiful feature of Cordilleran glacier-valleys. The process of silting up these lakes is slowly going on; and here on a minute scale is seen the whole principle of delta formations, silt and vegetation combining to build out as complicated and characteristic deltas as those of the Mississippi or the Nile.

A glance at the glacier designation upon Wahsatch Range in the accompanying map will show three spots of color indicating the former existence of ice. The high group at the head of Cottonwood and American cañons had an extension of twenty miles from north to south, by at least ten in the direction of the cañons. Mill Cañon, Cottonwood, Little Cottonwood, and American Fork had their glaciers, which have left ordinary U-shaped valleys and characteristic traces of ice-abrasion and accumulation of morainal material.

The valley of the Jordan at the western base of the Wahsatch is but a few feet above the level of Salt Lake. In consequence, the narrow Wahsatch Range, which rises to an elevation of about 12,000 feet, has upon its westward slope a steeper and deeper declivity than is seen elsewhere in the Fortieth Parallel area, and hence down these steep slopes the glaciers, though limited, pushed to a lower level than upon the Uinta or Rocky Mountain slopes. The glacier of Little Cottonwood came down to an elevation of 5,000 feet, or nearly to the mouth of the cañon, and its terminal-morainal material covers nearly the whole gate of the gorge.

On the eastward slope, toward Provo Cañon, ice was confined to the higher summit regions, and down the eastern side in general there were but slight local glaciers. Along the upper tributary cañons which feed Cottonwood and Little Cottonwood cañons, the glaciated surfaces are distinctly shown wherever the rock has a position and character fitted to retain them.

Here again the slopes of débris, though not on so large a scale as in the Uinta Mountains, are a prominent feature of the topography, and are rapidly progressing toward the obliteration of the solid parts of the mountains. In the case of granite bodies here, this disintegration is less rapid than in the quartzites and other distinctly bedded formations. Even in the hardest granites, however, it is rapidly progressing, and, as in the Uinta, the final obliteration of the solid ridges is only a question of brief geological time. From this should always be excepted those vertical precipices due to faults and fissures, whose contour protects them from disintegration.

Farther north in the Wahsatch we have observed two minor localities, one east of Farmington and the other on Ogden Peak, in both of which glaciers were present; and although they piled up a considerable amount of morainal débris on the eastern slope of the range, they nowhere descended below 7,000 feet, and perhaps not below 7,500. The actually lowest point of descent is difficult to determine, owing to the disintegrated Tertiaries and the more recent accumulation of modern material over the moraines. They are, however, of no special scientific interest.

The glaciers of Humboldt Range were confined to two regions, one the high group lying west and northwest of Franklin Lake, and the other the detached elevated mass north of Sacred Pass, in the region of Clover Peak and Mount Bonpland. At both of these points the summit of the range gives ample evidence of glaciation. The upland amphitheatres, owing to the narrowness of the ridge, never have the broad, flat bottoms characteristic of wider ranges. On the contrary, each glacier sloped rapidly from the head of its *névé*, and developed at once the deep, ship-like section. The glacier of the South Fork of the Humboldt, which descended along the western side of the range, carved cañons over 3,000 feet in depth. Standing at the top of the South Fork *névé*-slope above Lake Marian, and looking down the curved course of the ancient glacier, the cañon flanks and bottom are seen to be everywhere smoothed down to a general graded slope, to be more or less encumbered by the general débris which was deposited when the ice finally melted, and to show here and there more or less *roches moutonnées.* In general, the *roches moutonnées* over the whole of the Fortieth Parallel exposures are less frequent than broad, flat, smooth-polished surfaces. The glacier of the South Fork, which descended perhaps lower than any other in the range, being much the greatest, reached an altitude of 6,500 feet. Along the eastern side of the range, particularly in the Mount Bonpland region, the sharp eastern slope is deeply carved by rounded amphitheatres having nearly perpendicular walls. In this northern group of glaciers the rocks upon which they acted were of gently westward dipping beds of gneiss and quartzite. As a consequence, the nearly horizontal eastern edges were exposed along the eastern slope of the range, and the cañons carved down these edges in sharp, almost precipitous faces, while in descending on the west they followed the backs of the strata and carved less deeply. The gorges on the west, coming down from Mount Bonpland and Clover Peak, rarely show a depth of over 1,000 feet. The eastern foot-hills are encumbered with glacial débris, both under Mount Bonpland and in the region of the Overland Ranch.

Standing upon any one of the high summits of the glaciated regions, it is interesting to look down upon deeply carved glacial valleys which open out upon the plains on either side, having in their bottoms innumerable glacial lakelets which reflect the dark blue of the sky and contrast strangely with the gray glacial wreck and morainal material and the dusky alpine vegetation. In the northern, or Mount Bonpland group, the rocks, having a more compact, solid texture, are more easily converted into débris piles, while in the southern region, owing to the readier decay of the granitoid mass, there is more fine gravel and less sharp, angular débris. Upon a rock which easily crumbles it is evident that the cracking force of sudden contraction would have a minimum effect; and there is no glaciated region within the Fortieth Parallel limits where débris plays so limited a rôle as in the region of White Cloud Peak and Lake Marian. Even here, however, there are some slight débris slopes, which are of course referred to post-Glacial disintegration.

West of Humboldt Range the points of actual glaciers are but three, and they amount to absolutely nothing as geological phenomena.

At Shoshone Peak, at Quiednanove or Star Peak in the West Humboldt, and on the high summits of Granite Springs Range north of Mud Lake Desert, are isolated points sufficiently high to act as slight condensers, and to have developed insignificant local glaciers. In no case did the ice of these points descend below 7,500 feet.

The lowest points, therefore, to which a glacier of the Fortieth Parallel descended were in Little Cottonwood Cañon, 5,000 feet above sea-level, and on Ute Fork on the south side of the Uinta Mountains, where the ice reached 6,600 feet. Upon the grander slopes of the Sierra Nevada, in latitudes somewhat to the south of the Fortieth Parallel, glaciers forty miles in extent poured down the great cañons of the Sierras to an altitude of certainly not more than 2,400 feet, and possibly to still lower levels. The superior size and importance of the Sierra glaciers are due not alone to the greater altitude of the *névé*, or to a wider extent of tributary surface, but also to a climatic difference, which may be observed even now between the Sierras and the interior ranges.

While the blue color on the accompanying map shows the distribution and extension of actual glaciers, it presents absolutely no indication of the snow-distribution of the same period. With the exception of the three detached localities in western Nevada, the glacier localities exactly represent the present regions of perpetual snow; that is to say, at the head of each one of the cañons of extinct glaciers are banks which are fragmentary relics of the old *névé*, varied annually in their depth and extension. Owing to the frequent slight oscillations of climate, these snow-fields either advance or shrink from year to year, the residual autumnal bank showing very great variation.

On highly inclined slopes, where the snow accumulates to a considerable thickness and solidity by pressure and regelation, it compacts itself into a quasi-icy mass, and on sufficiently inclined slopes develops a downward motion. Motion alone, however, does not constitute a glacier, since, as is well known, all the *névés* of true glaciers possess a motion.

Mr. Muir, in his studies of the high Sierra Nevada, has been frequently announcing the discovery of glaciers, based on simple evidence of motion. Years before he entered the Sierra Nevada, his identical snow-fields were studied by several members of the Geological Survey of California, and their motion was as well known to them as to him. It is a nice matter to draw the line between a well compacted moving *névé* and an actual glacier; but the distinction is a true one.*

All the snow-banks of the Fortieth Parallel, when on slopes of over 20°, possess the characteristic interior motion of glacier ice. But they are nothing more or less than the remnants of *névés*, and in extraordinary seasons all of them are obliterated. In the dry season of 1864–'65 the writer examined many of the regions since described by Mr. Muir in the Sierra Nevada, and in not a few cases his so-called glaciers had entirely melted

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*Agassiz, in his *Étude sur Les Glaciers*, page 43, says, "La limite superficielle entre le glaccier et le névé est là où la glace de la surface passe de l'etat compacte ou sub-compacte à letat grenu." And again, on page 44, "Le passage du glacier au névé n'est moins que tranché à la surface; il dépend en beaucoup de cas de la position du glacier, de la vitesse de sa marche, et d'une foule d'autre circonstances. M. Desor a eu l'heureuse idée de chercher un moyen plus sûr d'en apprécier la limite, et il a trouvé que celle-ci ne commencent à surgir que là où la glace a acquis une certaine consistance; car, comme nous le verrons plus tard en traitent des moraines, il n'y a que la glace compacte qui soit susceptible de pousser les blocs à la surface; les névés n'en sont pas capables, à cause de leur incohérente. L'apparition des moraines à la surface du glaciers indiquerait ainsi la limite certaine entre les glaciers proprement dits et les névés."

away. The absurdity of applying the word "glacier" to a snow-mass which appears and reappears from year to year will be sufficiently evident.* All winter snow-fields move when on a sufficiently inclined slope. I have seen the winter snows, averaging six or eight feet deep at the Emma Mine, in the Wahsatch, move down the mountain flank with such power as to overturn and crush strongly constructed buildings; yet these same fields promptly disappeared on the approach of summer, and gave way to abundant herbaceous vegetation. Motion alone is no proof of a true glacier.

Since so small a fraction of the Cordilleras was covered by ice during the Glacial period, it becomes an interesting question to determine what were the conditions and geological operations during the Glacial period in those parts of the country which were not subjected to actual glaciation. While the U-curved cañons are absolutely confined to the demonstrated tracks of glaciers, other cañons shaped like a V, due unquestionably to aqueous erosion, are traced down the less elevated parts of the same ranges on which glaciers occur, and also on all ranges of any considerable elevation in the Cordilleras. As to the U cañons, it is evident that they were either excavated by the glaciers themselves or else were preëxisting gorges modified and given their present cross-section by the rocky under-surface of the glacier. That they were not Tertiary, is evident from the fact of their being cut in many places through the basaltic flows which were clearly of late Pliocene. It is evident that the cañons post-date the most recent volcanic outpourings of the Fortieth Parallel. Recent volcanic activity, producing lava streams later than the cañons, and even flowing down the cañons, is described to the south of our work by J. W. Powell; but such phenomena do not occur in the field of this work.

Cañons, as before remarked, occur upon all the ranges, as well in non-glaciated as in glaciated regions, the only difference in their phenomena being the rounded cross-section of the glacial cañons, and the broad, amphitheatral forms at their heads, and the V shape of water-worn gorges. In

* It is to be hoped that Mr. Muir's vagaries will not deceive geologists who are personally unacquainted with California, and that the ambitious amateur himself may divert his evident enthusiastic love of nature into a channel, if there is one, in which his attainments would save him from hopeless floundering.

instances of long glacial cañons which descend to levels considerably below the terminations of the ice-limit, the cross-section of the cañon changes rapidly from a U to a V shape. The continuity of single cañons changing from the U to the V section shows, either the synchronism of the two forms of sculpture, or that the round-bottomed upper parts of cañons are later modifications of the V gorges. All the sharp cañons in the non-glaciated parts of the ranges, and in ranges which were always wholly destitute of glaciers, are the result of the eroding power of torrents derived from the immense precipitation of the Glacial period.

In the sculpture of the summits and peaks of the non-glaciated ranges is also clearly to be seen the action of *névé* erosion, in the easily recognizable ice-work which results in amphitheatres. An examination of all the peaks of our region shows a majority having a sharp side to the north and east. This, of course, is true only where erosion has been the dominant force in producing the shape of the peak. In the case of faulting and unusual local toughness of strata, as also in those rocks which easily disintegrate instead of splitting asunder from the effects of cold, there is no recognizable preponderance of steep faces to the north and east.

The greater part of the ranges within the Fortieth Parallel area are traced approximately from north to south, and it is easy to see that upon the shaded or north side of the peaks, ice would remain longest and continue longest to do its shattering work. But the equal number of steep faces to the east is to be accounted for by another set of causes. The dominant wind over the whole Cordilleras is the return trade, which blows from a little south of west and unloads its moisture during the seasons of precipitation on the higher parts of the ranges. Owing to the velocity of this wind, a greater amount of snow falls in the eddy on the eastern or lee side of the ranges than on the windward side, and in consequence the snow-banks on the eastern summits are thicker and linger longer into the summer than those on the western. That the north and east sides of mountains have been most snow-burdened, and hence most glaciated, is very clearly shown on such peaks as Mount Shasta in California, a single, immense, isolated volcanic cone, presenting upon all sides approximately the same surfaces for snow to rest upon. The glacier valleys which are eroded down its sides and extend out through its foot-hills are a remarkably clear record of the distribution of ice-work. The southwest half of the mountain, as compared with the northeast, had the smaller glaciers, and retains to-day infinitely the lesser amount of snow. Only broad banks of moving *névé* exist upon the former side, while upon the north and east active glaciers are still doing their work, and the ancient moraines are on a scale greatly superior to those of the other half. So, too, the northern and eastern exposures of Mount Shasta are most deeply sculptured away by glaciers, and they consequently have a much higher surface-angle than the other flanks.

This rule, which is true of Shasta, is true of all the other high volcanic peaks of the North American Cordilleras, and when applied to the configuration of mountain ridges is found to be applicable in their minuter topography. A great majority of the granite peaks of the Sierra Nevada, as well as the high lava peaks, and in great part the individual mountain peaks upon the ridges of the Great Basin region, show the influence of this wind-governed distribution of snow, in the steepness of their eastern slopes, and in the lingering ice-action under the northern shade of the rock-masses.

The dip of the beds and the different hardness of mountain materials have, of course, often had a leading effect in giving the configuration; but so far as it is determined by forces of erosion, that erosion has been greater upon the north and east sides. Had erosion been due in any considerable extent to rains, it is clear that the accidents of original form would have dominated and determined the lines of drainage and the forms of peaks. Had water-erosion formed the peaks, they would have been cut by deep ravines, which usually is not the case. On the contrary, they are carved away in broad, recurved amphitheatral shapes, such as could never have been the result of water. And the effect of streams is evidently limited to that portion of the drainage beyond the limits of the *névé* action.

There are, then, over the whole Cordilleras three types of erosion which have created the chief topographical forms—*névé*, glacier, and torrent work.

First, and highest in point of altitude, is the *névé* erosion which has resulted in glacier sources, amphitheatral forms, broad recurved mountain faces, and in post-Glacial time in the débris-piles of all the regions of the high summit. This energetic degradation is now tearing down the solid ridges which formed the peaks and bounded the amphitheatres during the Glacial period. *Névé* action is varied greatly in intensity, having a maximum on the high summits of the Sierra Nevada, which by their altitude and proximity to the moisture-laden wind of the Pacific receive by far the greatest relative snow-fall. There, especially in the region between the head of Stanislaus River and Walker's Pass, which was the great glacier region of the range, the summit peaks and middle Sierra slopes are now encumbered by enormous slopes of débris, nearly all of which have accumulated since the occupation of the amphitheatres and cañons by glaciers.

On Mount Shasta the relics of former great glaciers are in some instances entirely buried by débris, and the very existence of some of them would have been unknown but for the accident of a very warm summer, when the writer was enabled to detect the presence of long bodies of moving ice beneath deep accumulations of angular and sub-rounded débris. In other words, it is evident that the production of intense *névé* erosion does not require any very deep accumulation of snow, and that a comparatively slight annual snow-fall in the higher altitudes will produce an immense shattering force, while a very large accumulation of snow would produce a glacier and to some extent prevent the shattering effects of *névé* erosion.

The size of the blocks developed by the *névé* shattering differs widely, according to the material and its own interior structure. Brittle bedded quartzite offers the easiest materials for contraction and expension to work upon; and in consequence its angular blocks are not only easily developed, but the removal of the blocks, which takes place by the leverage of expanding ice frozen in the cracks, is facilitated by sliding the shattered rock along the smooth bedding-planes. Consequently, in all regions where high peaks are formed of quartzite, we find a very great accumulation of débris, which varies in size according to the hardness, uniformity of texture, and thickness of bedding of the formation. Conspicuous examples of this are the whole summit of the Uinta, the quartzite strata flexed around the granite of Mount Clayton in the Wahsatch, Pilot Peak in Ombe Range, and Dome Mountain in the Toyabe. This same action is also observable in some of the limestone heights, especially in those of Ogden and Weber cañons, where slopes of over 3,000 feet are actually covered with rough, angular fragments that have been dislodged from the tops and dashed down the slopes. Among the granite débris of the Sierra Nevada are the largest specimens of detached fragments that I have seen. On some of the slopes composed of uniform and very compact granite, blocks of twenty or thirty feet in diameter are not unknown.

As a whole, this process of disintegration has been in operation from the beginning of the Glacial period in all high Cordilleran regions, and as soon as the glaciers disappeared it began upon the exposed sides of their cañons, continuing its work up to the present day.

In the immediate future, in a geological sense, unless some climatic change takes place, every lofty peak and ridge of the Cordilleras, except those which from their precipitous faces or from other peculiar causes are defended from the action of snow, will be covered with a protecting mass of disintegrated and shattered blocks. Not a few instances may be observed where this has actually taken place, and the peaks and surrounding ridges are mere mounds of débris, which in their turn are rapidly shattering into angular gravel and forming gravel-clad peaks and ridges. This ice-sculpture is of course reduced to a minimum in a period of maximum glaciation. It is evident that the Himalayas are in a condition similar to the Cordilleras in relation to this process. The glaciers have shrunken immensely from their earlier Quaternary extension, the débris-slopes are vastly greater than any elsewhere exposed in the world; and the phenomenon of actual glaciers pushing along under an enormous load of superincumbent débris which I have mentioned at Mount Shasta is seen in the Himalayas on an infinitely greater scale, as for instance the glaciers of the upper Ganges. Except such peaks as are the result of upheaval or ejection, all the high mountain summits are the result of ice sculpture, none of the modern details having been given since the disappearance of the Glacial age. In the total amount of disintegration and transportion of rock now progressing, the labor of *névés* must be considered the most important element.

The glacial cañons, as already mentioned, reach a maximum depth of a little over 3,000 feet; and it becomes a question of great interest to determine whether this immense amount of excavation was actually the result of the abrading force of moving glaciers with their *moraines profondes*, or whether the cañons are the result of aqueous erosion afterward modified by glaciers. There is not a particle of direct evidence, so far as I can see, to warrant the belief that these U-shaped cañons were given their peculiar form by other means than the actual ploughing erosion of glaciers; nor do the objections to this belief advanced by certain observers, based upon the moderate amount of detritus transported by the existing glacier-streams of the Alps, seem to be worthy of serious consideration, since the Alpine glaciers of the present day are at best but the shrunken relics of the former system; and with the vastly greater accumulations of snow in the ice period there is every reason to believe that the thickness, movement, and energy of the glacier must have been much greater, and that its power of abrasion would be correspondingly increased.

The transported material of the Glacial period was of two kinds: first, fragmentary, angular blocks, which were disintegrated from the summits by *névé* action; and, secondly, the fine silt which is carried out by sub-glacial waters and borne down in the glacial rivers. The entire drainage of the Fortieth Parallel region west of the Wahsatch poured into a series of lakes which occupied the present basins of Utah and Nevada and many of the valleys of the upland Nevada plateau. The silt was spread out upon lake-bottoms of the period, and forms the lacustrine deposit which is designated upon the geological maps of the Atlas as Lower Quaternary. In several limited and exceptional cases this is still covered by relics of ancient lakes; in general it has been laid bare by subsequent desiccation of the early lakes, and covers the bottoms of their basins with a horizontal sheet. Excepting a few wells and shallow cuts of very modern erosion, it cannot be examined, since the drainage of the present period, instead of opening up sections, has constantly the tendency to bury it beneath the detritus now accumulating.

East of the Wahsatch the entire country possessed, during the Quaternary period, a free drainage to the ocean, from the basin of Green River down the Colorado, and from the country east of Rawlings Station into the Mississippi, through the various branches of the Platte. There are here, consequently, no lacustrine Quaternary deposits worthy of note, and the entire Quaternary age is represented by accumulations along the valleys of the rivers, and a thin variable coating of unstratified æolian Quaternary, which is nearly everywhere found over the surface, except where washed off by recent erosive forces or denuded by winds. The Quaternary valley deposits following the rivers and their tributary streams east of the Wahsatch are of considerable thickness, but possess, with a few local exceptions, no regular system of terraces such as marks the Recent period in eastern America. While the valleys give evidence of the existence of former great rivers, there are no successive periods of recession, and in general nothing like the important deposit of Champlain gravel displayed by the rivers of the East. It is quite possible, however, that if there were terraces formerly developed along the river courses, they have been subsequently obliterated by great floods. As it is, the rivers usually flow over a Tertiary or Cretaceous plain, and display on their banks the rocks of those periods, the broad flood-plain of the river being usually flanked by a single but variable low bluff of Quaternary sand and gravel a few feet in height.

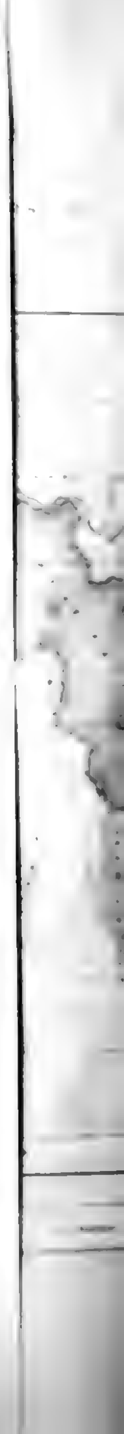
A further Quaternary phenomenon mentioned earlier in this section is observed in many of the ranges which border upon an area to the south, and extend thence down to the Mexican boundary. I allude to a steep talus-slope bordering the ranges and extending at a very considerable angle downward to the middle of the valleys, where there is either a narrow drainage-line or a considerable flat valley, according to the distance apart of the bounding ranges and the scale of the Quaternary accumulations. It is obvious that where large Quaternary lakes, as in the case of western Nevada and western Utah, rose to a considerable height along the foot-hills of the ranges, the cañon mouths discharged the silts of the Glacial period, as well as the bowlders and pebbles borne along by torrents, directly into the waters of the lake, where they were assorted and deposited according to the simple laws of sedimentation. Where there were no Quaternary lakes—in other words, where the valleys had a free drainage—the fine materials were carried on by the stream-drainage, while the coarse and heavy detritus constantly built up a talus at the foot of the ranges, sloping from the cañon mouth down to the valley middle. This phenomenon is observed with increasing magnitude toward the south. In Oregon, in middle California, and in the country of the Fortieth Parallel, it never amounts to a very conspicuous formation; but on the southern part of Toyabe Range, along the flanks of the White Mountains in California, and indeed everywhere south of the 39th parallel in southern Nevada, California, and Arizona, these long wash-slopes are important topographical features.

In the general formation of cañons it is evident that their upper or high mountain halves have been most steeply eroded. The projection of a profile of a cañon bottom shows a deep, sharp curve at the head and a gradual approximation to a level toward the cañon mouth. In other words, it is in the upper part of these cañons (as well in gorges occupied by the glaciers as in those occupied by torrents) that the sharpest erosion has taken place. Suppose, now, that the form of the valley into which the mountain torrents delivered their freight was so broad and open that the material poured into it accumulated faster than it could be carried away, it is evident that there would be banked up against the flanks of the ranges increasingly high piles of pebble and bowlder material, and in those regions where disintegration greatly predominated over distant transportation the talus-slopes would reach higher on the range. A single condition causes these talus-slopes to rise highest along the mountain flanks at the mouth of the cañons. It is, that the floods, while compressed within the narrow walls of the cañons, are able to transport immense blocks of the rock down to the mouth of the cañons, but at that point their waters rapidly spread out and immediately lose the power to transport the heaviest bowlders. The mouths of some of these cañons are banked up with great, sloping piles of bowlders, 1,000 feet high, which are not, in any sense, the result of débris-making forces *in situ*, but are actually high mountain débris brought down by torrents held in the narrow walls of the gorge—torrents which discharged their load the moment they emerged from the cañon mouth and spread out as shallow streams.

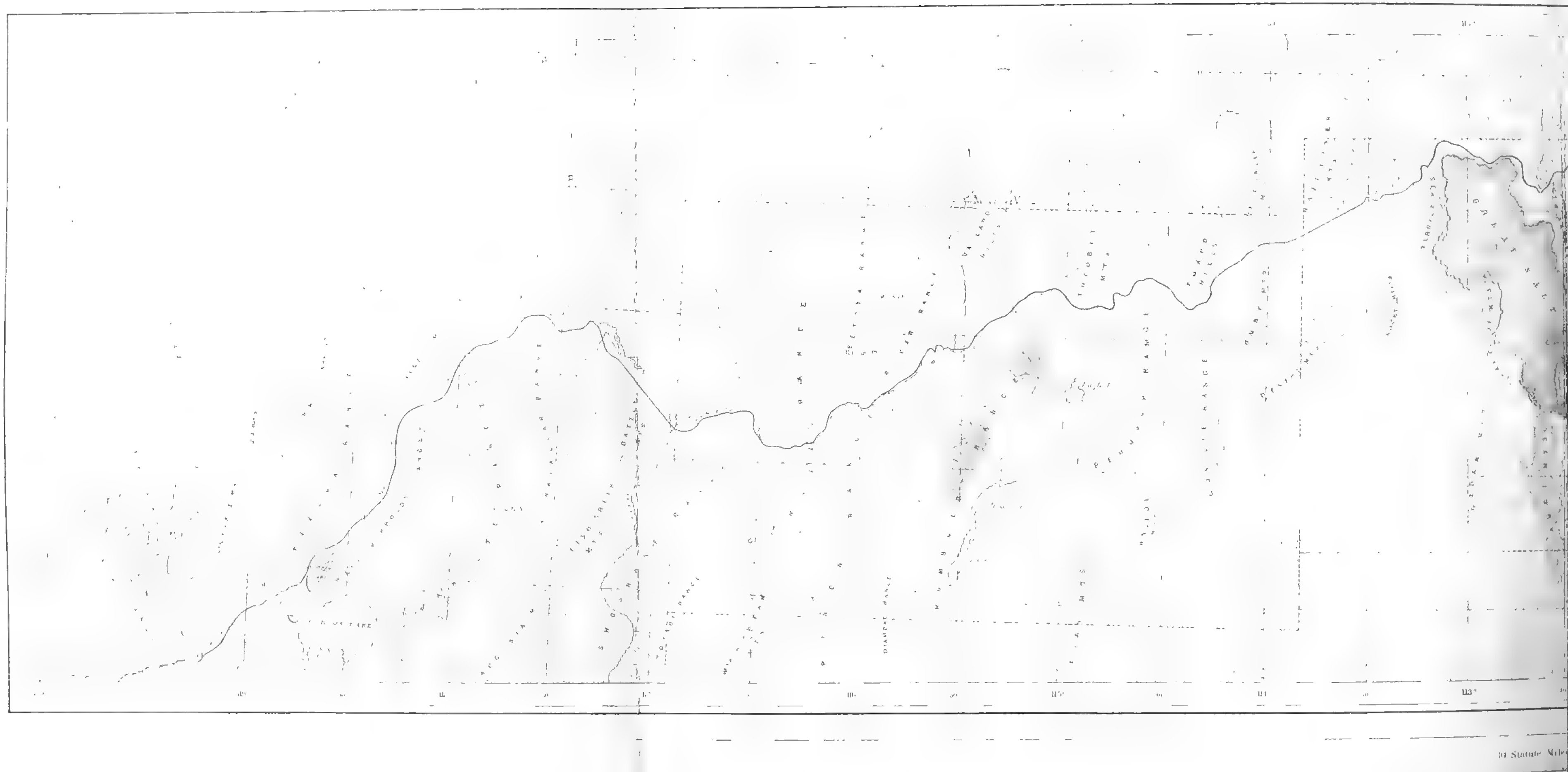
Along the eastern base of the Sierra Nevada these slopes are seen developed on a magnificent scale from Bishop's Creek to Walker's Pass. But even there they are not equal to the slope of the opposite or White Mountain side of the valley, and farther south they are of still grander proportions. It is noticeable that in the region of the greatest glaciation these bowlder talus slopes are rarely seen, and, indeed, they are in great measure a southern phenomenon; whence I judge that they were chiefly developed in those regions which were not glaciated, but were great *névé* and torrent regions during the Glacial period.

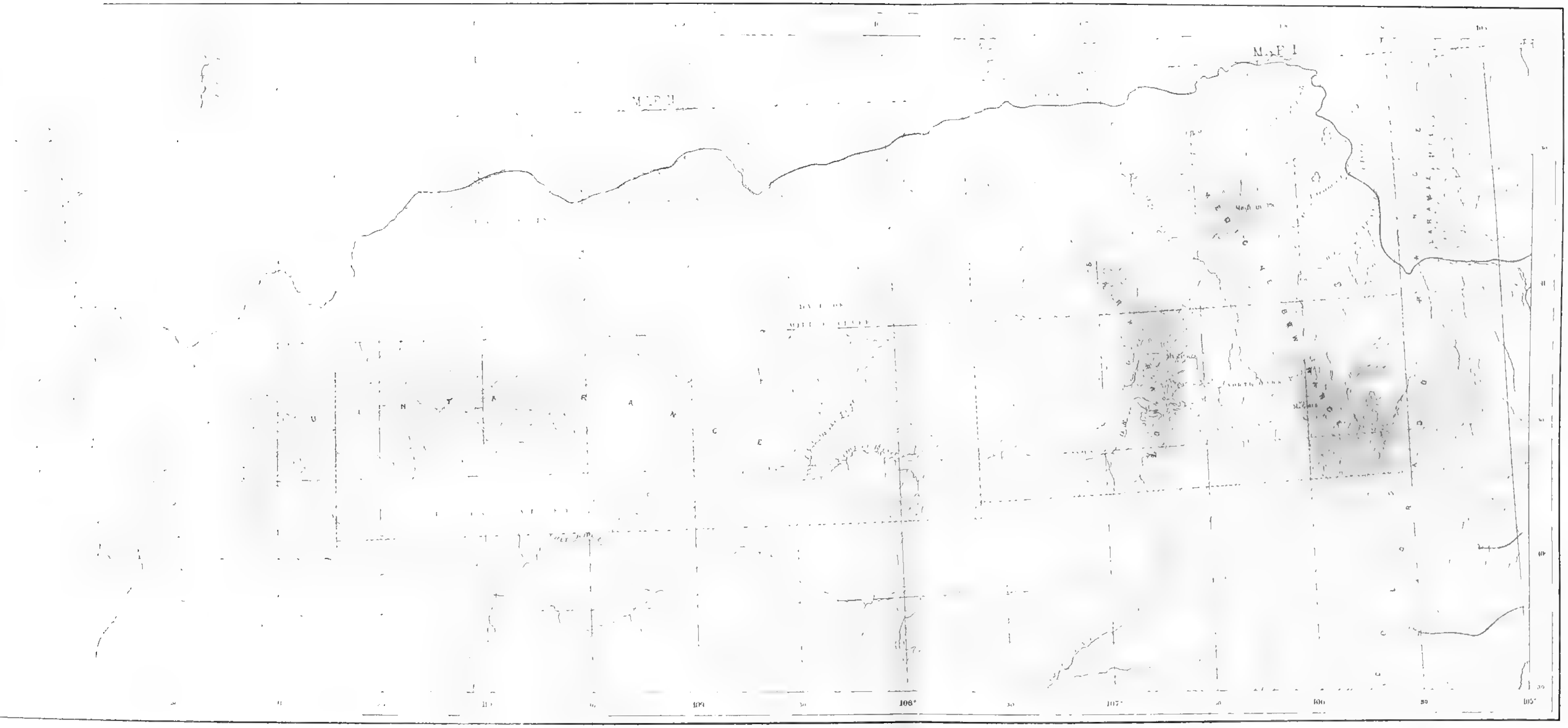
The modern streams have often cut down for considerable depths in these talus-deposits, showing them to be made up of a variety of bowlders, both sub-rounded and angular.

In the comparatively rainless regions of Nevada, Arizona, and California, where these talus-slopes most abound, the cañon bottoms are often absolutely dry, except in case of accidental storms or for a limited period during the melting of the mountain snows. The explorer often rides up mile after mile of cañon-bed filled with fine gravels and sands, whose surface is absolutely parched and dry, the only water being found either by digging down to the bed-rock or where some outcropping ledge diverts a feeble flow to the surface. Many are entirely dry. Over the drier regions of the whole Cordilleras it is no uncommon thing to find a cañon from 1,000 to 2,000 feet in depth without a drop of water moistening its bottom. No more powerful commentary on the immense change of climate between the cañon-cutting period and the present could be recorded. Even the transporting power of these steep cañon torrents might have remained almost a mystery, but for occasional water-spouts, as they are called—immense, sudden, deluging rain-storms, which, at rare and exceptional moments, discharge their waters into one of these mountain gorges. On such occasions bowlders six or eight feet in diameter are swept down the cañon with a fearful rush, and are sometimes carried out on the talus-slope for half a mile Indeed, the mouths of almost all the grander cañons which carry the drainage of a considerable mountain area show trains of débris with large angular bowlders often weighing many tons. If in the inconsiderable storms which exceptionally visit this rainless region at present such an immense transporting force is developed, it is no matter of wonder that during the period of long continued and constant annual torrents the enormous amounts of ice-shattered mountain débris which rolled down upon the cañon bottoms should have been swept out on the plain to build up these vast talus-slopes. It is clear that they represent a period in which the accumulation in and transportation through the cañon exceeded the amount of material which



GLACIERS OF T





108°
107°
106°
105°

would have been produced by the erosion or deepening of the cañon alone.

A glacial or **U** cañon carries bowlder-accumulations throughout much of its length in the form of terminal moraines. The bottom rock, when not covered with soil or bowlders, shows glacial scorings as far down the cañon course as the **U** shape extends.

There is no modification since the last melting out of the glaciers.

The **U** part opens downward into the **V** part of the gorges.

The Great Sierra or Uinta cañons may have the **U** form for forty miles from the summit and then suddenly give way to the **V** form.

It is evident either that there was an original **V** formed cañon which the subsequent glacier occupied and modified as far as it descended, or else that the whole cañon was simultaneously cut, the **U** by glaciers and the **V** by floods below the point where the ice gave out.

Since the cañons are post-Pliocene, *i. e.*, wholly within the Quaternary, the question naturally suggests itself, If the deep **U** gorges, often 3,000 or 4,000 feet deep, were only modified, not actually made by glaciers, what torrent period was there within the Quaternary, and prior to the glaciers whose tracks are so fresh in the cañon beds?

As will appear later, the chemistry of the Quaternary lake basins and the relation of the unstratified to the stratified Quaternary materials combine to show two distinct periods of extensive flooding in post-Pliocene time, separated from each other by an interval of desiccation. It seems only natural to correlate these two epochs of excessive moisture with the two glacial ages which Dawson has demonstrated in British Columbia, and which are so well established in Europe. From all points of view, the earlier of the two, marked as it was by considerable ice-sheets, was the greater ice age.

Now, since in both ice periods the western United States was free from the great northern ice-field, it is possible that the floods incident and subsequent to the first ice age and its disappearance made the great **V** cañons and at last obliterated the traces of the earlier mountain glaciers, and that in the second glacial period the trunk glaciers modified the **V** cañons as far as they descended, into the **U** form. The actual proof or disproof of this hypothesis is wanting; it is quite harmonious with the known facts, and seems more in accordance with present ideas of ice erosion than the other alternative of supposing the U gorges to be the direct sawing down of a rock-shod glacier. If this hypothesis, advanced here merely tentatively, should receive acceptance, it will be evident that the ordinary glacial markings and moraines in the region south of latitude 48° are wholly the work of the second or Reindeer glacial epoch, and their extraordinary freshness would coincide with that view.

LAKES OF THE GLACIAL PERIOD.—A most important feature of the Quaternary period in the Great Basin region was the two extensive fresh-water lakes which occupied depressed portions of the interior drainage—lakes whose former limits are indicated by singularly well preserved terrace-lines traced around the ancient shores. The highest of these old beach-lines represents a level of overflow for each lake, and beneath that level is a series of descending terraces which mark successive pauses in a general desiccation. Besides the terraces and sediments of these early lakes, there remain a few residual lakes of saline waters which linger in the deepest hollows of the bottoms of the extinct seas; Great Salt Lake being the most conspicuous example. Elsewhere over the dry beds and shores are products of desiccation and of the chemical reactions of the constituents of the wasting lakes.

A word as to the origin of the basins will serve to bring us to the direct consideration of the lakes.

I have shown that during the Pliocene epoch, while so large a part of western America was covered by great fresh-water lakes, the climate was sub-tropical, the fauna and flora representing a condition not unlike that of southern Florida—palm trees and crocodiles typifying an atmosphere of great and uniform mildness. At the close of the Pliocene, the orographical disturbances which I have shown to have taken place over the western part of the United States must of themselves have produced new climatic conditions, even though the astronomical factors of the terrestrial climate remained the same.

It is now clear, as first advanced by General G. K. Warren, and as abundantly substantiated later by myself, that the inclined plane of the whole system of the Great Plains received its slope by mechanical tilting subsequent to the deposition of the Pliocene strata. A part of that Pliocene lake bed, which was over a thousand miles in length from north to south, is now depressed beneath the waters of the Gulf of Mexico, and part of its once level strata reach 7,000 feet above sea-level. It is therefore clear that a change of 7,000 feet has taken place in the altitude of the boundary of the lake. Passing to the Great Basin, it is there seen that the two sides of the Pliocene lake of that region sank from 1,500 to 2,000 feet.

The lake of the Plains, after its inclination to about its present position, bore upon its surface a series of rivers which had free drainage to the sea, and during the entire Quaternary period the waters derived from the melting of the Glacial age in the Rocky Mountains all easily flowed eastward and had an uninterrupted marine delivery. On the other hand, in the region of the Great Basin, the result of the subsidence of the two sides of the Pliocene lake was to form two interior basins, that of Utah and that of western Nevada, whose levels of outlet were about 5,000 feet above sea-level, while the bottoms of the basins were in the region of 4,000 feet. These two early Quaternary basins, made by the subsidence of the east and west edges of the Pliocene lake-bed, had, below the level of their water delivery, depressed areas each about equal to the surface of Lake Huron.

The two lakes were very nearly of the same size, but the altitudes of their ancient surfaces, unless they have suffered disturbance since desiccation, differed by several hundred feet. It becomes a question of great interest to know whether, at the time of the formation of these basins, the Pliocene lakes, whose existence we now know by their sedimentary beds, were actually yet filled with water, and whether the orographical movements which outlined the new basins simply drained off the water from the general area into two deep hollows. It is well known that a full aquatic fauna of the Pliocene lakes shows that the waters were strictly fresh. At the same time, among the upper Pliocene beds are found horizons which are impregnated with alkaline salts—chlorides and sulphates. They are slight in extent, and not comparable with the alkaline deposits in the Quaternary. But in order to have made a saline deposit in the bottom of a fresh-water lake it is essential to have completely evaporated the waters.

The presence of these alkaliferous Pliocene beds would seem therefore to indicate several perhaps brief periods of desiccation during the last of the Pliocene age. A second argument in favor of dry basins at the beginning of the Quaternary is the fact that the earliest deposits on the sides of the extinct lake-basins are subaerial gravels, which were swept far down into the hollows of the basins, although probably never reaching the immediate bottom of the valleys.

The phenomena of these lakes are, first, the topographical indications of the maximum extent and loci of outflow; secondly, the periodically gradual desiccation; thirdly, the mechanical deposits of the lake; fourthly, the products of successive desiccations.

On Analytical Map VI. accompanying this sub-section are seen these two great Quaternary lakes restored to their former outlines, as indicated by the levels of their uppermost terraces. To that in Utah, G. K. Gilbert* has given the name of Lake Bonneville. For the western Nevada body, I propose the name of Lake Lahontan, in honor of the gallant French explorer.

LAKE BONNEVILLE.

Lake Bonneville extended from about the parallel of 42° southward to 37° 30′, the meridian of 113° representing nearly the middle of the lake. The extreme width was in latitude about 40° 21′, where the east-and-west extent was 180 miles. From north to south it had a stretch of about 300 miles. For the outline of the southern half of Lake Bonneville, I take the data from the map of Lieut. G. M. Wheeler, which carries the lake-area

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*Gilbert was the first to treat this lake systematically. His pages concerning it, in Vol. III., Geographical Surveys West of the 100th Meridian, do not mention his having taken for his map the northern part (nearly half) from the then unpublished topography of this Exploration; but the map itself credits the topography to me. Doubtless the appropriation was made after the pages were printed. In my map accompanying this section I have taken that part of Lake Bonneville south of the 40th parallel from Wheeler's map, the Bonneville work thereon being Gilbert's. In other words, we have each taken topography from the other; and although Gilbert has gone over and studied the great lake through the Fortieth Parallel area, I have kept carefully within my own lines. Gilbert's study of the area and outline, and his thorough way of working out the outlet, are entitled to all praise. Since he precedes me in publication, I give here little space to the points he has so well discussed, namely, the general features and the mechanical sediments of the lake. All the points as to the sediments brought out by him were previously observed by my colleagues and myself, and I have only one minor point of difference with him, which will appear in the sequel. Avoiding as far as possible any extended repetition of prior statements, I devote myself more particularly to the chemical phenomena of desiccation.

of Mr. G. K. Gilbert. For the northern half of the map, namely, north of the 40th parallel, the data are taken from the maps of this Exploration. Escalante Valley, representing the southernmost arm of the lake, was never examined by us, and its addition to the area of Lake Bonneville is, like all the south half of the lake, due to Mr. Gilbert. I have always felt some hesitation in considering this important basin as a part of Lake Bonneville, and have expected that Mr. Gilbert would finally regard it as a distinct lake of greater altitude, which drained north into the larger body.

Between the 39th and 41st parallels the mountain ranges of the Utah Basin for the most part rose above the surface of the water and formed an interesting archipelago, separated by more or less shallow arms of the lake. The deepest hollow is represented by Great Salt Lake, which is of course the desiccated remnant of the fresh-water sea. The ancient high-water mark of Lake Bonneville is traced in the form of a very evident terrace along the foot-hills of Wahsatch Range, the Promontory, all the islands which now rise high enough out of the lake, and indeed all the insular and bounding ranges within the limits of the ancient body. The present water-level of Great Salt Lake, after correction of the Central Pacific Railroad level by the addition of the error at Sacramento, is about 4,250 feet above the sea. The uppermost terrace, which is clearly recognizable, is about 940 feet above the level of the lake in 1872, making the altitude of the water-level of Lake Bonneville 5,190 or 5,200 feet.

From the 40th parallel to the northernmost exposures of the highest terrace, the barometer, observed synchronously, showed no appreciable difference of level, from which I conclude that the northward subsidence of land during the Champlain epoch either did not take place in this part of the interior of the continent, or else its effects were wholly south of the 40th parallel. Gilbert, always keenly alert to discover any facts bearing on this question, inclines to attribute the superior level of the Escalante Valley upper terrace to a movement later than the occupation of the area by water. If his surmise is correct, it would be directly opposite to the general law of the Champlain subsidences, in which the northern, not the southern land was depressed. Until it shall be fully substantiated that Escalante Valley was a part of Lake Bonneville, and not, as I suspect, a superior lake draining into it, the probabilities to my mind seem against a rise of the southern part of the lake in post-Bonneville time. After the above was in the printer's hands a further reference to the subject was made by Gilbert,* who reiterates a change of level due to orographical action, and if I understand him correctly he discovers two kinds of level-change, one due to subsidence after the manner of the Champlain depression, the other to strictly orographical mountain-faults, such as are described in his communication to the Philosophical Society of Washington.

The configuration of the country to the south of the southern limits of the ancient lake is conclusive that it had no outflow in that direction. But the divide between the Utah Basin and the depression of Snake River falls below the level of the upper terrace, and it is therefore clear that the lake poured its waters into the valley of the Snake, and thence through the Columbia into the Pacific Ocean. That these waters were at that time essentially fresh, is rendered probable by the species of fish which are in the land-locked streams that flow into the present dry Bonneville Basin; also by the remains of fresh-water mollusks found in the calcareous tufa which is in many places the cementing material of the gravel of the upper terrace. The 5,190-foot beach, or, as fixed by Gilbert, 5,178, was called by him the Bonneville Beach. To a somewhat less prominent but still very persistent terrace, about 360 feet below, Gilbert gave the name of Provo Beach.

Below the upper shore-line is a series of successively lower terraces, indicating a gradual recession of the waters down to the present level of the lake. This recession is obviously due to the excess of evaporation over the inflowing rivers. On the subject of the outlet Gilbert has the honor of discovery and priority in announcement.† He stated in a communication to the Philosophical Society of Washington, January 13, 1877, that Red Rock Pass, near Oxford, Idaho, gave exit to the former overflow of Lake Bonneville, and at the same time mentioned a slight post-Glacial movement of the great west-face fault of the Wahsatch. Gilbert, in restating his discovery, has added the fact that the river channel at Red Rock Pass had cut down to the level of the Provo Beach, thus accounting for that feature.

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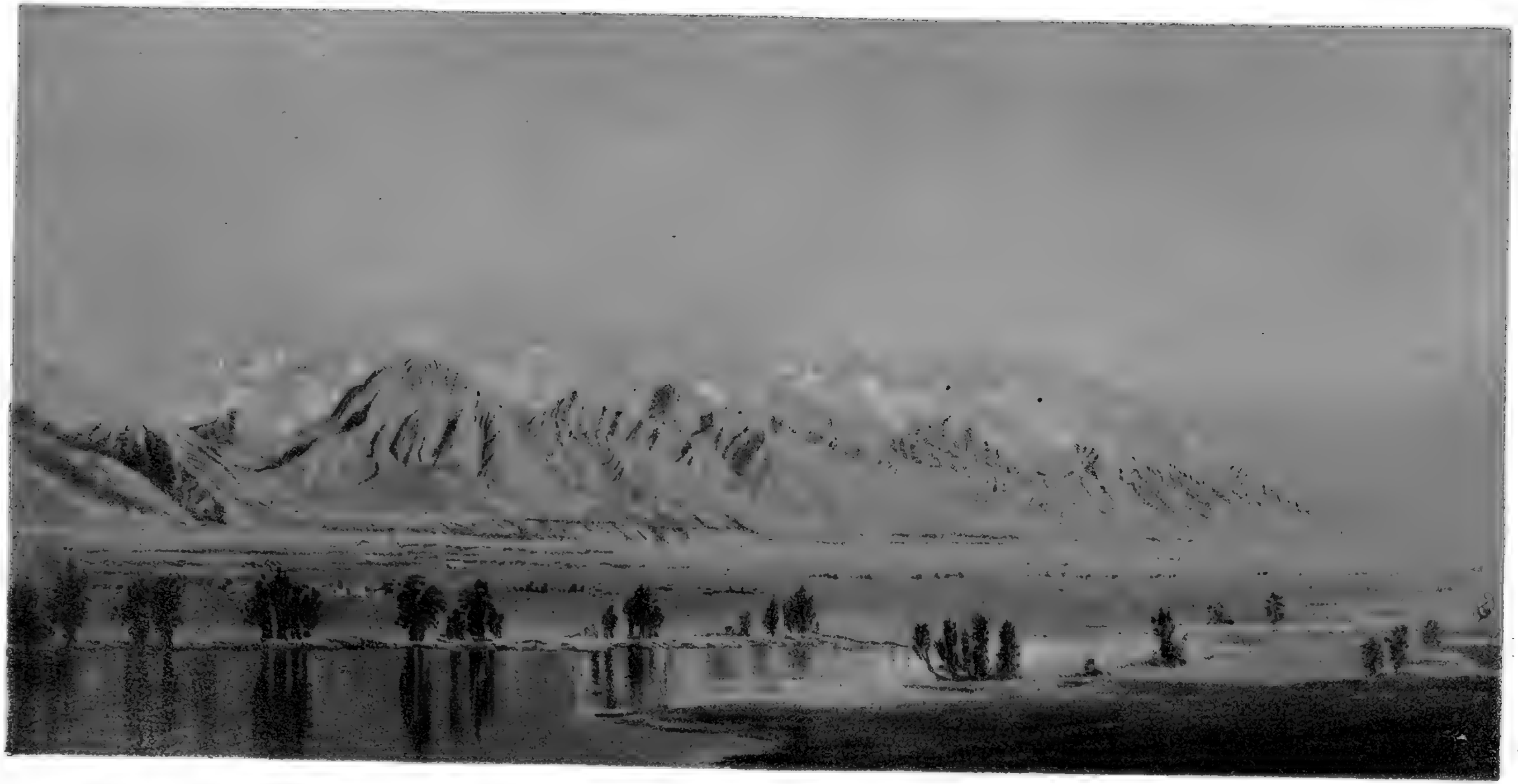
* American Journal of Science and Arts, Vol. XV., April, 1878.

† Since the above was in type, Peale, in the American Journal for June, 1878, disputes Gilbert's claim, and recalls Bradley's mention of Red Rock Pass.



WASATCH RANGE FROM SALT LAKE CITY, UTAH

The mechanical deposits within the area of Lake Bonneville consist, as Gilbert has shown, first, of subaerial gravels washed down by flood and stream, and rolled down steep slopes by rain and wind; secondly, of the finer detrital and precipitated matters which have accumulated on the floor of the lake in strata of sandy, clayey, and calcareous mixture, and which, in the present desiccated age, are exposed, undisturbed beds, the greater part of whose area is uncovered by later subaerial gravels.

The subaerial unstratified deposits were continuous or at least recurrent formations, covering the whole lapse of Quaternary time over the bounding-slopes of the Bonneville area which were not at any time water-covered. It is seen that the gravel series is divided or interrupted by the stratified beds; in other words, that in point of sequence there is, first, a heavy bed of gravel, both rounded and angular, of a maximum exposure (the bottom being concealed) of 200 feet; secondly, the stratified sediments which overlap the earlier gravels; and thirdly, a latest gravel, varying from 75 to 150 feet, which since the last desiccation has been washed down the basin-slopes and over the edges and a considerable area of the surface of the fine Bonneville strata. My observations on all these points agree in detail with Gilbert's.

By reference to the Geological Atlas accompanying the report, it will be seen that east of the Wahsatch, in the region which during all the Quaternary age had free fluviatile delivery to the sea, the Quaternary is colored in one tint. It consists, besides the irregular coating of soil, the result of chemical and mechanical disintegration of rocks, a feature too inconspicuous to show on the general geological maps, of river-bottom accumulation of no great extension. Although the eastern part of the work touches the Lœss deposits of the plains, it merely touches them, and that in their least characteristic region. As I have no considerable light on the question, the Lœss is not discussed.

West of the Wahsatch the Quaternary is shown in two colors: one, denominated Lower Quaternary, is the great lacustrine formation; the other, or Upper Quaternary, is intended to embrace the sheet of subaerial gravel which is subsequent to the latest desiccation, and hence later in age than the lacustrine Lower Quaternary. The lowest or ante-sedimental gravels are not shown on the map, from the fact that they are nearly always covered by the two later divisions. All these were, however, recognized in the Bonneville Basin and in that of Lake Lahontan.

Geological Maps III., IV., and V. show in the basin of the two great Quaternary lakes, and elsewhere in the area of lesser extinct contemporaneous lakes in middle Nevada, a wide expanse of the Lower Quaternary or lacustrine beds, and the still greater distribution of the most modern subaerial gravels.

Avoiding as far as possible the repetition of Gilbert's reasoning, I yet find it necessary to say here, as he has said before, that the sequence and stratigraphical relations of these three members of the Basin Quaternary, not only for Bonneville, but for the whole Great Basin region, indicate, first, a dry period in which subaerial gravels were washed down into basins; secondly, a filling of the depressions with water, during whose occupation the stratified deposits covered the broad basin-bottoms and considerably overlapped the earlier subaerial gravels; thirdly, an age of desiccation, in which the lake waters dried out and the Upper Quaternary or most modern sheet of subaerial gravel washed down over the earlier gravels and over the dried surface of the lake beds. There are other considerations, to appear later in this section, which confirm this interesting proof of two desiccation-epochs, and considerably enlarge our conceptions of the history of the period.

The Lower Quaternary (Bonneville beds of Gilbert) contains an abundant molluscan fauna, of which the following are the most important forms:

Limnæa desodiosa
Pomatiopsis lustrica.
Amnicola Cincinnatensis.
Succinea lineata.

The latest subaerial gravels have yielded a skull of *Bison latifrons* and fragments of bones, supposed to be reindeer.

The evaporation of such a great body of fresh water could only result in the concentration of the soluble salts and the precipitation of those whose chemical nature forbade their continued solution in the increasingly strong alkaline water. The uppermost terraces are made of the washed gravel and pebbles of a beach deposit, which in most cases are quite securely cemented together by a calcareous tufa. In places the entire material of the terrace is of more or less porous tufa, in which are enclosed but few rock fragments, sometimes angular and sometimes rounded, in all cases derived from the neighboring hill. A characteristic specimen of this tufa, collected on the main terrace at Redding Springs in Salt Lake Basin, and analyzed by Mr. R. W. Woodward, of this Exploration, is given in the table of chemical products due to the evaporation of Lake Bonneville. It is seen to consist essentially of carbonate of lime, with a small percentage of silicic acid (for the most part, doubtless, included sand, but also to a slight extent as combined silica), a low percentage of alumina, a trace of sesquioxyd of iron, 3½ per cent. of magnesia, a little soda and potash, and a trace of lithia and phosphoric acid, with a constant minute proportion of water. The specific gravity of the tufa is from 2.4 to 2.3. If the reader will refer to the table of the desiccation-products of Lake Lahontan, he will observe that the tufa of that great companion body of fresh water possessed, down to the minutest constituent, precisely the same chemical nature.

The tufa of the Lake Bonneville terraces is a fine, compact, grayish-yellow mass. When acting as a cement for the terrace-beach pebbles, it usually occurs in concentric layers enveloping the pebbles, with the interstices filled in with a fine granular carbonate. Where it exists in solid cakes, as on the terrace above Redding Springs, it has in great measure the porous texture characteristic of calcareous tufas and travertines. In thin section under the microscope it presents a curious, opaque appearance, and has a light, earthy-gray color, carrying innumerable fine, dust-like particles, which are simply the mechanically entangled silt of the shore. Through the absolutely opaque section are cloudings of transparent material, which, under crossed nicols, are seen to be microcrystalline masses. The individual crystals are too small to display the color phenomena of calcite, but by the analysis they are unquestionably a fine microcrystalline lime-carbonate. Considerable passages of the transparent carbonate wander in cloud-like forms through the more opaque material. The latter is doubtless opaque simply from the mechanical suspension of minute mineral particles. Organic matter like the roots of water-plants, as well as minute mollusks, is enveloped in the mass. One peculiarity, as seen under the microscope, is the development of concentric circles, which are defined by a banded arrangement of the included foreign particles, or by the spherical arrangement of a homogeneous, gray, cloudy material, the origin of whose opacity is unknown, since the highest power of the microscope fails to resolve it.

In the table of analyses of this lake is given also the composition of the present water of Salt Lake, which is seen to consist essentially of chloride of sodium, sulphate of soda, sulphate of potash, sulphate of lime, and chloride of magnesium. Among these the chlorides of sodium and magnesium greatly predominate, while the united sulphates of soda, potash, and lime reach about 10 per cent. of the entire solid material. In the analysis it will be seen that Professor Allen has computed all the lime as sulphate. It is a noticeable fact that in such a dense saline solution, one in which the solid matter is approximately 15 per cent. of the entire weight, there are none of the alkaline carbonates which are characteristic elements in the saline lakes farther west.

The percentage of sulphate of lime is not too high to remain in solution, even in waters of far less density. Indeed, the analyses of nearly all the European rivers show a higher percentage of sulphate of lime in the entire sum of solid material than do the waters of Salt Lake. The chloride of magnesium, representing one tenth of the entire solid contents of the lake, is present in unusually high proportion. Lithia, though given in the analysis only as a trace, is present in sufficient quantity to give an invariable reaction in the spectroscope from the contents of a single drop of water.

In many respects the present solution in Great Salt Lake differs from that of any other saline lake. The Caspian, a far fresher water, with but six tenths of 1 per cent. of solid material, has its salinity chiefly made up of the chlorides of sodium and magnesium, with the sulphates of magnesia and lime; but there is also an appreciable percentage of bicarbonate of lime and magnesia, elements entirely lacking in Great Salt Lake. The Dead Sea, on the other hand, has a far higher total of saline matter, varying, according to different analysts and specimens, from 14.7 to 26.3 per cent. of the whole weight. In the Dead Sea, magnesium chloride is the predominating salt, according to Gmelin and Marchand. In the absence of carbonates, Great Salt Lake resembles the Dead Sea; but in the enormous predominance of chloride of sodium over all other salts, and in the entire absence of carbonates, it is unlike any other large lake the analysis of whose waters has been published. A case of even more exclusively sodium-chloride solution is the small lake of saturated brine which, in the rainy season, overlies a bed of nearly pure chloride of sodium in Osobb Valley, western Nevada, containing only chloride of sodium, with minutest traces of chloride of magnesium and sulphates of the two bases.

At the time of the Stansbury expedition, in 1849, the level of Great Salt Lake was about eleven feet lower than at present, and the area of the lake as surveyed by him gives 1,700 square miles. From our survey we estimate 2,360 square miles of lake surface, an increase since Stansbury's work of 660 square miles. The balance between inflowing waters and evaporation was about even, showing only slight oscillation from before Stansbury's time till 1866. From 1866 to the present, a slight climatic oscillation has occurred, by which the influx of waters is in excess of evaporation, and hence the level of the lake has risen about eleven feet, covering a wide expanse of lowland, and making its greatest encroachments westward over the nearly level floor of the desert and northward over Bear River Bay. In consequence the solution has been diluted, from a point where, according to the analysis of Dr. L. D. Gale,* the water yielded of solid contents 22.4 per cent., to its present low density. Gale's analysis is evidently at fault in showing no sulphates of potash and lime. From the analysis of the present water it is evident that the carbonate of lime, almost invariably the predominating salt of all heretofore examined rivers, is less soluble in the presence of a strong alkaline solution like the modern Salt Lake than it is in pure fresh water; while the sulphate, nearly always inferior to the carbonate in river waters, is able to remain in solution in the presence of sulphate of soda and the chlorides of sodium and magnesium. In consequence, the carbonate of lime which is continually poured in by the rivers is promptly pre-

* Stansbury's Exploration and Survey of the Valley of the Great Salt Lake of Utah, 1853, p. 419.

cipitated. That these waters also refused to hold in solution the carbonate of lime when they were comparatively fresh, is proved by the important deposits of calcareous tufa upon the upper terrace. Had the waters of the lake at the time that it possessed an outflow been exactly like those of the rivers, it is difficult to see why the carbonate of lime which they introduced should have crystallized out in the form of tufa; but at the time of its greatest expansion the lake no doubt contained a great number of hot springs, swelling the flood with both alkaline and calcareous solutions. In the presence of these salts the carbonate of lime went down; and while the fresher lake contained sufficient carbonate of lime to furnish the material for the tufa terraces, the more concentrated waters of to-day are absolutely free from that salt. The same phenomenon is constantly observed near the mouths of rivers which deliver into the sea, where the carbonate of lime brought down by the fresh streams is deposited in the form of a fine crystalline precipitate, which is seen in the deltas cementing the sand and gravel of the estuary.

While the tufa represents the insoluble and the present lake waters the soluble portions of the contents of Lake Bonneville, there are upon the desert plains in the neighborhood of the lake, residua of evaporation which during the annual rainy season soak down into the Lower Quaternary beds, and during the dryer months by capillary attraction are drawn to the surface and dry, leaving glistening saline efflorescences, which are of great effect in the peculiar arid landscape. The valley of Deep Creek sends down a small stream bearing the drainage of a valley which in general is lifted entirely above the level of Lake Bonneville. The creek waters flow out and gradually evaporate over the Quaternary beds At the point of sinking, the ground is more or less covered with a white efflorescence of no great thickness and of variable purity. A specimen collected was analyzed by Mr. Woodward, and the result is given in analysis 24 of the Bonneville table. The insoluble portions are the sand and gravel which are unavoidably collected with so thin an efflorescence. The salt consists essentially of chloride, carbonate, and sulphate of soda and potash; when theoretically combined giving 38.25 of chloride of sodium, 37.09 of carbonate and bicarbonate of soda, and 17.54 of sulphate of soda, with 4.71 of sulphate of potash. The salt in this basin collected by us is peculiar as containing the only carbonate of soda which we have observed within the area of Lake Bonneville. Analysis No. 25 is of the efflorescence upon the lower Quaternary beds of the Great Desert, between Granite Peak and Cedar Mountain, on the old Overland Stage Road; and as it occurs in considerable thickness, often an inch or an inch and a half, the specimen is remarkably pure, having 97 per cent. of soluble matter. It is essentially a normal chloride of sodium, yielding upon analysis 99.37, with a slight admixture of sulphate of lime, amounting to only about two tenths of one per cent.

At the southern extremity of Promontory Range, the Archæan siliceous and argillaceous schists, coming down nearly to the water's edge along the eastern shore, present a cliff nearly 50 feet in height of dark shaly schists, dipping about 25° to the west. The whole cliff is deeply shattered and seamed with interlacing fissure-lines, and the rocks are variably decomposed and coated with a white aluminous efflorescence. Dr. Gale, in the Stansbury report, gives an analysis of this alum, and classifies it as manganiferous.* Prof. J. Lawrence Smith† also gives an analysis of the same alum, having crystallized it from an aqueous solution. Mr. Woodward's analysis of the salt collected by us gives sulphate of magnesia 57.07, sulphate of iron .87, sulphate of alumina 37.48, sulphate of potash .37, chloride of sodium 3.04, and excess of sulphuric acid 1.17. It will be seen that this differs from the analyses of Professor Smith and Dr. Gale by the absence of manganese, and the very small percentage of iron, which evidently replaces it. The specimen collected by this Exploration was obtained twenty-two years after the former, and probably there has been a radical change in the character of the salt. The analysis as given by Mr. Woodward makes the mineral a richly magnesian alum, with a little chloride present as an impurity. It is rather a pickeringite than a bosjemanite, which was clearly the salt analyzed by Professor Smith.

Copious springs, rich in chloride of sodium, with a little sulphate of soda and sulphate of potash, flow out from under the limestones along the

* American Journal of Science and Arts, Vol. XV., 1853, p. 434.
† American Journal of Science and Arts, Vol. XVIII., 1854, p. 379.

eastern base of Promontory Range, and add their salts to the already strong chloride solution of the lake.

Upon the old Overland Stage Road, west of River Bed Station, was a stage-house known as Dugway Station. Analysis No 27 is of the saliferous strata of the upper Quaternary, taken from two feet below the surface in a ravine near the station. It is essentially a fine but gritty sand deposit, with a soluble salt distribution through the interstices. It only contains about five per cent. of saline matter. The analysis yields 86.33 of chloride of sodium, 1.05 of sulphate of soda, 9.11 of sulphate of lime, 1.9 of sulphate of magnesia, with a small excess of sulphuric acid. The surface of the desert, made up of a loose, calcareous, clayey soil, mixed with a good deal of fine sand, was also examined chemically. The result in analysis No. 28 shows that there were but five tenths of 1 per cent of soluble matter, and the main portion of the insoluble is sulphate of lime. A little chloride of sodium and an unimportant amount of sulphate of magnesia make up the soluble part. In other words, from the surface-soil has been leached out the greater part of the soluble salts, while from the strata a few feet below is obtained a sample having eight times as much soluble matter, and that chiefly made up of chloride of sodium and sulphate of magnesia.

Along the base of Wahsatch Range, at Salt Lake City and north of Ogden, are important hot springs pouring a large volume of heated waters into the lake drainage. They contain sulphuretted hydrogen, carbonates of lime and magnesia, sulphate of soda, and chloride of sodium, the latter being in all cases much the largest factor. South of Utah Lake the bed of the ancient lake has not been examined by this Exploration.

From a qualitative examination of numerous salines, besides those whose quantitative analyses are given in the accompanying table, it seems that the predominant salts of this whole basin are chlorides of sodium and magnesium, with sulphates of soda, lime, and potash, the latter always in much less quantity than the chloride salts. The efflorescence at the sink of Deep Creek is the only alkaline carbonate observed; and even if in the localities not visited by us there should be found other sources of alkaline carbonate, they must remain as exceedingly unimportant and exceptional salts in this basin. It is essentially a chloride basin, with the addition of a moderate amount of sulphate salts. It would seem that the carbonate of lime, which is now brought in by the present drainage, either goes down as a crystalline precipitate of carbonate, or decomposes some of the sulphates and remains in solution as sulphate of lime, of which the present waters bear .85 solid in 1,000 liquid grammes. Interesting spherical carbonate of lime sands are observed at several points on the beaches and lake bottom, notably near Black Rock on the west shore of Promontory and on Bear River bay. Under the microscope these globular sands are seen to possess a concentric structure, the layers made up of what appeared to be crystallites. From the numerous chloride and sulphate springs within this basin, it is clear that, although now the lake is very concentrated, the present constituents have been the predominating ones as far back as we have any chemical clew. While it is well known that in process of time there is a change in the chemical products of springs, yet there is no local reason to suppose that in this case they have been other than chloride and sulphate springs. In the case of Lake Lahontan, as will be shown later, there has been a great chemical change in the character of the salinity, but there is no reason to infer that a parallel change has taken place in the Bonneville area.

The desert efflorescences arise from strata which were thoroughly impregnated with the salts of the lake at the time of its desiccation, and which come out upon the surface in the dry months, and during periods of rain are partially drained into the lake and partially soaked back into the strata. To the springs and to the rivers which flow into the lake we must look for the true source of supply of the ingredients of the lake; and while the prominent salts of the rivers are carbonates and sulphates of lime, those of the thermal springs are chlorides and sulphates of the alkalies. To the rivers, therefore, are due in great measure the tufaceous material and limy sand, while to the springs are probably due the alkaline properties of the lake. The saline zones seen at points in the Pliocene strata, although they never possess a high percentage of soluble matter, are sufficient to indicate periods of desiccation during the Pliocene, or, in other words, oscillations in the dryness of climate quite analogous to the two dry ages shown by the subaerial gravels of the Bonneville area of Utah, which has been the theatre of two or more periods of important desiccation, with an accompanying concentration of solutions.

A few alkaline incrustations in middle Nevada, outside the limits of the two great Quaternary lakes, are of some interest and are given here in table of chemical analyses No. IV. In the same table are included for convenience some hot-spring products which will not be specially mentioned.

Among the more interesting salines, the following may be particularly noticed:

Clover Valley, which lies directly east of the highest part of the Humboldt Mountains, carries the well known Eagle Lake, and receives the drainage of a considerable area. Some of the streams which flow from the mountain into this basin sink into the gravelly Quaternary, and always, during the dry, warm season, there is a limited amount of saline efflorescence at or near their sinks. A specimen collected by us shows an amount soluble in water of 37.8 per cent. Under analysis, it proves to be composed of 24.96 of chloride of sodium, 39.04 of carbonate and bicarbonate of soda, and 33.88 of sulphate of soda, with a trifle of sulphate of potash. It will be seen that this mixture of chloride, carbonate, and sulphate is the characteristic mixture of the lakes of western Nevada, and the high percentage of carbonate already shows a change from the Bonneville area.

On the west side of Humboldt Range, in the valley of the North Fork of the Humboldt, near Peko, there is also an alkaline efflorescence which permeates the sandy soil of the flood-plain of the river. This saline matter is a seepage from the alkaliferous strata of the Pliocene which covers a great portion of the country drained by the North Fork of the Humboldt. These sands, as collected, contain 53 per cent. of soluble matter, of which only a small proportion ($7\frac{1}{2}$ per cent.) is chloride of sodium, while there is the unusually high proportion of $83\frac{1}{2}$ per cent. of carbonate and bicarbonate of soda, with 4.6 per cent. of sulphate of soda and 4.4 per cent. of biborate of soda. These salts, the result of carbonate and borate springs, have impregnated more or less of the Pliocene strata on both sides of the river; but this is the most typical and richest of the carbonate efflorescences of this region.

Number of analysis.	Loc	Mg S̈	F̈e	S̈i	S̈	Total.
24	Sink of Deep Cre	. .	. .	. .	. .	. .
		. .	. .	. .	. .	. .
25	Great Desert, betw and Cedar Mou	. .	. .	. .	0.04	99.65
		. .	. .	. .	0.13	100.03
26	Alum Bay, Utah	7.07	F̈e S̈ 0.87	Äl S̈ 37.48	1.17	100.00
		7.01	F̈e S̈ 0.83	Äl S̈ 37.25	1.21	100.00
27	Dugway Station, road, Great Des below surface.	1.71	. .	. .	0.05	99.00
		1.90	. .	. .	0.58	98.97
28	Surface, Dugway S	. .	. .	. .	. .	. .
		. .	. .	. .	. .	. .

Number of analysis.	Loca
29	Main Terrace, Re Lake Desert.

Number of analysis.	Loca	Ca S̈	Mg Cl	Cl	Total.
30	Salt Lake water*	.858	14.908	Excess. .862	149.940

DESICCATION-PRODUCTS OF LAKE BONNEVILLE.

Saline Efflorescences.

Number of analysis.	Locality.	Analyst.	Per cent. soluble in water	F̈e	Ca	Mg	Ṅa	Na	K̇	K	Cl	C̈ Excess above mono-carbonate.	C̈ Fixed.	S̈	Oxygen equivalent.	Total.	Na Cl	Na C̈+Ċ	Ṅa S̈	K̇ S̈	Ċa S̈	Ṁg S̈	F̈e	S̈i	S̈	Total.
24	Sink of Deep Creek - - - - -	R. W. Woodward	31.25	. .	. .	. .	26.47	16.50	2.55	.	23.20	4.91	13.36	12.05	. .	99.04	38.25	37.09	17.54	4.71	. .	. .	. .	. .	. .	. .
			31.25	. .	. .	. .	26.39	16.37	2.51	.	23.14	5.00	13.36	11.91	. .	98.68	38.14	37.17	17.37	4.63	. .	. .	. .	. .	. .	. .
25	Great Desert, between Granite Rock and Cedar Mountain.	"	97.00	. .	0.10	. .	. .	39.06	tr.	.	60.31	. .	. .	0.18	. .	99.65	99.37	. .	. .	. .	0.24	. .	. .	. .	0.04	99.65
			97.00	. .	0.09	. .	. .	39.28	tr.	.	60.49	. .	. .	0.17	. .	100.03	99.68	. .	. .	. .	0.22	. .	. .	. .	0.13	100.03
26	Alum Bay, Utah - - - - - -	"	36.55	0.35	Al_2O_3 11.26	19.02	. .	2.24	. .	0.28	1.85	. .	. .	64.96	0.04	100.00	3.04	. .	. .	0.37	. .	57.07	F̈e S̈ 0.87	Äl S̈ 37.48	1.17	100.00
			36.55	0.33	Al_2O_3 11.18	19.00	. .	2.16	. .	0.30	1.86	. .	. .	65.11	0.06	100.00	3.05	. .	. .	0.65	. .	57.01	F̈e S̈ 0.83	Äl S̈ 37.25	1.21	100.00
27	Dugway Station, Overland stage-road, Great Desert, Utah, two feet below surface.	"	4.83	. .	3.84	0.57	. .	34.56	tr.	.	52.53	. .	. .	7.37	0.14	99.01	86.61	. .	1.31	. .	9.32	1.71	. .	. .	0.05	99.00
			4.83	. .	3.76	0.63	. .	34.88	tr.	.	52.37	. .	. .	7.21	0.12	98.97	86.33	. .	1.05	. .	9.11	1.90	. .	. .	0.58	98.97
28	Surface, Dugway Station - - -	"	00.50	. .	31.22	1.84	. .	9.54	. .	.	9.78	. .	. .	45.60	0.54	97.44	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
			00.50	. .	30.87	2.41	. .	9.20	. .	.	10.81	. .	. .	45.48	0.50	98.27	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .

Thinolite (Pseudo-Gay-Lussite).

Number of analysis.	Locality.	Analyst.	S̈i	Äl	F̈e	Ċa	Ṁg	Ṅa	K̇	L̇i		Ḣ	C̈	Total.	Specific gravity.
29	Main Terrace, Redding Spring, Salt Lake Desert.	R. W. Woodward	8.40*	1.31	tr.	46.38	3.54	0.48	0.22	tr.	PO^5 tr.	1.71	38.20	100.24	2.4, 2.3, 2.4
			8.22*	1.20	tr.	46.50	3.52	0.54	0.22	tr.	PO^5 tr.	1.62	38.33	100.14	. . .

* Combined silicic acid and sand.

Lake Water.

Number of analysis.	Locality.	Analyst.	Ċa	Ṁg	Ṅa	K	Cl	S̈	B̈	P̈	Oxygen equivalent.	Total.	Specific gravity.	Na Cl	Ṅa S̈	K̇ S̈	Ċa S̈	Mg Cl	Cl	Total.
30	Salt Lake water* - - - - - - -	O. D. Allen - -	.3570	6.301	66.978	2.901	83.946	8.215	tr.	tr.	18.758	149.940	2.4, 2.5	118.628	9.321	5.363	858	14.908	Excess. .862	149.940

* Solid grammes in 1000 grammes' weight of water.

LLEL.

	Na B̈	K Cl	K̇ S̈	Ca Cl	Ca S̈	Mg Cl	S̈i	Insol. res.	Ḣ		Total.
											99·42
			1·94							CO^2 0.43	100.25
	4·49										100.21
		0.88		11·94	6.31	8.80				Na 1·53	100.89
		0.87		12·11	5·84	8.55				Na 1.68	100.10
			9·14							0.63	99·83
			9·32							0·74	99·53
3											
3								0.13	0.52		100.00
3			5·31		2·77		0.10			SO_3 0.37	99·05
3											
4			2.82								100·77
			2.68								101·05
4											
4											
43											
44											

Salines and Hot-Spring Products.

Number of analysis.	Locality.	Analyst.	Per cent. soluble in water.	Fe	Ca	Ca	Mg	Mg	Na	Na	K	K	Li	Cl	C Excess above mono carbonate	C Fixed	S	B	P	Si	H	Insol. res.	Oxygen equivalent.	Total.
31	Cortez Valley (Efflorescence.)	O. D. Allen			tr.						tr.							tr.						
32	Clover Valley (Efflorescence.)	R. W. Woodward	37.80						35.66	9.79	1.04			15.15	3.35	15.27	19.99	tr.	tr.					100.25
33	North Fork Humboldt Peko (Efflorescence.)	"	53.00						46.81	2.97				4.58	10.07	30.78	2.59	2.41						100.21
34	Alkali Flat, Humboldt Valley (Efflorescence.)	"	16.40			6.16		2.22		29.62		0.46		57.97			3.72						0.74	100.89
			16.40			6.08		2.16		29.45		0.46		57.83			3.44						0.68	100.10
35	Spalding's Salt Marsh, Smoky Valley Flat, Nevada. (Efflorescence.)	"	92.00							35.90	4.94			54.62			4.37							99.83
			92.00							35.82	5.04			54.27			4.40							99.53
36	Hot Spring, Ruby Valley (Incrustation.)	"		1.75	0.80				1.06		0.27									88.79	7.33			100.00
				1.74	0.82																7.31			
37	Hot Springs, Humboldt Range (Incrustation.)	O. D. Allen																tr.						
38	Hot Springs, Humboldt Range (Incrustation.)	"			1.17				39.87		2.87			2.32			53.23			0.10			0.52	99.05
39	Hot Springs, Humboldt Range (Incrustation.)	"		4.23	10.20		2.48		12.36		1.50			3.40		4.91	16.69					42.04		97.81
40	Hot Springs, Ruby Valley (Efflorescence.)	R. W. Woodward	57.86						50.46	0.84	1.53		tr.	1.29	29.22		17.43		tr.					100.77
			57.86						51.10	0.64	1.45		tr.	0.99	29.30		17.57							101.05
41	Steamboat Springs, Geiger Grade (Incrustation.)	"		Al+Fe 0.80	0.14		0.05		0.75		0.18		tr.							92.67	5.45			100.04
				Al+Fe 0.65	0.18		0.05		0.99		0.15		tr.							92.76	5.47			100.25
42	Steamboat Springs, Geiger Grade (Incrustation.)	"		Al+Fe 0.72	0.41		tr.		0.46		0.26		tr.							90.11	7.56			99.53
				Al+Fe 0.53	0.33		tr.		0.37		0.27		tr.							90.42	7.55			99.47
43	Sediment from Hot Springs, Reese River Valley. (Incrustation.)	"		Fe 0.44	48.98		0.94						tr.			39.02	0.24				10.38			100.00
				Fe 0.42	48.98		0.96						tr.			38.70	0.21				10.73			100.00
44	Hot Spring, Grass Valley (Incrustation.)	"		0.26	48.32		3.98						tr.			39.07					8.70			100.33
				0.12	48.26		4.11						tr.											

Number of analysis.	Na Cl	Na C	Na C+C	Na S	Na B	K Cl	K S	Ca Cl	Ca S	Mg Cl	Si	Insol. res.	H		Total.
31	78.31			21.11											99.42
32	24.96		39.04	33.88			1.94							CO² 0.43	100.25
33	7.55		83.57	4.60	.49										100.21
34	71.43					0.88		11.94	6.31	8.80				Na 1.53	100.89
	71.05					0.87		12.11	5.84	8.55				Na 1.68	100.10
35	90.06						9.14							0.63	99.83
	89.47						9.32							0.74	99.53
36															
37	96.48	0.96		1.91								0.13	0.52		100.00
38	3.82			86.66			5.31		2.77		0.10			SO_3 0.37	99.05
39															
40	2.13		67.19	28.63			2.82								100.77
	1.63		67.75	28.99			2.68								101.05
41															
42															
43															
44															

In Diamond Valley, between Diamond and Piñon ranges, is a remarkable exposure of the Lower Quaternary, being the bed of an extinct lake composed of strata of sand and clay of excessively fine material. During the wet season, and at times throughout the whole year, there is still a shallow lake near the northern end of the valley, which is a strong solution of sulphate, carbonate, and chloride, in which, however, the carbonate predominates over the sulphate, and at times equals the chloride. During the drier seasons the whole of this broad alkali flat, for a distance of ten or fifteen miles, is a clean, hard, white sheet of alkaline and calcareous clay, which upon drying receives a glaze like hard-finish, and indeed is almost as hard as the plaster upon a wall. Heavy teams driven across it scarcely leave a wheel-print, and the sun reflects from it as from a marble pavement.

In Crescent Valley, between Piñon Range and Shoshone Peak, is an area of wet clay and quicksand, which receives the drainage of several saline springs, and bears upon the surface in the drier portions of the year a variable incrustation of salt. This is almost a pure chloride, with a very little sulphate and carbonate. Owing to the influx of the saline springs, this whole clay is kept in a very soft and plastic condition, and, as there is no outward drainage, the salts accumulate and stand during the moist periods in pools of saturated brine. The salts of nearly all these predominant chloride deposits are used for commercial purposes, chiefly for the chloridizing of silver ores.

East of Toyabe Range, in Smoky Valley, there is a prominent depression, formed of Lower Quaternary stratified clays, which receives the drainage of the mountains on both sides, and is a wet, marshy clay-bed during winter, and a hard, smooth, alkali flat during summer. At the northern or lowest portion of this alkaline plain there is a region of reasonably pure chloride of sodium, which is derived from the evaporation of saline springs that pour their water into the valley. The salt proves to have 90 per cent. of chloride of sodium and a little over 9 per cent. of sulphate of potash.

Interesting hot springs occur in the northern part of Ruby Valley, between Frémont's Pass and the Overland Ranch. They are essentially like the Icelandic geysers, depositing a tufa which is about 90 per cent.

silicic acid, with small additional percentages of sesquioxyd of iron, lime, soda, and potash. These hot springs, besides depositing a large amount of pure white siliceous geyser tufa, discharge waters carrying more or less of the carbonates of potash and soda, which pass into Ruby Lake, a shallow body of water occupying the trough-like depression of the valley. The lake is predominantly a carbonate one, but it is of such a weak solution that fish are able to live there. All the spring waters of central Nevada, with the few exceptions of those having their origin in granite, are strongly impregnated either with salts of lime or with those of the alkalies.

Humboldt and Reese rivers, like almost all modern rivers, carry carbonate of lime in excess over all other salts, but all the Nevada rivers have also a variable amount of free alkaline carbonates. On entering the brackish lakes at the sinks of these rivers, the carbonate of lime mainly goes down, and the alkaline carbonates, chlorides, and sulphates remain to enrich the saline solution.

LAKE LAHONTAN.

Already, in the account of the Tertiary, it has been shown that at the close of the Pliocene period the lake which stretched over the present area of the Great Basin suffered disturbance, its two sides subsiding to form two new deep basins. The depression of Lake Bonneville extended from latitude 37° 30′ to latitude 42°. The corresponding depression of the west of the Great Basin lying at the east side of the Sierra Nevada extended from latitude 41° 30′ southward to about the same latitude as the southern waters of Lake Bonneville. The general area of the lake was somewhat less than that of the Utah depression, and its altitude also was a few hundred feet lower. As the widest area and deepest depression of Bonneville Lake were under the bold heights of the Wahsatch, so in the depression in western Nevada the greatest depth and the greatest width are opposite a high group of the Sierra.

To the western Nevada and California Basin I have given the name of Lake Lahontan, in honor of the French explorer. There is no single large sheet of water like Great Salt Lake in the present desiccated bed of Lake Lahontan, but there are several considerable bodies whose united area is about equal to half the present lake surface of the basin of Bonneville. Walker, Carson, and Truckee rivers carry the eastward drainage of the Sierra Nevada and flow into the west side of the old lake basin. The Humboldt enters it from the northeast and flows for over a hundred miles within its former boundaries.

A very considerable part of the area of Lake Lahontan was occupied by lofty mountainous islands which rose above the surface to heights often of several thousand feet. The Pah-Ute, Humboldt, Montezuma, Pah-tson, Sahwave, Truckee, and Lake ranges were all gathered as a great group of islands in the middle area of the lake.

Southward, the shore-line was noticeable for its long, deep bays, entering the land to the east and surrounding complicated, narrow peninsulas. The entire beach line is well defined by a series of terraces, cut, like those of Lake Bonneville, in the steep, rocky slopes of the mountainous shores and islands, or gently excavated along the easy slopes of the inclined Tertiaries. Walker, Carson, Humboldt, Winnemucca, and Pyramid lakes, receiving the present influx of water, represent relics which the general desiccation has spared.

One of the most interesting of the recent geographical features in this area was the bifurcation of Truckee River on its downward flow. Emerging from Virginia Range, it turns a sharp right angle and flows northward in the valley depression between Virginia and Truckee ranges, the general level of the country declining to the north. The Truckee here flows in the bottom of a sharp cañon which it has cut through the horizontal Pliocene beds. Northward these beds are bevelled off, and near the south end of Pyramid Lake the river flows out upon a plain, its banks lined with wandering groves of cottonwood trees. At the time of our first visit to this region, in 1867, the river bifurcated; one half flowed into Pyramid Lake, and the other through a river four or five miles long into Winnemucca Lake. At that time the level of Pyramid Lake was 3,890 feet above the sea, and of Winnemucca about 80 feet lower. Later, owing to the disturbance of the balance between influx and evaporation already alluded to as expressing itself in Utah by the rise and expansion of Great Salt Lake, the basin of Pyramid Lake was filled up, and a back water overflowed the former region of bifurcation, so that now the surplus waters all go down the channel into Winnemucca Lake, and that basin is rapidly filling.

Between 1867, the time of my first visit, and 1871, the time of my last visit, the area of Winnemucca Lake had nearly doubled, and it has risen from its old altitude about twenty-two feet, Pyramid Lake in the same time having been raised about nine feet. The outlines as given upon our topographical maps are according to the survey of 1867, and form interesting data for future comparison.

The regions of the two great Quaternary lakes have this general geological difference: Bonneville was an area of depression as early as the Eocene, but during the Miocene had free drainage to the sea; Lahontan was a land area during the Eocene, but during the Miocene was a lake basin.

In the present desiccated period the aspect of the Lahontan area does not differ very greatly from that of Lake Bonneville. It is a series of alkaline clay plains, composed of undisturbed Lower Quaternary beds, the equivalent of the Bonneville clays, surrounded by more or less inclined regions of subaerial gravel between the actual Lower Quaternary level areas and the mountain foot-hills. The mountain ranges, such as the Pah-Ute, Montezuma, and West Humboldt, rise from 3,000 to 6,000 feet above the ancient lake bottom, their rugged sides for the most part bare of any conspicuous vegetation, carrying upon their upper heights a few scattered piñon and cedar trees. Nowhere reaching to the level of perpetual snow, and in general either of dusky desert colors or displaying the brilliant, variegated tints of the volcanic series, the general aspect of the mountains is of unrelieved barrenness.

The clay plains, during the dry summer months, are covered with efflorescences of soluble alkaline salts, which in many instances give the appearance of fields of snow.

In particular, the basin of the Carson-Humboldt Sink affords landscapes of the most peculiar type. The various channels of Carson River are margined by bands of intensely green vegetation, sharply hemmed in by the absolutely barren surface of the desert. The plains are either ashen gray or snowy white, and the waters of the lake reflect the colors of the sky or the tints of the neighboring mountains. Along the foot-hills is traced with perfect distinctness the old beach-line of the extinct lake, its even, horizontal terraces carved into the Tertiary slopes or escarped in the hard volcanic bluffs.

The altitude of the surface of Lake Lahontan was 4,388 feet, or about 800 feet lower than Lake Bonneville. A cursory examination of the country lying north of the lake area indicates that there was no outlet in that direction. South of the great archipelago formed by West Humboldt, Montezuma, and Truckee ranges, with their dependencies, was a broad stretch of lake without islands, including the basin which now contains the two saline lakes of Carson River. Along the foot-hills of the Pah-Ute and the hills to the south of Carson River, the old beach-lines are exceedingly well displayed, and, wherever the slope is sufficiently gradual, the recession of the water marked, as in the case of Lake Bonneville, numerous terraces, indicating pauses in the general progress of desiccation. South of Walker's Lake and Gabb's Valley, the outline of the basin is hypothetical, and is constructed from a few barometrical notes afforded me by Mr. A. D. Wilson. I have never examined the region of a supposed outflow to the south, but a singular topographical feature, known as Forty-Mile Cañon, south of the Ralston desert, seemed to me to afford a possible solution of the question of the drainage of the lake. The accounts brought by prospectors of Forty-Mile Cañon indicate that its waters formerly flowed southward, and it is not at all impossible that the surplus of Lake Lahontan found exit through that channel and flowed southward along the slope of the continent.

The valley of the Great Desert of California from San Gorgonio Pass southward to the Mexican line affords a close parallel to the area of Lake Lahontan It is far lower in altitude, its extreme depth being below the present tide-level. There, however, as on the mountain coasts of Lake Lahontan, the terrace lines are recorded in well defined beaches, and wherever the character of the underlying rock was at all calcareous there is an accumulation of tufa which either encrusts the surface in thick beds or acted as a cement for inflowing gravels, forming a shore breccia.

As compared with Lake Bonneville, the chief characteristic difference in the phenomena of terraces and shore lines is the great abundance in the Lahontan basin of calcareous tufas. Modern subaerial gravels have been in great measure washed down over the calcareous matter, but it frequently exists even on the broad bottom of the lake in thick accumulations—covering areas of several miles with a tufaceous deposit from twenty to sixty feet thick. As will be seen later, this tufa is of very great chemical interest, and its mineralogical nature affords a clew to the history of the lake. From its very great importance and its peculiar origin, I have taken the liberty of giving it a lithological name. Since it formed on the shores of the lake, I have called it, from the Greek *Θὶς* (shore), Thinolite.

During all the Quaternary the high mountains have afforded the loci of disintegration and removal. Aside from the period of great cañon-cutting, the general frost and snow disintegration, and the recurrence of annual storms and floods, have swept down from the mountain flanks and from the cañons an enormous amount of sub-angular fragmental material partly in the condition of fine sands, but largely of coarse gravel, of which the fragments vary in size from a hazel-nut to blocks of several tons in weight. The thickness of these deposits is nowhere seen, but from the manner in which they build up talus-slopes against the foot-hills of the mountains it is evident that there can not be less than one or two thousand feet in some extreme instances.

From every mountain and range foot declines this gentle slope, the larger materials next the mountains, the smaller washed out to greater distances. The uppermost gravels of this series, when traced down into the level desert areas, are seen to overlie the horizontal stratified sands, clays, and marls of the Lower Quaternary, which are an undisturbed formation of an unknown depth. In the stream-cuts which have opened extremely modern sections in the subaerial gravels, it is seen that the stratified Lower Quaternary overlies a considerable portion of the subaerial gravels; indicating a former expanse of water during which the lake area encroached upward and outward over the older subaerial gravels, a final recession from its extreme expansion, and a subsequent pouring down of modern subaerial gravels over the exposed surface of the sedimentary beds. This is the same phenomenon which Gilbert has described within the basin of Bonneville. It is best shown, over the Lahontan area, in the region of Pyramid Lake and the flanks of Truckee and Lake ranges near their northern ends, where are considerable exposures of the lower and earlier gravels. Near the height of the uppermost terrace the gravels are largely cemented by calcareous tufa, as they are upon the higher terraces at Lake Bonneville; but in passing downward the calcareous deposits are very different, the tufa occurring in enormous masses 30 to 60 feet thick, and with little inclusion of foreign rocky fragments.

The broad area of Mud Lake Desert, the floor of Gabb's Valley, and the clay flats surrounding the two Carson lakes are conspicuous examples of the larger exposures of the Lower Quaternary lacustrine clays and sands. As in the Bonneville region, the lower and earlier subaerial gravels show to such a very small extent in the exceptional modern cuts that they could make no feature upon a geological map.

Organic life seems to have been much rarer in Lahontan Lake than in Bonneville. A few *Planorbis* are the only species of *Mollusca* we have found embedded in the gravels. One or two deep wells have been sunk on the Carson Desert, in the hope of finding a water free from the prevalent alkaline salts, and these display from 80 to 100 feet of Lower Quaternary beds composed chiefly of clay and sand, with far less of the marly or calcareous matter than may be seen at the Dugway well in Bonneville Basin.

A partial examination of the waters and desiccation-products of the Lahontan area has resulted in the discovery of some very interesting chemical facts. Among the waters which now enter the basin as rivers or exist in the form of lakes, perhaps the most interesting are those of Pyramid, Humboldt, and Soda lakes.

Pyramid Lake has a specific gravity of 1.0027; its solid contents computed for a thousand grammes of water and expressed in grammes show: Chloride of sodium, 2.8871; carbonate of soda, .5384; sulphate of soda, .2485; carbonate of lime, .0178; besides a little magnesia and carbonic acid. It is essentially a chloride lake, with the presence of carbonates of soda, magnesia, and lime, and a little sulphate of soda. The relative proportions of chloride of sodium and sulphate of soda in Pyramid Lake do not greatly differ from the ratio of the same salts in the far denser solution of

Salt Lake, but the waters differ widely by the presence of carbonates of soda, lime, and magnesia. The high proportion of carbonate of soda, amounting to one sixth of the total saline contents, accounts for the presence of the carbonate of lime. It was seen that in the solution of Salt Lake carbonate of lime did not exist. That salt, as it was delivered by the inflowing rivers, either suffered double decomposition with the sulphate of soda, remaining as sulphate of lime, or, as was evidently true of the greater amount of the carbonate, fell as a precipitate. The possibility of carbonate of lime, even in the small percentage which is present in Pyramid Lake, remaining in solution in the presence of so much chloride of sodium and sulphate of soda, is unquestionably to be accounted for by the presence of carbonate of soda.

Humboldt Lake, which is really a mere expansion of Humboldt River, is a water of considerably less salinity than Pyramid Lake, having a specific gravity of 1.0007, with a total amount of saline matter of 88.8 solid in 1,000 liquid grammes. It differs quantitatively from the water of Pyramid Lake by the inferior percentage of chloride of sodium, and qualitatively by the astonishingly high percentage of chloride of potassium, which amounts to nearly one third of the entire saline contents. In the Pyramid Lake water there is an excess of magnesia over the carbonic acid with which to combine it. In the Humboldt Lake water, however, besides the necessary carbonic acid to unite with the magnesia, there is an excess amounting to .0425 of free carbonic acid, and there is also a minute percentage of phosphoric acid. It is highest in the percentage of carbonates of any water in the basin, with the exception of the Soda Lakes north of Ragtown. Traces of boracic and silicic acid occur in both Pyramid and Humboldt lakes, and their waters also gave, under the spectroscope, a distinct reaction for lithia.

For a detailed description of the little Soda Lakes lying on the desert north of Ragtown, Nevada, the reader is referred to Chapter V., Vol. II. The water of the larger Soda Lake is of very great interest, since from its dense solution at all the drier periods of the year, when the fluid is concentrated by natural evaporation, the mineral gaylussite crystallizes on the edges of the basin and on any bits of organic matter which may be floating or lying in the lake. It is a dense water, having, at the time of our examination, in 1,000 liquid grammes, solid contents of 114.449 grammes, and a specific gravity of 1.0975. Although the proportion of carbonate of soda to chloride of sodium is not so high in this lake as in the waters of Humboldt Lake, its large carbonate tenure, amounting to 29.2482 of carbonate of soda, .0652 of carbonate of magnesia, with a considerable excess of free carbonic acid, makes it the most important carbonate water in the Lahontan area. Of chloride of sodium there are 69.9413 grammes, and of sulphate of soda, 13.7626. Sulphide of sodium is present, amounting to .2384, and sulphate of potash equalling 3.6513. Like the Humboldt water, it has a little combined silica. It is therefore a chloride, carbonate, and sulphate water, in which no lime whatever was detected by the most delicate tests. It is interesting that in a lake which is especially noted for the annual production of fine crystals of gaylussite, there should be no trace of lime in the water. It is evidently true that in the presence of a high proportion of alkaline carbonates every atom of lime which the annual floods wash in from the surrounding calcareous soils is at once seized by the alkaline carbonate, and made up into gaylussite. Prof. O. D. Allen, of Yale, who executed the above analyses, also made a careful examination of the solubilities of Nevada gaylussite in clear water and in weak carbonate solutions. The mineral was readily acted upon in the presence of sulphates and chlorides and a small proportion of carbonate of soda. It retained its integrity only in solutions with a considerable excess of alkaline carbonate. An examination of the evaporated salt is given in the table of analyses No. V. of the desiccation-products of Lake Lahontan. The gaylussite itself yielded 19.19 of lime, 19.95 of soda, 29.55 of fixed carbonic acid, a trace of sulphuric acid, 31.5 of water, and .2 of insoluble residue, which was altogether small particles of sandy material; the water percentage being a little higher and the insoluble residue a little lower than the analysis of Boussingault given in Dana's Mineralogy. The artificial production of gaylussite by Fritsche, requiring an enormous excess of carbonate of soda, is thoroughly in keeping with the chemical reactions of the Soda Lake water. It is interesting to observe that all the forms which crystallize in this lake are thin in the direction of the orthodiagonal, producing short, flat crystals, like Figure 607 in Dana's Mineralogy.

The occurrence of these two lakes is so peculiar and interesting as to demand more than a passing mention. The surface of the country in their neighborhood is about 4,000 feet above the sea-level, and is formed of the level beds of Lower Quaternary strata, here consisting of sandy clays, having a surface which has been modified only by æolian erosion and the slight effect of rains and storms. The two basins lie within an eighth of a mile of each other, and they are almost exactly circular, the larger having a bank varying from 35 to 150 feet in fine perpendicular walls, and a diameter of about five eighths of a mile. The smaller lake occupies a similar crater-shaped basin, its banks having a height of from 50 to 70 feet, and at the date of its highest water the diameter is hardly more than one fifth of a mile. In the smaller lake during the drier periods of the year the solution becomes very dense, and a considerable part of the bottom of the lake is laid bare, with a thick incrustation of trona over the exposed portion. Neither basin has an outlet. The larger one is fed by a cool fresh-water spring on the northwestern side, which pours from a gravel stratum just above the lake. The formation of these depressed, funnel-like hollows in the middle of a Quaternary desert, having no outward drainage, and only varying in their density according as the humid or the evaporating period advances, is not altogether easy to account for. The presence of much basaltic material on the banks and narrow margin of beach, and the circular, crater-formed depression which the lake occupies, lead us to suspect that during the period of the occupancy of this region by Lake Lahontan, when the Lower Quaternary beds were in process of accumulation, and when there were at least 500 feet of water over the present surface, these crater-like lakes were points of extremely powerful springs, deriving their great activity from volcanic sources.

Extremely powerful springs are now observable, coming to the surface from very great depths in the strong alkaline solution of Mono Lake. That water, besides being densely charged with alkaline carbonates, is also characterized by the abundant presence of borates, its solution being far denser than any of the considerable lakes of the Lahontan area. Rowing on its surface

in a boat of considerable size, over water of a depth of more than a hundred feet, I came upon strong springs of rather fresh water, which rose above the level of the lake in low mounds, and this constant fountain-like projection of fresh waters above the surface was strong enough to deflect the boat from its course. The diameter of some of these cold-water mounds was from 100 to 150 feet. A jet like this evidently necessitates a very powerful pressure of water at the lake-bottom, where the spring emerges from the sandy material of the floor. If from any cause the basin of Mono Lake, which is now covered with fine lacustrine muds, should be exposed by the desiccation of the lake, and the great spring jets cut off from their source of supply, on the horizontal beds which are now accumulating over the bottom would undoubtedly be found crater-like basins similar to those of the alkaline lakes near Ragtown.

Plate XXVI. in this volume gives a very correct idea of the general appearance of the larger Ragtown lake, showing the high, steep banks, with the beach-line underneath them and the lower banks on the left. The smaller lake is shown in Plate XXII., Volume II., where the trona fields may be seen on the partially dried lake-bottom. In later pages it will be seen that an enormous amount of alkaline carbonate must formerly have characterized the waters of one period of Lahontan. The origin of these alkaline carbonates is among the most difficult of the chemical problems of the region. That this carbonate was not a result of the organic decomposition of other salts, will become evident from a glance at the enormous quantities involved. Only a very few of the thermal or cold springs of the whole Great Basin country are now delivering carbonated alkalies. The hot springs of Ruby Valley, which deposit a liberal incrustation of geyser silica, yield a considerable proportion of carbonate of soda. It is not improbable that the Ragtown lakes, with their dense carbonate solutions, represent the relics of a once copious source of the salt.

Among the efflorescences found upon the desert, that at Magg's Station on the Truckee desert is nearly pure chloride of sodium, only varied by less than 2 per cent. of sulphate of lime. At Hardin City, however, in the Black Rock region, the efflorescence of the great Mud Lake desert yielded in 100 parts, 18.47 of chloride of sodium, 52.10 of carbonate of soda, with

27.55 of sulphate of soda. This is the only instance of a considerable area of efflorescence, in which the alkaline carbonate exceeds the united chlorides and sulphates. At the sink of Quinn's River the efflorescence contained chiefly sodium chloride, varied only by sulphate of soda and lime. A similar salt, with a higher proportion of sulphate of lime, occurs as an efflorescence through the alkaline earth near Buffalo Station. From the lesser Soda Lake near Ragtown comparatively pure trona is taken, having a composition of 40.77 of soda, 37.88 of carbonic acid, with a little chlorine and sulphuric acid, and 20 per cent. of water.

I have already remarked that the most interesting chemical result of the desiccation of Lake Lahontan was the enormous deposit of thinolite tufa. In the immediate foot-hills of some of the higher ranges, the terraces and slopes, thickly incrusted with a gray coral-like material, are covered over with the most recent subaerial gravels. This is particularly the case along the Osobb Valley, which lies between Augusta and Pah-Ute ranges. So, too, along the slopes south of Carson Lake, on the divide between Carson and Walker basins, much of the thinolite surface is covered with extremely modern gravelly detritus, but here and there along those slopes, wherever the topography was steep enough to preserve a rocky front, the crusts of gray and whitish tufa are still uncovered. Even along the flat bottom of the desert, at elevations of about 4,000 feet, there are long reefs covered with the tufa, which rises in most peculiar and fantastic forms, standing up often in cylindrical chimneys, having an obscure, partly obliterated tube in the axis. Some of these chimneys are ten and twenty feet in height. For the most part thinolite has an extremely rough, ragged surface, full of intricate interstices, rarely in the region of Carson Lake showing any considerable exposure. In the region of Humboldt Lake, on the slopes of Montezuma Range, it is nearly overwhelmed with modern débris, but along the railroad are a few rocky ledges covered with coatings five to ten feet thick of tufa. Single isolated groups of fantastic forms occur southwest of Oreana, rising above the Quaternary plain, which is based upon the horizontal Tertiary of the Humboldt group. Along the slopes of Pah-Ute Range which face the Carson desert are but few traces of thinolite; but on the south foot of

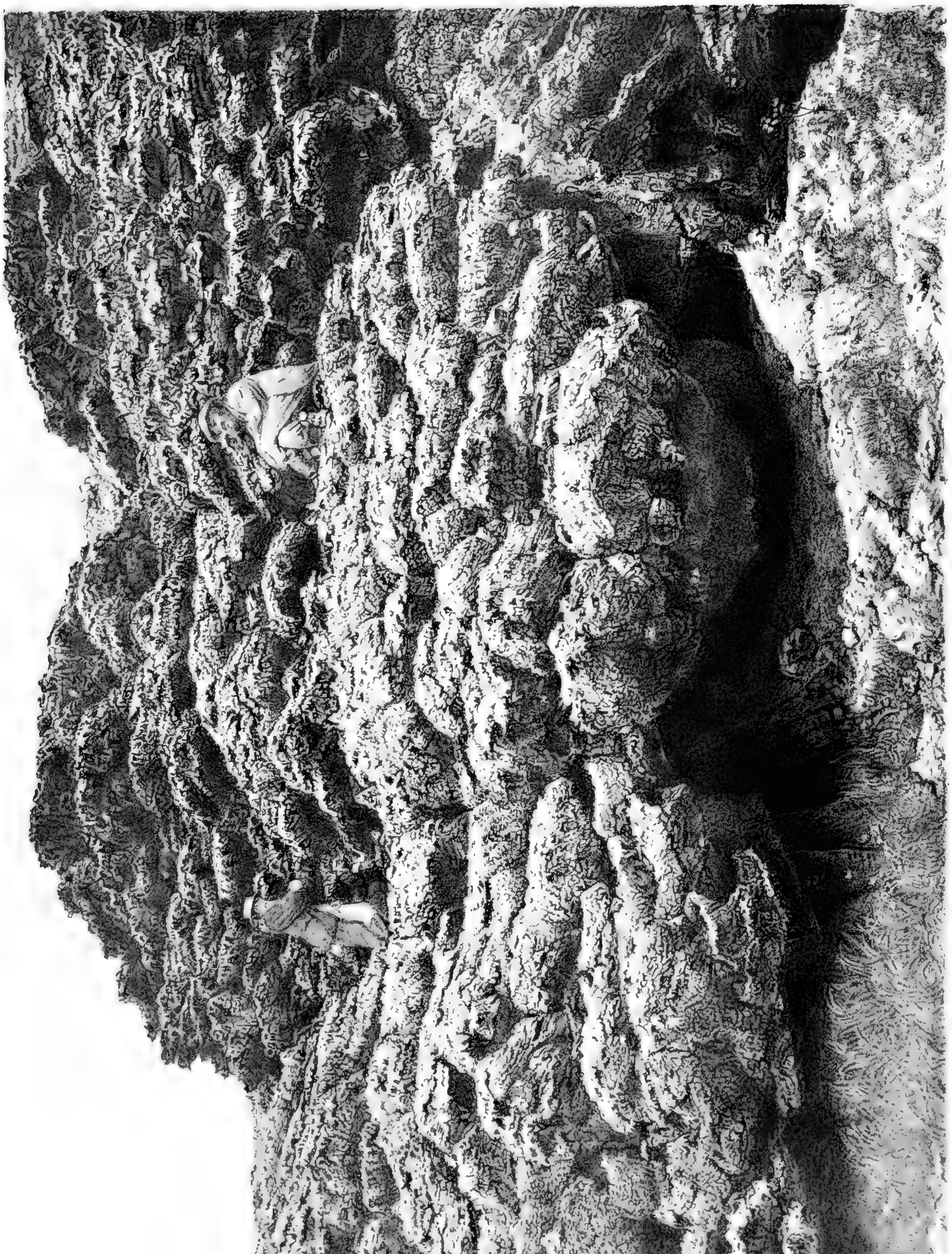
West Humboldt Range, which directly overlooks Carson Lake, the upper terraces show considerable incrustations, never, however, over five or ten feet in thickness.

By far the best general exhibitions of the material are in the neighborhood of Pyramid Lake and the valley of the Truckee. Here the steeper slopes of Lake Range and of the northern projection of Virginia Range, where they flank the lake, are thickly coated with pure gray thinolite, which at the uppermost levels carries a considerable amount of angular and sometimes rounded fragments, imbedded as in a conglomerate.

Decidedly the most interesting single specimens of thinolite outcrops are to be seen at the Domes, the Pyramid, and Anahó Island. The Domes particularly are of extreme interest. They are a series of bold spheroidal forms, partly bordering on the east shore of Pyramid Lake opposite the Pyramid, and partly rising as detached, abrupt islands above the surface of the water. They are immense botryoidal masses, always showing more or less of an obscure central opening, as if they were due to spring currents and had been built up like some of the domed mounds of thermal springs. The Domes themselves are from fifty to sixty feet in height, the calcareous material generally of a light-brown and light-gray color. The Pyramid, a remarkable detached island from which the lake takes its name, rises about a mile from the shore, having an extremely narrow base and an altitude of about 400 feet. Plate XXIII. shows the thinolite domes and the Pyramid. Almost its entire surface is incrusted with relics of a thinolite coating, which at one time must have covered it uniformly.

About three miles from the eastern shore is the bold Anahó island, which reaches 500 feet above the surface. Terrace lines having been observed fully 500 feet above the present water's edge, no doubt this island was formerly entirely covered by the waters of Lake Lahontan. The island is about a mile across, and fully three quarters of its surface are thickly covered with thinolite, or show traces of its former presence where modern erosion may have removed it. The incrustations on the steep upper slopes of the island around the central peak are extremely peculiar. They possess a rough botryoidal surface, which has the appearance of being made up of huge mushroom-like forms that overlap each other like roof tiles. When closely studied, each special mushroom-like member is seen to have an independent central stem. Plate XXIV. gives a near view of a portion of this singular thinolite surface. The coating is from ten to twenty feet in thickness, and the surface is one of the roughest imaginable geological exhibitions. It is only equalled by the frothy and porous surface of a newly congealed lava-flow.

The lower valley of Truckee River is cut through a cañon of horizontal sands, assumed from their connection with the Humboldt beds to be of Pliocene age. This cañon, in continuing northward toward the lake, cuts deeper into the formation, and at last the abrupt banks are over 200 feet in height. Upon the plateau-like summit of the beds, on the edges of both the east and west walls of the cañon, thinolite appears in very curious forms. It occupies the surface of the Pliocene beds in broad mushroom-like bodies, varying from two to eight feet in diameter, having smooth, round surfaces entirely free from the coral-like openness of structure observed in the great banks where they are incrustations on the inclined rocky surface. The peculiarity of these mushroom-like formations is, that they are gathered together, forming a complete surface of country, touching edge by edge, and that from the middle of these round bodies there is a distinct stem which penetrates the Pliocene sands to a depth of from one to three feet. Besides these, the Pliocene itself is more or less coated with irregular flat sheets of thinolite. The effect upon the edge of the cañon wall or upon the edges of the side ravine, where erosion has cut away the supports of the mushrooms and left them overhanging on the brink of the walls, is peculiar in the extreme. Certain limited passages of the Pliocene surface carry these mushrooms, extremely small, about the ordinary dimensions of the edible fungus. Specimens, with a central stem, and the whole root phenomena, were submitted to a competent botanist, who at once saw in them petrifactions of fungoid growths; but they are without doubt of a concretionary or crystallitic origin. The lower figure of Plate XXV. gives an idea of these mushroom forms on the edge of a cañon, Pliocene strata showing below. It is evident that the thinolite tufa formed after a considerable bevelling of the Pliocene, but before the final cutting of the present Truckee Cañon, since the thino-



TUFA BANK, ANAH ISLAND, PYRAMID LAKE, NEVADA

lite nowhere covers the sides of the cañon, but comes in an even sheet up to the very edge of the walls on both sides.

The immediate surface of the rough thinolite coatings on the rocks at Pyramid Lake is very well shown in the upper left-hand detail figure of Plate XXV. The curious, rude, botryoidal surface, with its markings and pits, is seen, and a little within the botryoidal zone may be detected the irregular, imperfect forms of crystals. The left-hand middle figure of the detail plate shows a region of the underlying irregular crystals just underneath the superficial botryoidal zone. This is composed of an intricate net-work of imperfect octahedrons, varying from an inch to one sixteenth of an inch on the shorter axis, but elongated up to a foot in length. The right-hand upper figure of Plate XXV. gives a better view of these irregular, distorted, long octahedrons, and shows also their manner of interference, and the peculiar branchlets which grow out at angles from the sides of the main crystals.

A large number of thin sections from the solid beds of thinolite, from mushrooms of the Truckee valley, from the smooth surface of the Domes, and from a variety of solid thinolite material collected over the Carson and Humboldt desert, when examined under the microscope show distinct translucent crystalline forms, surrounded by a dull opaque gray substance, which, as the sixteenth objective shows, derives its gray color from a cloud of minute foreign particles. The included distinct crystals vary in size from very minute forms to half an inch in diameter, and show numerous angles which, when measured, show close approximation to the angles of gaylussite.

I submitted several of the more perfect crystalline forms to Prof. J. D. Dana and Mr. E. S. Dana. After a very careful examination they confirmed my reference of the mineral form to gaylussite. Unable to obtain specimens of the "clavos" from Lagunilla, in Maracaibo, I have not been able to compare the elongated nail-form of the octahedrons of that locality with similar bodies here; but the Lahontan forms of the thinolite crystals are unquestionably a peculiar development of the mineral gaylussite. Over a very large part of the thinolite area these imperfect crystals are abundant. This is true of all the porous developments of tufa. On the other hand, wherever it is smooth and consolidated, thin sections show the inclusion of a large number of minute octahedral crystals having the long nail-shape, with others more related to the shorter shapes of the larger Soda Lake. A full examination of a large number of field localities and collected specimens leads me to the belief that the entire thinolite formation, with all its enormous development, its extent of hundreds of miles, its thickness of 20 to 150 feet, was nothing less than a gigantic deposit of gaylussite crystals.

Referring now to the table of analyses of desiccation-products of Lake Lahontan, it will be seen that there are three analyses given of the thinolite—one from the tufa dome on the shore of Pyramid Lake, one from a reef in Carson desert, twelve miles north of Ragtown, and one from the basaltic slopes of Truckee Range just above the mushroom-capped Pliocene strata, where their surfaces of thinolite abut against the foot-hills east of the cañon.

The included silica, which is chiefly mechanically entangled sands, and not an integral part of the crystalline thinolite, varies from 2.19 per cent. to 7.27 per cent., and the alumina varies correspondingly from 8 per cent. to 2½ per cent. The included foreign material is, therefore, siliceous and feldspathic sands. The percentage of magnesia rises in one instance, at the Carson desert, to 4 per cent.; there is always a little soda, a little potash, traces of phosphoric acid, about 1 per cent. of water, and about 90 per cent. of carbonate of lime. The thinolite is, therefore, practically, and leaving out of consideration the mechanical impurities, a pseudomorph of carbonate of lime, after gaylussite.

The chemical deductions from this interesting fact are of exceeding importance in the history of Lake Lahontan. In the study of the alkaline desert lakes near Ragtown, we have seen that at the stage of the greatest fullness of water or greatest weakness of solution the gaylussite crystals are redissolved and none are to be seen. On the other hand, at the close of the long evaporating-period of the summer, the waters having very materially diminished and the solution become dense up to the point of crystallization, gaylussite freely separated out.

A spirit-level determination of the highest observed thinolite places it at 470 feet above the 1867 level of Pyramid Lake, whereas the highest

observed terrace-lines are about 500 feet above the 1867 level of the lake. There were therefore about thirty feet between the highest level of the lake and the highest point at which thinolite formed. From its highest development there were nearly continuous sheets incrusting the mountain slopes upon both sides of Pyramid Lake down to the water level, and, at the time of the examination in 1867, sailing over the very clear water in the neighborhood of the Pyramid, Anahó Island, and the Domes, and also when standing at the top of the Domes and on the Pyramid, it was seen that the thinolite formation extended far beneath the level of the water. It is probable that we saw at least thirty feet of thinolite surface below the water level.

The present solution of Pyramid and Winnemucca lakes is so low in saline contents that the mineral gaylussite, which was the original basis of the thinolite, could not by any possibility be formed. Moreover, the present waters are so weak in alkalies that carbonate of lime is still held in solution. It is therefore evident that, at the time of this enormous crystallization of gaylussite, the great body of Lake Lahontan, filling up the area of four degrees of latitude in length by three degrees in breadth, with an average depth of 400 or 500 feet, must have been of sufficiently strong carbonated solution for the production of the mineral gaylussite.

The experiments on the solubility of this mineral by Professor Allen, already mentioned, and the existing facts of its natural production by the concentration of the carbonated waters of the Ragtown Soda Lake, show that a dense solution of carbonate is essential to the formation of gaylussite. The thinolite itself, a pseudomorph of carbonate of lime after gaylussite, shows at once that the original mineral was formed in the highly carbonated alkaline solution; the pseudomorph being a subsequent result of the addition of calcareous matter to the solution, the lime replacing the carbonate of soda of the gaylussite, and transforming it into carbonate of lime.

Whether we consider the solution after the formation of gaylussite, or still later after the liberation of carbonate of soda from the gaylussite during the act of pseudomorphism, it is evident that the whole Lahontan basin, up to the level of the highest thinolite, must still have been a concentrated carbonate solution. When we now realize that the lake has dried away, and whatever alkaline tenure it had at the period of desiccation must have been gradually concentrated in the lower residual basins—namely, the present existing lakes within the Lahontan area—and when we further consider that the present lakes are so fresh as to permit the healthy life of numerous fishes, including one or two of the *Salmonidæ*, it is evident that the present waters do not represent the residual concentration of the great carbonate lake

To account for the enormous accumulation of saline matter in the original Lake Lahontan to a sufficient density for the development of gaylussite, it is of course obviously necessary that the lake should have had no outlet; in other words, its waters were constantly concentrating by evaporation, never flooded out by any considerable overflow. The occurrence of such a tremendous formation of alkaline carbonates, to say nothing of the other contents of the lake, necessitates a very long period during which the surface of Lake Lahontan was some distance below its level of outlet. To account for the existing presence of the weak solutions of the residual lakes, it is necessary, after the formation of gaylussite and its pseudomorphism into thinolite, to suppose a flood-period during which the lake had free drainage over its outlet, and which continued long enough to wash out practically the whole saline contents of the great lake.

The chemical nature of thinolite, therefore, necessitates, first, a long continued period without drainage to the sea, during which the inflowing waters, derived both from the direct drainage of the tributary rivers and from the carbonate-producing springs of the basin, were enormously concentrated by continued evaporation; secondly, the solution having arrived at the required density, a general development of gaylussite crystals incrusting the walls and slopes of Lake Lahontan. Supposing the solution concentrated to the point of the formation of gaylussite, we have no direct means of saying whether the mineral would form over the whole sides and bottom of the basin, or whether it would simply form on the shores as the waters concentrated and the lake shrank by evaporation. The analogy of Ragtown Soda Lake would seem to indicate that gaylussite forms only near the surface, and the arrangement of the tufas over considerable terraces would further seem to warrant the belief that it was a shore product marking the gradually retiring water-line. It is, however, chemically quite possible that with a solution of moderately uniform density and of sufficient concentration for the development of crystals, they might form simultaneously over the bottom and sides; but that seems the less probable hypothesis. A further argument in favor of the thinolite having formed as a shore deposit, is to be found in the occurrence of angular and rounded beach gravels in it at numerous points, although generally the thinolite found upon the immediate bottom of the lake is rather free from included fragments. This, however, would naturally be the case from the remoteness of these lake-bottom thinolite bodies from any shore line where pebbles could have been washed in among the forming crystals of gaylussite.

If the desiccation was carried down, say to the present amount of water within the Lahontan area, the entire surface of the extreme low levels must have been covered by an enormous saline residuum composed of the excess of soluble salts over the amount required for the gaylussite. The present condition of the basin and the freshness of the lakes show that after this period of desiccation came a second flood-period, which raised the level of the lake to its height of overflow and washed out all the soluble salines of the basin. In this process of refilling the lake and diluting the solution, it is evident that there would still be carbonate enough to preserve the gaylussite, because gaylussite had continued to form down to the lowest levels. In the second flood-period which removed the great saline contents, during the process of filling the lake, there must have been either a cessation of the addition of carbonates by springs, or an excess of lime brought in by the rivers. At all events, the process of pseudomorphism occurred before the solution was weak enough to redissolve the gaylussite crystals.

When we realize that during the formation of gaylussite as seen in Ragtown Soda Lake there must always be a great excess of carbonate, and all the lime is made into gaylussite, it must be admitted that in the age of pseudomorphism there must have been density of solution sufficient to retain the crystals, and yet lime enough to furnish the material for the pseudomorph. It is rather a delicate chemical question, how the solution ever should have contained lime enough for the pseudomorph, and yet carbonate of soda enough to prevent the re-solution of the gaylussite. In a single alkaline deposit, that of the upper Humboldt Valley, there is a considerable amount, reaching in one instance 12 per cent., of chloride of calcium. Suppose after the formation of gaylussite, the lime, instead of coming in as carbonate by the slow delivery of the rivers, was a hot-spring product in the form of chloride. The chloride of calcium coming into the presence of an excess of carbonate of soda, double decomposition would occur, making carbonate of lime and chloride of sodium, providing the solution were of the requisite density. It would seem that a process of that kind might account for the substitution of carbonate of lime for the carbonate of soda of the gaylussite. However that may be, a second flood-period evidently washed the entire basin free from all soluble saline contents, and maintained it for some time as a pure fresh-water lake.

The subsequent desiccation of that lake, starting with a pure, fresh water, and carried down to the present almost complete drying-out of the basin, is the last fact in the history of this lake of which we have any knowledge. We are therefore warranted in assuming, first, a lake having an outlet; secondly, the sinking of the level of that lake by evaporation below the level of outlet; thirdly, the long continued concentration by evaporation of its saline solution up to the point of the formation of gaylussite; fourthly, the desiccation of this lake and development of the great incrustations of gaylussite crystals, and possibly, though not probably, the formation of the pseudomorph; fifthly, the coming on of a second flood-period which filled the basin to its point of overflow; sixthly, the maintenance of the lake at its maximum level long enough to wash out the soluble salts completely, and probably, during this period, the formation of the pseudomorph; seventhly, the modern rapid desiccation from the point of maximum fullness down to the present, in which only the few lowest basins contain the meagre residual weakly saline lakes.

When we come now to correlate the features of this chemical history with those brought out by the relation of the sediments of Lake Bonneville, as clearly shown by the observations of Gilbert* and myself, we find that the reading of the sedimentary deposits shows, first, a period in which the lake basins were dry, and during which subaerial gravels washed down

* United States Geographical Surveys West of the One Hundredth Meridian, Vol. III., Geology, Chap. III.

the slopes far into the heart of the lake basin; secondly, a flood-period in which the lacustrine sediments accumulated over the whole floor of the lake, overlying the lower extension of the earlier subaerial gravels; and, thirdly, the present period of desiccation, in which the waters of the lake have dried out and a second subaerial gravel formation has been washed down its slopes, covering the edges of the lacustrine sedimentary beds.

Gilbert, therefore, beginning at the present, shows our period of dryness to be immediately preceded by a period of high humidity, in which Lake Bonneville was filled to the brim, and a period of dryness anterior to the Bonneville Lake. The chemical history of Lake Lahontan, when correlated with this, shows not only those three periods, but a period of humidity anterior to Gilbert's earliest age of dryness. For the clear reading of the chemistry of Lahontan is: our modern period of desiccation corresponding to the period of latest subaerial gravels, as displayed both in the basin of Lahontan and of Bonneville; a period of flood immediately preceding that, during which the saline contents of Lahontan were washed out, and during which Bonneville was filled to its highest terrace; Gilbert's earliest period of dryness, which corresponds to the age of the thinolite desiccation of Lake Lahontan. The appearance of thinolite itself up nearly to the highest terraces of Lahontan shows a period of moisture anterior to Gilbert's first period of desiccation.

Gilbert justly remarks that the Bonneville beds appear as an episode occurring between two periods of aridity. The addition of a still earlier period of humidity to this series of climatic changes could never have been arrived at from the lake sediments alone, since the lacustrine beds of the second humidity-period would naturally cover up and obscure those of the first humidity-period.

Could we obtain a section deep enough on the borders of the two lakes, beneath the earliest subaerial gravels which Gilbert and I have observed in both basins, there would doubtless be seen still earlier lacustrine beds underlying the bottom of the thinolite.

That Lake Lahontan was filled before the formation of the first gay-lussite, is proved by the position of the pseudomorph of that mineral nearly up to the point of outflow. The earliest knowledge, then, we have of these lakes is of their being full. When we compare the amount of salinity which was retained within the lake basin in the first period with that which is now observed as the result of the second desiccation-period, it is at once seen that the first lake had an enormous excess of soluble salts over the second lake, since its chemical residua on evaporation contained such a vast amount of carbonate. Making all due allowance for any change in the chemistry of the springs of the basin, which at that time must have yielded an immense amount of the alkaline carbonates, and which now yield very little of the same salts, it will be seen at once that the period of concentration of the first lake, namely, the period at which it was maintained at a high level, though below the point of outlet, must have been enormously longer than in the second age of desiccation, since the residual products of the second period of desiccation are not enough to render even the small existing lakes very saline. We are therefore warranted in assuming for the first age of humidity of the lake an enormously long continuance as compared with the second. The first long-continued period of humidity is probably to be directly correlated with the earliest and greatest Glacier period, and the second period of humidity with the later Reindeer Glacier period.

The Quaternary lakes of the Great Basin are therefore of extreme importance in showing one thing—that the two glacial ages, whatever may have been their temperature-conditions, were in themselves each distinctly an age of moisture and that the interglacial period was one of intense dryness, equal in its aridity to the present epoch.

It is worth while to emphasize the fact that the present is essentially a period of desiccation, as contrasted with the wet periods during which the Quaternary lakes were filled. The Glacial periods, then, must have been far more moist than the climate of to-day. As regards the heat-condition, I have before called attention to the fact that the mean annual temperature over a considerable part of the United States Cordilleras is to-day lower than over the still glaciated portion; that the difference between the glaciated and the still colder regions is simply one of relative moisture.

Suppose a secular change to occur now, in which the climate of the northern hemisphere should for a time become colder than at present. It is obvious that there would be less evaporation of the oceanic moisture, and that the winds which carry that moisture over continental areas would be even drier than at present. Even with the relative humidity which now characterizes these winds during a lowering of the temperature, it is extremely doubtful whether glaciers would form. In the presence of greater cold there would be a greater precipitation relative to the moisture of the continental atmosphere; but that atmosphere itself would be correspondingly drier from the diminished supply evaporated from the ocean surface. On the contrary, in a warmer period, the sea-winds blowing over the continent would bring a greater amount of moisture, and there would be, as regards the whole area, a correspondingly greater precipitation; and the cold, high-altitude points or climatic islands of low temperature would still act as powerful condensers and extract from the moister winds more snow than at present. The instructive example of New Zealand affords an illustration of the abundant production of glaciers in a climate of higher mean temperature and greater relative humidity than that of the United States.

Late writers on the Great Basin, especially G. K. Gilbert, have called attention to the rise and expansion of Salt Lake. I have already shown that between the period of the Stansbury survey and that of my own there was an increment of 600 square miles in the area of the lake, and a rise of eleven feet. In popular discussions, it has frequently been suggested that the additional cultivation of the desert lands by the system of artificial irrigation introduced by the Mormons had brought about the change.

This hypothesis is too absurd to require detailed refutation. The cycle of moisture which has recorded itself in the increased volume of Salt Lake is also evident in many other localities and in different ways. Mono and Owen's lakes at the east base of the Sierras show a corresponding rise, and, as has been stated before, all the residual lakes in the basin of Lake Lahontan evince the same change. When it is remembered that the moisture-bearing wind, indeed the entire source of aerial moisture for the whole western Cordilleras, is the upper, constantly blowing west-to-east wind, it will be seen that no changes of cultivation of unimportant, isolated agricultural regions could possibly have brought about the general increase of humidity. This increase of the volume of the lakes has taken place in the presence of an enormous power of evaporation. Over a very large part of the Great Basin the average climate is so dry that there is a wide permanent difference between the observations of wet and dry bulb thermometers. During the period of maximum evaporation in midsummer and even in November I have recorded differences of 36°. Observations were made by my party with a series of evaporating-pans, which were observed in the shade and in the sun, and by means of a delicate micrometer screw actual hourly and daily evaporations were noted. A half inch a day was not an uncommon result in the dryest period of the year.

It becomes a question of great interest to determine whether this recently observed climatic oscillation is within the range of frequent occurrence, or whether it is a noteworthy departure from the climatic habit of the immediate past. Some light is thrown on this question in the alpine regions of the Sierra Nevada and the higher points of the desert ranges. The phenomena, however, are so much more clearly shown upon the Sierra summit, that I confine myself to that region in discussing this point.

Below the line of perpetual snow is a variable, open region of about 1,000 feet in altitude, in which the tree-growth is rather sparse and comprises only strictly alpine species. Below that point, from Alaska nearly to the Mexican line, is a continuous dense growth of coniferous forest. A very large number of observations on the average age of the timber growth at its upper limits shows a mean of about 250 years. Since the late cycle of increased moisture, the winter accumulation of snow on the Sierra summit is evidently greater than since the earliest growth of the present forest.

The barren zone which I have mentioned, between the perpetual snow and the main timber growth, represents a region where the snows accumulate too thickly for the propagation of the coniferous species, and may be said to express the downward limit of the encroachment of snow for 250 years.

In the present climatic change the snow accumulation is greater, and extensive avalanches where the topographical configuration favors, have begun to pour down into the true forest belt and to sweep before their rush considerable areas of mature tree growth An avalanche starting in a high alpine gorge ploughs its way downward, not infrequently mowing down a half mile of adult trees. It is obvious that no such avalanches could possibly have occurred during the germination and growth of this forest.

On the summit of the Central Pacific Railroad Pass are a considerable number of well grown coniferous trees. An examination of them during the construction of the Pacific Railroad showed that they were at that time being seriously damaged, and in some cases actually killed, by the drifting snow-crystals borne on the strong west winds during the winter storms, the notch or depression of the pass making a sort of funnel, through which the wind blew with unusual violence, concentrating its freight of sharp snow-crystals, which not only wore away some of the foliage of the trees, but actually cut off the bark from exposed positions and sawed into the wood for several inches. An inspection of the branches thus cut showed that the annual rings had formerly perfected themselves, and that the snow had worn off a considerable portion, often several inches, of the thickness of the wood, leaving a smooth polished surface, displaying the cut edges of the layers of annual growth. From these facts it would appear that the existing climatic oscillation began before the year 1870, and was the first of its kind for over 250 years. The year 1866 is about the date of the increase of Salt Lake. Mono Lake shows a rise in 1864, and the destructive Sierra avalanches began about 1860. Although unimportant in its general results, this oscillation becomes a matter of very great interest from a theoretical point of view.

The mechanical and chemical facts which have been observed in the Quaternary phenomena of the Fortieth Parallel show that post-Pliocene time has been marked by a very long period of very great humidity, followed by a period of intense dryness, which gave way to a second but briefer epoch of humidity, which was rapidly succeeded by the present age of drought. In comparing these climatic phenomena with what we can tell of the Pliocene, the Quaternary appears to have been a much more varied age. In the deposits of the Pliocene there are certain alkaline beds which I have noted, and which seem to me to mark periods of desiccation; but in all the mountain phenomena and in the sediments there are no appearances which could suggest the presence of a considerable glaciation.

We know from the fauna and flora of the Pliocene that it was a warm age, permitting palms and crocodiles to extend as far north as the British line. The interior of the continent had at least two enormous fresh-water lakes, one covering the area between the meridian of the Wahsatch and that of the Sierra Nevada, the other the province of the Great Plains. To maintain these great interior lakes it must therefore have been an age of very great humidity.

During the Quaternary age most modern mountain topography received its present form. Most, if not all, of the sharp cañons were carved, and the mechanical results of that erosion are seen in the great accumulations of subaerial gravel in regions of interior drainage like the Great Basin, and in deposits of unknown thickness classed as Lower Quaternary, which gathered on the beds of the Quaternary lakes. The long carbonate-lake period which followed the first great flood-age of the Quaternary was an age of desiccation even greater than the present, as is proved by the occurrence of thinolite on the deep bed of Pyramid Lake. In other words, the lakes of that period were practically completely dried.

During the long continuance of that earlier drought a very large amount of the Fortieth Parallel area must have been even more devoid of desert vegetation than at present, and the dry west wind must then have drifted an enormous amount of fine sands from west to east. Even now this process is seen in operation at various points in the Cordilleras, where trains of dunes are gradually moving eastward. This is especially observable in the region of the Colorado desert in southern California, where the prevalent west wind sweeps the desert floors clean of their fine loose material and banks æolian sands high up on the west faces of the mountain ranges. If Richthofen's theory of the æolian origin of Loess be finally accepted, the dust deposit which is now the Loess of the Mississippi Basin might readily, as Pumpelly has shown, have blown from the desiccated regions of the western Cordilleras during the great drought which immediately followed the first great flood or glacial period.

Contemporaneous geological action on the area of the Fortieth Parallel is confined to the slow and extremely limited transportation of material by the rivers, the feeble æolian transportation, the slow accumulation

L.

Na B̈	K̇ S̈	Ċa S̈	Insol. res.	Ḣ		Total.
. .	. .	1.63	1.97	0.73	. .	100.00
. .	. .	. .	. .	. .	. .	98.12
. .	. .	1.75	1.82	8.57	. .	100.00
. .	1.93	. .	. .	. .	SO_3 0.24	99.06
. .	. .	. .	. .	. .	. .	. .
. .	. .	. .	. .	. .	. .	. .
. .	. .	. .	. .	. .	. .	. .
. .	. .	. .	. .	. .	. .	. .
. .	0.99	. .	2.81	+ free CO_2 28.83	. .	100.00
. .	. .	. .	. .	. .	Na 0.04	99.87
. .	. .	. .	. .	. .	Na 0.13	99.96
11.30	. .	. .	. .	. .	. .	100.00
11.38	. .	. .	. .	. .	. .	100.00
. .	. .	. .	. .	. .	. .	. .

S̈	Ċa C̈	Ṁg C̈	Ṁg	C̈	S̈i	P̈	Total.
.	.0178	. .	.1281	.0157	. .	. .	3.2365
. .	. .	. .	. .	. .	. .	. .	. .

DESICCATION-PRODUCTS OF LAKE LAHONTAN.

Efflorescences and Lake Salts.

Number of analysis.	Locality.	Analyst	Per cent. soluble in water.	F̈e	Ċa	Ca	Ṁg	Mg	Ṅa	Na	K̇	K	L̇i	Cl	C̈ Excess above mono-carbonate.	C̈ Fixed	S̈	B̈	P̈	S̈i	Ḣ	Insol. res.	Oxygen equivalent.	Total.
45	Maag's Station, Truckee Desert	O. D. Allen																						
46	Hardin City	"																und.						
47	Sink of Quinn's River	"																						
48	Buffalo Station	"			tr.					36.29		0.87	tr.	42.97			15.82	tr.						
49	Gay-Lussite, Soda Lake, Ragtown	"			19.19				19.95					tr.		29.55	tr.				31.05	0.20		99.94
50	Trona, Soda Lake, Ragtown	"							40.77					0.46		37.88	0.35				20.07	0.30		99.83
51	Salt from Soda Lake, Ragtown	"							40.53					0.98		36.74	0.75	tr.	tr.		19.93	0.80	0.22	99.51
									40.57					0.97		36.87	0.71	tr.	tr.		19.87	0.80	0.22	99.57
52	Salt from small Soda Lake, Ragtown	"									tr.		tr					tr.	tr.					
53	Deposit from Soda Lake, Ragtown	R. W. Woodward	78.50						51.34	0.21				0.26	11.39	36.15	0.52							99.87
			78.50						51.33	0.31				0.29	11.39	36.16	0.48							99.96
54	Brown's Station, Humboldt Lake	"	33.00						22.80	19.53	tr.			30.15	2.48	6.50	11.76	6.78						100.00
			33.00						22.88	19.51	tr.			30.12	2.48	6.50	11.73	6.78						100.00
55	Salt, incrusting decomposed Rhyolite, Red Hills, West Humboldt.	"	4.50		Chiefly Na Cl on surface of specimen.																			

Number of analysis.	Na Cl	Ṅa C̈	Ṅa C̈+C̈	Ṅa S̈	Ṅa B̈	K̇ S̈	Ċa S̈	Insol. res.	Ḣ		Total.
45	95.67						1.63	1.97	0.73		100.00
46	18.47	52.10		27.55							98.12
47	85.27			2.59			1.75	1.82	8.57		100.00
48	70.81			26.08		1.93				SO₃ 0.24	99.06
49											
50											
51											
52	1.10	66.27				0.99		2.81	+ free CO₂ 28.83		100.00
53	0.43		98.49	0.91						Na 0.04	99.87
	0.47		98.51	0.85						Na 0.13	99.96
54	49.67		18.15	20.88	11.30						100.00
	49.63		18.15	20.84	11.38						100.00
55											

Thinolite (Pseudo-Gay-Lussite).

Number of analysis.	Locality.	Analyst.	Si	Al	Fe	Ca	Mg	Na	K	Li		Ḣ	C̈	Total.	Specific gravity.
56	Tufa Dome, Pyramid Lake	R. W. Woodward	7.27*	2.14	tr.	47.27	2.89	0.51	0.22	tr	PO⁵, SO³ tr.	1.20	38.23	99.73	2.4
			6.90*	2.54	tr.	47.48	2.50	0.48	0.19	tr	PO⁵, SO³ tr.	1.20	38.52	99.81	. . .
57	Twelve miles north of Ragtown, Carson Desert.	"	2.23*	0.77		50.88	3.86	0.77	0.15		PO⁵, SO³ tr.		41.35	100.01	2.5, 2.5, 2.5
			2.19*	0.82		50.92	4.01	0.76	0.17		PO⁵, SO³ tr.		41.43	100.30	. . .
58	Near Wadsworth	"	3.01*	0.89		49.77	3.28	0.79	0.15		PO⁵, SO³ tr.	1.41	41.02	100.32	2.46, 2.46
			3.10*	0.86		49.80	3.25	0.88	0.20		PO⁵, SO³ tr.	1.40	40.94	100.43	. . .

* Combined silicic acid and sand.

Waters.

Number of analysis.	Locality.	Analyst.	S̈i	Ċa	Ṁg	Ṅa	Na	K	Li	Ċa C̈	C̈ Fixed.	C̈ Free.	Cl	S	S̈	B̈	P̈	Oxygen equivalent.	Total.	Specific gravity.
59	Pyramid Lake	O. D. Allen	tr.		.1292	.4234	.8999	tr.	tr.	.0178	.02392	und.	1.3870		.1400	tr.			3.2365	1.0027
					.1271										.1403					
60	Soda Lake	"	.2050		.0230		42.8380	1.5970	tr.		2.6490	2.3368	39.3914	.0978	.4303	tr.		6.3465	114.449	1.0975
61	Humboldt Lake	"	.0325	.0176	.0274		.2785	.0609	tr.		.1070		.2952		.0253	tr.	.0006	.0427	88.8020	1.0007

Number of analysis.	Na Cl	Ṅa C̈	Ṅa S̈	Na S	K Cl	K̇ S̈	Ċa C̈	Ṁg C̈	Ṁg	C̈	S̈i	P̈	Total.
59	2.8871	.5384	.2485				.0178		.1281	.0157			3.2365
60	69.9413	29.2482	13.7626	.2384		3.6113		.0652		Free. 2.3368	.2050		114.449
61	.3957	.2494	.0450		.1162		.0314	.0577		.0425	.0525	.0006	88.606

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of calcareous precipitates and river sediment in the beds of the present shrunken lakes, the disintegration of mountain tops and formation of angular, high-mountain débris, and the few rare instances of true orographical action, in which the solid rock foundations of the country are absolutely faulted, the most conspicuous example of the latter being the great fault described by Prof. J. D. Whitney* in his account of the Owen's Valley earthquake of 1872.

* Overland Monthly for August and September, 1872.

CHAPTER VI.

RÉSUMÉ OF STRATIGRAPHICAL GEOLOGY.

It is the purpose of this chapter to present in the briefest possible manner the leading outlines of stratigraphical geology in the area of the Fortieth Parallel. In the foregoing chapters I have given the reader a summary of such facts as seemed to be necessary to a general comprehension of the sequences and subdivisions of the sedimentary geology. It seems appropriate that the enormous developments of strata which have there been described should be succinctly shown in their broader geographical and historic relations.

In the 120,000 feet of sedimentary accumulations the grander divisions of Archæan or Azoic, Palæozoic, Mesozoic, and Cenozoic are distinctly outlined by divisional periods of marked unconformity. Considered as a whole, there is a noteworthy fullness in the geological column. None of the important stratigraphical time-divisions are wanting except those obscure intermediate deposits which in other countries lie between the base of the Cambrian and the summit of the crystalline Archæan series. From the first of Cambrian age to the present every important interval of time is recorded in the abundant gathering of sediments, which are with singular fullness characterized by appropriate and typical life-forms

As in all other geological fields, the most important interruption of the continuity of deposit was at the close of the Archæan age, and the most striking difference between any two successive groups of rocks is that which characterizes the relations of the Archæan and the Palæozoic. With the exception of a few slates of supposed Huronian age, which the microscope shows to be richly charged with crystallites, all the non-eruptive Archæan rocks have passed from the original condition of detrital beds into sheets or bodies of distinctly crystallized material.

Not only are the Archæan exposures of such frequency over the Fortieth Parallel area as to insure a moderately complete knowledge of stratigraphical sequence and materials of the period, but also, owing to the relations which have been described with the overlying Palæozoic, I am able to reconstruct with considerable accuracy the topographical configuration of the Archæan surface. Supposing all the post-Archæan rocks to be removed, and considering what we now know of the whole area at the close of the Archæan age, the first prominent fact is, that coextensive with the greater part of the Cordilleras—that is, from longitude 104° westward as far as the Archæan exposures extend—was a great Archæan mountain system built up of at least two sets of nonconformable strata, referred to Laurentian and Huronian; the lower and older composed of granitoid gneisses chiefly made up of quartz and orthoclase, but carrying a little mica, sparing triclinic feldspars, and chlorite pseudomorphous after garnet and mica.

Over these, whether with actual conformity or not is undetermined, lies an enormous series of mica gneisses rich in quartz and biotite, orthoclase ordinarily exceeding plagioclase. The earlier aplitic gneisses and the later mica gneisses expose about 25,000 feet each of conformable beds.

A third group, nonconformable with the earliest aplitic series, the relations with the intermediate mica-gneiss series being unknown, consists of mica and hornblende schists passing upward into slates, quartzites, limestones, and dolomites.

In the mica schists biotite predominates, and is usually associated with an excess of orthoclase over plagioclase. When muscovite replaces biotite it is frequently accompanied by garnet. The hornblendic schists are generally characterized by the presence of zircon, and, as a rule, carry plagioclase in excess of orthoclase. Interstratified with the quartzites are beds of smooth, rounded conglomerates, sheets of dioritic (hornblende-plagioclase) schists, and in one or two instances hydromica (paragonite) rocks associated with kyanite and staurolitic schists. The limestones, prominently dolomitic, are usually intercalated with mica gneisses, or overlie the oldest quartzites. The mica gneisses, which form the lowest part of the third group, so closely resemble the highest mica gneisses of the second group, that, although they are never exposed in conjunction, it is supposed that they are one and the same series, and that groups No. 2 and No. 3 are conformable, making, therefore, but two conformable series, the lower granitoid beds and the upper composite group, as described.

The geographical range of the lower series is confined to the country between the 104th meridian and the Wahsatch. The upper series appears to extend over nearly the whole Fortieth Parallel area. West of the Wahsatch the folded, crumpled, dislocated masses of these sedimentary Archæan groups are invaded by plastic, structureless granites of four lithological types, for whose petrological characteristics the reader is referred to the second section of Chapter II. and to Volume VI.

Upon grounds set forth in Section IV. of Chapter II. it is clear that the general topography prior to the deposition of the earliest Cambrian rocks was that of a great mountain system, displaying lofty ranges made of crumpled strata, enormous precipices, a result of mechanical dislocation, and, finally, a type of high mountain sculpture of such broad, smooth forms as to warrant the belief that subaerial erosion had never carved and furrowed the mountain flanks with the sharp ravines characteristic of modern mountain topography. East of the Rocky Mountains, in the geological province of the Great Plains, there are no Archæan outcrops; and when we consider the comparative thinness of the later sedimentary beds superposed over that region, the absence of outcropping Archæan masses piercing through the later sediments is excellent proof that over that area Archæan mountain ranges did not exist. This is important as defining the Archæan Cordilleras within the limits of the modern Cordilleras, or, as is a more strictly correct view, the ancient Archæan Cordilleras have determined not only the general area but much of the local detailed structure of the modern Cordilleras.

The topographical features of the present terrestrial surface are far less grand than the Archæan orography. The great Archæan precipices brought to light in Uinta and Wahsatch ranges are absolutely unparalleled in the topography of to-day. That prior to Cambrian time this mountain system was a land area, is clear from the absence of interpolated sets of strata between the finished crystalline mountains and the unconformable Cambrian sediments. In the modern dislocations and disturbances which have enabled us to gain these profound views of the Archæan mountain systems, there is one interesting topographical element which we fail to reach. Never arriving at the bottom of the Cambrian sediments, we are at a loss to know the physical characteristics of the valley bottoms which lay between the Archæan ranges. Whether they contained relics of a land detritus, or whether they were washed smooth by the subaerial drainage of the period, we do not know.

There is always a complete, sharp, unmistakable nonconformity between the crystalline Archæan topography and the superjacent sediments.

Considered as a whole, the Palæozoic series constituted a conformable body, laid down over the rugged Archæan mountain system. It first appears in the region of the Rocky Mountains with a total thickness of about a thousand feet, the strata surrounding and abutting against permanent Archæan islands, which, during the whole Palæozoic and Mesozoic, were lifted above the level of deposition. Throughout all Palæozoic time only 1,000 feet of strata accumulated over our part of the Rocky Mountains, and we get no glimpses of deeper hollows in which lower Cambrian beds might have been deposited. Passing westward, the series gradually thickens to 32,000 feet in the region of the Wahsatch and about 40,000 feet at the extreme western Palæozoic limit, longitude 117° 30′, where, from the evidences of shore-phenomena, and the non-continuation of the beds westward, we are warranted in assuming the Palæozoic coast.

Superposed in unconformable succession over the gigantic crystalline mountain ranges, some of the tips of the highest peaks still rose above the level of the (*inter se*) strictly conformable Palæzoic series. At the close of the Palæozoic, the uppermost sheet of Carboniferous material, extending from the Nevada Palæozoic shore eastward through the whole Fortieth Parallel area, was only interrupted by a few island-like granite peaks which were above the level of deposition; the great mass of the Archæan topography by that time having been completely buried. Of the character of the Archæan land which still, at the close of the Palæozoic, formed the westward barrier to the ocean and the source the main detrital material, we know very little.

The Carboniferous strata which are found west of the old shore-line in California and Oregon seem to me rather to indicate shallow bays and gulfs, which permitted the westward extension of the upper Palæozoic strata, while the great bulk of the series was stopped by a bold coast. Starting with a land area of Archæan ranges, and passing on through the Palæozoic period until the whole Archæan topography is buried in the deposits of a profound ocean, it is evident that the area has been one of very great subsidence. From its original altitude above sea-level it has been depressed to the ocean plane, and then downward until even the ocean-bed deposits have overwhelmed all but its highest peaks.

Viewed regardless of the age of the individual beds, the Palæozoic series can be divided by the character of their materials into four great groups. The first is a purely detrital Cambrian, which, although of comparatively fine sediments, in the presence of occasional conglomerates gives evidence of repeated subsidence.

The second group is the great limestone series, beginning with the Pogonip Cambrian limestone, and extending upward to the top of the Lower Coal Measures for 11,000 feet, only interrupted, in the horizon of the lower Devonian, by a sheet, from 1,000 to 2,000 feet thick, of fine quartzitic detritus. This enormous group of 11,000 feet of limestone, characterized by abundant pelagic faunæ ranging from the Primordial to the top of the Lower Coal Measures, represents in general an age of deep seas. Toward the Nevada Palæozoic shore, however, in all the beds of the Lower Coal Measure limestones, argillaceous and siliceous impurities characterize the western exposures, and these are marked by a single horizon of carbonaceous beds associated with land plants. As it is underlaid by limestone and immediately overlaid by limestone, both deep-sea deposits, it is evident that this episode of dry land was a moment of true elevation.

At the close of the deep-sea lime-period came a third great stratigraphical division of the Palæozoic—Weber quartzite—a body of pure siliceous detritus from 6,000 to 10,000 feet in thickness, characterized by conglomerates both in the near neighborhood of the granitic islands and close to the Nevada shore.

This is immediately succeeded by the fourth group or Upper Coal Measure limestone, a body about 2,000 feet thick of strictly pelagic material.

The whole Palæozoic, therefore, may be summed up as to its material as two periods of mechanical detritus, interrupted by one and followed by another period of deep-sea lime-formation. While in the conglomerates which appear in all the siliceous members of the series we have evidence of episodes of shallow waters, yet the occurrence of 13,000 feet of limestone indicates enormous intervals of the continued sway of profound ocean.

When compared with the corresponding series, as displayed in the Appalachian system, it differs, first, by the absence, as it thus far appears, of those not infrequent orographical disturbances which render the Appalachian Palæozoic groups repeatedly unconformable among themselves; secondly, while land areas were common from the close of the Devonian in the east, and the materials fail to show any great continuance of ocean sway in the region of the Appalachians, in the Cordilleras there is evidence of but a single temporary land episode, and that most restricted in its area. Taken as a whole, the Palæozoic was distinctly an age of ocean sway.

Accompanying this chapter are two tables, Nos. VI. and VII., in which are given analyses of the members of all the sedimentary series whose constitution seems to afford a chemical interest. The tables are divided into, first, the deep-sea and lacustrine limestones and the composite calcareous Tertiary and Cretaceous rocks; secondly, siliceous and pure detrital rocks, the sandstones, quartzites, &c.

It is not intended in this chapter particularly to discuss the character or causes of those mechanical movements in the solid earth which successively elevated and depressed various portions of the Cordilleran area; but it is impossible adequately to conceive of the stratigraphical grouping without a passing mention of those mechanical events. After the close of this great conformable Palæozoic deposition, wide-spread mechanical disturbance occurred, by which the land area west of the Nevada Palæozoic shore became depressed, while all the thickest part of the Palæozoic deposits from the Nevada shore eastward to and including the Wahsatch, rose above the ocean and became a land area. Between the new continent and the old one which went down to the west, there was a complete change of condition. The land became ocean; the ocean became land. In the rising of the Palæozoic, however, the elevation proceeded no farther eastward than the Wahsatch. East of that point, the Upper Carboniferous beds were still the undisturbed ocean-bottom; but instead of receiving sediments either from the destruction of organic life within the ocean area or from the distant continental sources to the west, the newly elevated land-mass, extending from the Wahsatch west to 117° 30′, became the area from which was derived the post-Carboniferous detritus to form the great Mesozoic series that, east of the Wahsatch, were laid down conformably upon the still submerged and still undisturbed Carboniferous.

Upon the western side of the new land-mass, the Archæan continent, having gone down, made a new ocean-bottom, and upon this immediately began to accumulate all the disintegration-products of the new land-mass which the westward draining rivers and the ocean waves were able to deliver. Throughout the Triassic and Jurassic periods the western ocean was accumulating its enormously thick group of conformable sediments upon an Archæan floor, while east of the Wahsatch, in the mediterranean ocean, the sediments of the Trias and Jura were accumulating conformably upon the Carboniferous; until, at the close of the Jurassic age, there had accumulated in the western sea 20,000 feet, and in the mediterranean sea 3,800 feet, of Triassic and Jurassic material.

The comparison of the Trias-Jura series, in these two separated seas, shows two things: first, that the western sea was very deep during the Trias; secondly, that the mediterranean was shallow during the Trias. In both cases the first half of the Trias was prominently a period of the reception of pure detritus, while the second half, especially in the western ocean, was characterized by the liberal intercalation of lime. The Jura, especially in the east, was an age of shallows, and its materials were almost altogether of clays and shales and shaly limestones. At the west, the lower members, as at the east, were prominently calcareous; but later, and closing the series, is an unknown thickness, certainly over 4,000 feet, of fine argillites.

At the close of the Jurassic age the western ocean, with its original floor of Archæan ranges overlaid by twenty-odd thousand feet of conformable Trias-Jura sediments, suffered abrupt orographical uplift, resulting in the formation of a series of sharp folds and elevating a portion of the ocean area, extending from the eastern shore outward and westward as far as the present west base of the Sierra Nevada, making an addition to the continent of 200 miles, the Sierra itself constituting the most western and most elevated of the newly formed mountain ranges. The character of the orography of this period of disturbance is that of tangential compression, in which the gentler action was close to the old shore in the meridian of 117° and most powerful in the crumpled western slope of the Sierra Nevada, where the Triassic and Jurassic series have their enormous thickness crushed into a mass of almost indistinguishable folds, the rocks thrown into vertical dip and crowded together, making a belt of strata about fifty miles broad. This orographical action continued southward as far as the defined range of the Sierra Nevada extends, and northward along the whole shore of the Pacific, probably as far as the Alaskan peninsula. Passing northward from the region of the Fortieth Parallel, where the new addition to the continent measured about 200 miles from east to west, the zone of crumpled Mesozoic was depressed so that the new ocean shore at the beginning of the Cretaceous age touched the west base of the Jurassic fold of the Blue Mountains of eastern Oregon.

While this powerful dynamic action was taking place on the west side of the land area, there still remained, so far as upheaval, subsidence, or folding is concerned, a complete calm in the region east of the Wahsatch. The uppermost shaly members of the Jurassic from the Wahsatch out to Kansas are immediately conformably overlaid by the basal members of the Cretaceous.

The revolution which produced this great change in the configuration of the country, although not recording itself over the area of the mediterranean ocean in any disturbance or nonconformity, was, however, signalized by a complete change in the character of the sedimentary material. The phenomena of the Cretaceous west of the boundary of California did not fall within the study of this Exploration, and have already been described by Professor Whitney in the Geology of California. Since the close of the Jura no marine sediments have been laid down between the west base of the Sierra Nevada and the Wahsatch.

During Cretaceous time the mediterranean ocean stretched from the eastern base of the Wahsatch into Kansas; and over the entire bottom of that body of water, with the exception of a few Archæan islands, which were still, as they had been throughout the previous ages since the beginning of the Cambrian, lifted above the plane of deposition, a continuous conformable sheet of Cretaceous sediments was laid down. Its greatest thickness was against the western shore of the ocean, namely, against the eastern base of the Wahsatch, where conformably over the top of the Jurassic shales are about 12,000 feet of Cretaceous beds. Passing eastward, this series in the province of the Great Plains near the eastern base of the Rocky Mountain system has thinned to 4,500 or 5,000 feet, and in western Kansas it reaches its thinnest development as described by the Geological Survey of that State.

The materials of the underlying Jura are all of excessively fine grain. Conglomerates are absent except on the immediate foot-hills of the Wahsatch. The fine summit shale-members of the Jura were immediately succeeded by a coarse siliceous conglomerate which stretches in an uninterrupted sheet from the base of the Wahsatch nearly to the easternmost exposures of the Cretaceous beds. The pebbles immediately bordering the Wahsatch are, in some instances, a foot in diameter. Farther east they gradually thin down to the size of a filbert, and in the region of Kansas are no longer to be seen.

In the extreme western Cretaceous exposures in the territory of Wahsatch and Uinta ranges, coal-beds appear at the very base of the series immediately upon the capping members of the Jura; and from that horizon to the summit of the series, throughout the whole 12,000 feet, they recur in that region. They increase in frequency after the close of the Fox Hill group, and are most abundant through the 4,000 or 5,000 feet of the closing or Laramie group of the series. The deduction from these frequent coal-beds is clearly that of land areas and of repeated subsidence throughout the whole Cretaceous age over the western part of the Cretaceous area.

In the region of the Great Plains, coal-beds are unknown below the summit of the Fox Hill. Beneath that horizon there is no evidence of a land surface in the eastern part of the Cretaceous field. The series, therefore, below the top of the Fox Hill was purely an ocean deposit in the region of the Rocky Mountains, but in the region of the Wahsatch was frequently above the limit of the marine waters, carrying upon its surface abundant vegetation.

Throughout the whole Cretaceous, below the top of the Fox Hill, the molluscan fossils are invariably marine, with the exception of certain intercalated groups of purely fresh-water shells near the region of the Wahsatch, which, from their position close to the Cretaceous ocean shore, are evidently the in-washings of a fluviatile fauna.

Regarded as a whole, the basal member is a single sheet of siliceous sediments and rounded conglomerates from 300 to 500 feet thick. Over this lies the great Colorado group, 2,000 feet thick in the west, 1,000 feet thick in the region of the Great Plains, made up chiefly of fine calcareous and argillaceous material, which toward the middle of the group is prominently formed of marls or limestones.

Above the horizon of the Colorado group the Fox Hill and Laramie are essentially of sandstones, about 9,000 feet in thickness in the region of the Wahsatch, about 3,000 feet in the region of the Great Plains. At the very summit of the uppermost or Laramie group are found Dinosaurs. The fauna up to the base of the Laramie is strictly marine. The Laramie itself carries the remains of an estuarial or brackish-water life, associated with strictly Mesozoic Saurians. With the close of the Cretaceous the conformable series of marine and estuarial deposits east of the Wahsatch come to an end, and the last moments of deposition were immediately followed by one of the most important orographical movements of the whole Cordilleran history.

From the eastern base of the Rocky Mountains to the eastern base of the Wahsatch the whole region was thrown either into wide undulations or sharp folds. So great a range as the Uinta, with its distinct, broad, flat anticlinal, was made at this period. Relatively to the present basin of the Colorado, the whole chain of the Rocky Mountains was elevated so as to define a broad, shallow depression, which now includes the waters of Colorado River. Powerful and important as this orographical movement was, it failed to disturb the coast deposits of the Pacific in California; but from reasons already given it seems probable that the first definition of Cascade Range was caused by its force. In the general geology of North America the most important result of this immediately post-Cretaceous orographical movement was the elevation of the whole interior of the continent and the complete extinction of the inter-American mediterranean ocean.

From the date of this movement no marine waters have ever invaded the middle Cordilleras, and the subsequent strata are all of lacustrine origin. The effect of this orographical movement was to leave that part of the Cordilleras which falls within our study with a free drainage to the sea, with the single exception of the basin of Colorado River, which, from its configuration, immediately became the receptacle of the vast fresh-water Ute Lake, within whose area accumulated the important Vermilion Creek group, the earliest of the fresh-water Eocene strata. Throughout the entire Eocene period the basin of Colorado River was the theatre of a series of four Eocene lakes, whose deposits—unconformable among themselves, as has already been described—amount in all to 10,000 feet; lacustrine rocks characterized from the bottom to the top by an abundant series of vertebrate life covering the whole lapse of Eocene time. The Eocene of the Fortieth Parallel region was a period of four lakes superposed, the unconformity of their deposits due to four orographical disturbances.

An important orographical movement took place at the close of the Eocene, by which the province of the northern Great Plains and a long, narrow tract of Washington Territory, Oregon, Nevada, and California, lying on the eastern base of the Sierra Nevada and the present Cascade Range, became depressed and received the drainage of the surrounding countries, forming two extended Miocene lakes. The deposits of the westernmost lake are chiefly the tuffs and rearranged ejecta of volcanic eruption. The deposits of the Plains are the simple detritus from the surrounding lands. The series on the west are over 4,000 feet thick; in the east they are not proved to be over 300 or 400 feet. Both contain abundant and typical Miocene vertebrate life.

The close of the Miocene was signalized by a powerful orographical movement over the area of the western Miocene lake, which threw the beds accumulated on its bottom into folds. Contemporaneously with this movement the Miocene lake of the east, by the subsidence of the surrounding country, increased so as to cover the whole province of the Great Plains.

The Pliocene opened, therefore, with two enormous lakes, one covering the basin country of Utah, Nevada, Idaho, and eastern Oregon; the other occupying the province of the Plains. The Pliocene deposits of the Plains lake are calcareous and sandy beds, which have no angular nonconformity with the underlying sheet of Miocene sediment, but which overlap it in every direction. The deposits of the great western lake are nonconformable with the Miocene and immensely overlap it to the east, doubling the area of Miocene sediment. Both of these Pliocene lakes—as do the Miocene—contain the remains of rich faunæ. The eastern lake received a maximum of about 2,000 feet of strata; the western lake has nowhere shown over 1,400 feet.

The close of the Pliocene was signalized by another orographical movement, which threw the sediments of the Great Plains lake into their inclined attitude, dipping 4,000 feet to the east and 7,000 feet to the south from the Fortieth Parallel region. This same orographical movement acted differently upon the sheet of sediments which covered the Pliocene lake of the Great Basin. Instead of tilting the entire lake, it broke in the middle, and the two sides were depressed from 1,000 to 2,000 feet thick, the shores faulting downward. The result of the post-Pliocene movement in the department of the Plains was to give thereafter a free drainage to the sea. The result in the area of the Great Basin was to leave two deep depressions, one at the western base of the Wahsatch, one at the base of the Sierra Nevada, which, in Quaternary times, received the abundant waters of the Glacial period and formed the two lakes that have already been described in the Quaternary chapter.

In summing up the general stratigraphical results of the section, it will be seen by referring to the tabular statement at the end of this chapter that there is exposed, from the bottom of the Cambrian to the close

TA

Number of analysis.
62
63
64
65
66
67
68
69
70
71
72
73

TABLE OF CHEMICAL ANALYSES. VI.—A.—UNITED STATES GEOLOGICAL EXPLORATION OF THE FORTIETH PARALLEL.

SEDIMENTARY ROCKS.

Limestones.

Number of analysis.	Locality.	Formation.		Analyst.	Insol. res.	Äl	F̈e	Ċa	Ṁg	C̈	Ḣ		Total.	Ċa, Ṁg, and C̈ combined. Ċa C̈	Ṁg C̈
62	Conglomerate ridge, east of Bear River.	Pliocene - -	Wyoming conglomerate	B. E. Brewster -	12.30	0.78		47.01	0.49	37.08	2.41	. . . .	100.07	83.05	1.03
63	Garden Valley Tertiary - - - -	" - -	Humboldt - - - -	" -	12.07	1.28	0.57	45.29	1.86	36.23	2.65	{ K̇ Ṅa } 0.90	100.85	. .	. .
					12.11	1.50	0.44	45.30	1.83	36.23	2.67	{ K̇ Ṅa } 0.51	100.93	. .	. .
64	Chalk Bluffs - - - - - - - -	Miocene - -	White River - - -	R. W. Woodward	1.49	. .	0.37	54.16	0.15	43.68		Ṁn 0.15	100.00	. .	. .
					1.52	. .	0.31	54.18	0.15	43.69		Ṁn 0.15	100.00	. .	. .
65	Upper stratum, Valley Wells - -	" - -	Truckee - - - - -	B. E. Brewster -	32.12	0.43		35.82	0.36	29.16	2.10	. . . .	99.99	. .	. .
66	Reed's Hill, near Carson River, east end of Triangular Range.	" - -	" - - - - - -	" -	. .	0.10		53.99	1.25	43.80	0.86	. . . .	100.00	. .	. .
67	Fossil Hill, Hot Spring Mountains	" - -	" - - - - -	" -	7.38	0.80	0.68	48.53	2.46	40.86	. .	PO5 0.16	100.86	. .	. .
68	Bridger Beds, Henry's Fork - - -	Eocene - -	Bridger - - - - -	" -	31.28	1.83	0.22	34.20	0.11	26.79	4.64	K̇ 0.33 Ṅa 0.18	99.58	. .	. .
					31.45	1.58	0.21	34.18	0.08	26.82	4.64	K̇ 0.33 Ṅa 0.28	99.56	. .	. .
69	Green River shales - - - - -	" - -	Green River - - -	" -	29.22	0.76	2.16	33.53	0.56	27.08	6.27	{ K̇ Ṅa } 0.38	99.96	. .	. .
					29.19[1]	0.87	2.20	33.57	0.68	27.03	6.20	{ K̇ Ṅa } 0.38	100.12	. .	. .
70	Brush Creek, sphærolitic sandstone	Cretaceous -	Colorado - - - -	" -	. .	. .	. .	24.58	. .	. .	. .	. . . .	. .	43.90	. .
71	Dry Creek, blue shale - - - -	" -	" - - - - - -	" -	. .	. .	. .	. .	. .	. .	. .	. . . .	. .	65.93	.
72	North Park - - - - - - - - -	Jurassic - -	- - - - - - - - - -	" -	6.55	0.92		50.57	0.36	40.18	1.50	. . . .	100.08	91.11	0.75
73	Laramie Plains - - - - - - -	" - -	- - - - - - - - - -	" -	2.77	0.79		29.90	19.31	45.05	1.35	{ K̇ Ṅa } 0.38	99.55	53.40	40.55
					2.95	0.54		29.69	19.36	45.14	1.30	{ K̇ Ṅa } 0.28	99.42	53.02	40.66

(1)

SiO_2 - - - - - - - - -	23.47
Al_2O_3 - - - - - - - - -	5.40
CaO - - - - - - - - -	0.26
MgO - - - - - - - - -	0.06
	62.19

TABLE

Number of analysis.	
74	Div U
75	Ra V
76	Gre I N
77	Rec
78	Sur
79	Clc
80	Ver
81	Ric U s
82	Gra
83	Eas
84	Wh
85	No
86	Hu
87	Ea
88	Pe
89	Cit
90	Fo
91	Un

SEDIMENTARY ROCKS

Limestones—(Continued.)

Number of analysis.	Locality.	Formation.		Analyst.	Insol. res.	$\ddot{Al}$	$\ddot{Fe}$	$\dot{Ca}$	$\dot{Mg}$	$\ddot{C}$	$\dot{H}$		Total.	Ca, Mg, and C combined. $\dot{Ca}\ddot{C}$	$\dot{Mg}\ddot{C}$
74	Divide between Cottonwood and Union Cañons.	Triassic - -	Star [Upper] - - -	B. E. Brewster -	1.61	0.26		52.16	2.47	43.70	. .	PO^5 trace.	100.20	. .	. .
75	Ravine north of Wright's Cañon, West Humboldt Range.	" - -	" - - - -	" -	4.52	0.19		51.69	1.04	41.75	0.81	PO^5 trace.	100.00	. .	. .
76	Greenish limestone below Upper Red, East Fork Du Chesne, Uinta Mountains.	" - -	Red beds [Lower] - -	" -	13.46	1.63		36.78	8.44	38.31	2.04	Mn O 0.20	100.86	65.68	17.72
77	Red Butte - - - - - - - - -	" - -	" " - -	" -	22.21	0.21		43.24	0.15	33.94	0.14	. . . .	99.89	76.75	0.32
78	Summit of Tenabo - - - - - -	Carboniferous	Upper Coal Measures	" -	20.99	1.09		39.76	2.80	32.80	1.06	Fe S^2 1.16	99.66	67.54	5.88
79	Clover Peak Range - - - - -	"	" " -	" -	2.71	0.27		30.39	20.07	45.72	1.71	. . . .	100.27	53.75	42.14
80	Vermilion Gap Rocks, lower series	"	" " -	" -	2.02	0.57		54.06	0.34	42.85	0.41	. . . .	100.25	96.54	0.71
81	Ridge west of Green River, between Uinta quartzite and Cañon sandstone.	"	" " -	" -	27.93	0.35		39.54	0.28	31.69	0.25	. . . .	100.04	70.61	0.60
82	Granite Cañon, Black Hills - - -	"	" " -	R. W. Woodward	0.34	0.16		34.95	17.36	46.55	0.23	. . . .	100.11	. .	. .
83	East slope of Black Hills - - -	"	Lower Coal Measures -	B. E. Brewster -	. .	. .		. .	. .	. .	. .	. . . .	99.29	60.09	39.20
84	White Pine limestone - - - - -	"	" " -	O. D. Allen - -	0.70 0.70	. . . .		55.38 55.31	0.25 0.26	43.70 . .	. . . .	. . . .	100.03 . .	. . . .	. . . .
85	North of Maggie Creek Gap, Nevada	"	" " -	B. E. Brewster -	4.36	0.44		53.17	0.36	42.10	. .	PO_5 trace.	100.43	. .	. .
86	Humboldt Mountains - - - - -	"	" " -	" -	1.35	0.36		54.51	0.27	43.13	0.11	PO^5 0.35	100.08	97.34	0.57
87	East Humboldt Range - - - -	"	" " -	" -	37.03[2]	1.51	0.59	33.29	0.75	25.57	0.39	{ Na O 0.14 KO 0.16 }	99.43	56.25	1.56
88	Peoquop Range - - - - - - -	"	" " -	" -	34.91[3]	0.38		34.33	1.12	27.77	1.25	PO^5 trace.	99.76	60.32	2.34
89	City Creek limestone - - - - -	"	" " -	" -	2.37	0.24		53.09	1.20	42.88	0.21	PO^5 trace.	100.00	94.45	2.52
90	Fossil Hill, White Pine Mountains	Devonian -	- - - - - - - - -	" -	1.23	0.39		54.06	0.71	43.29	0.34	. . . .	100.02	96.53	1.48
91	Underlying limestone, Muddy Creek	Silurian - -	- - - - - - - - -	" -	16.73[4]	0.60		43.23	2.18	36.20	1.17	PO^5 0.12	100.23	76.82	4.58

(2)

SiO_2	- -	18.99
Al_2O_3	- -	5.79
Fe_2O_3	- -	2.23
Ca O	- -	4.43
Mg O	- -	3.90

(3)

SiO_2	- -	31.53
Al_2O_3	- -	2.45
Mg O	- -	0.12
Loss	- -	0.81
		34.91

(4)

SiO_2	- -	13.45
Al_2O_3	- -	3.12
		16.57

TABLE OF CHEMICAL ANALYSES. VII.—A.—UNITED STATES GEOLOGICAL EXPLORATION OF THE FORTIETH PARALLEL

SEDIMENTARY ROCKS.

Quartzites, Sandstones, and Associated Occurrences.

Number of analysis.	Locality.	Formation.		Analyst.	$\ddot{\mathrm{Si}}$	$\ddot{\mathrm{Al}}$	$\dddot{\mathrm{Fe}}$	Fe	$\dot{\mathrm{Ca}}$	$\dot{\mathrm{Mg}}$	$\dot{\mathrm{Na}}$	$\dot{\mathrm{K}}$	$\ddot{\mathrm{C}}$	$\dot{\mathrm{H}}$		Total.
92	Cache Valley	Pliocene	Humboldt	B. E. Brewster	94.44	und.	und.	. .	. .	und.	. .	. .	. .	0.45	. . . . .	94.89
93	South slope, Uinta Mountains	Eocene	Uinta	"	87.46	und.	und.	. .	. .	. .	. .	. .	. .	2.61	. . . . .	90.08
94	Brown's Hole	"	Green River	"	62.43	14.57	tr.	. .	1.86	1.41	4.90 (Na + K)		. .	With organic matter. 14.86	. . . . .	100.00
95	Cathedral Bluffs, Wyoming	"	"	"	74.82	und.	und.	. .	und.	und.	. .	. .	und.	. .	. . . . .	. .
96	Black Butte	Cretaceous	Laramie	"	97.81	und.	und.	. .	. .	und.	. .	. .	. .	0.37	. . . . .	98.18
97	Ashley Creek, Uinta Mountains	"	Fox Hill	"	85.51	und.	tr.	. .	. .	. .	. .	. .	. .	0.51	Carbonaceous matter. 10.96	96.98
98	Saint Mary's Peak, Wyoming	"	"	"	94.76	2.99	0.23	. .	0.21	. .	0.13	0.41	. .	1.10	. . . . .	99.83
99	Camp Walbach	"	Dakota	"	95.46	2.69	0.18	. .	0.14	0.06	0.25 (Na + K)		. .	1.18	. . . . .	99.96
100	Red sandstone, Uinta Mountains	Triassic	. . . .	"	57.58	7.60	0.67	. .	$\dot{\mathrm{Ca}}\ddot{\mathrm{C}}$ 27.28	$\dot{\mathrm{Mg}}\ddot{\mathrm{C}}$ 2.04	1.15	2.06	. .	0.70	. . . . .	99.58
101	Divide between Cottonwood and Unionville Cañons.	"	. . . .	"	74.74	14.14	0.79	. .	1.61	0.39	0.92	5.29	. .	1.88	. . . . .	99.76
					74.72	14.10	0.81	. .	1.51	0.44	0.75	5.42	. .	1.83	. . . . .	99.58
102	Coyote Cañon	"	. . . .	"	Insol. res. $\ddot{\mathrm{Si}}$ 67.37, $\ddot{\mathrm{Al}}$ 5.69	2.15	1.30	. .	6.07	4.40	1.14	2.38	9.00	1.62	. . . . .	101.12
103	Near Cottonwood Cañon, West Humboldt Mountains.	"	. . . .	"	85.77	7.60	0.89	. .	0.27	0.23	0.79	3.39	. .	0.70	. . . . .	99.64
104	Cottonwood Cañon, West Humboldt Mountains.	"	. . . .	"	69.60	17.21	3.66	. .	0.74	0.71	tr.	4.50	. .	3.20	. . . . .	99.62
105	Weber Cañon, below Narrows, Wahsatch Mountains.	"	. . . .	"	93.96	und.	tr.	. .	. .	tr.	. .	. .	. .	0.80	. . . . .	94.76
106	Anthro's Cañon, Uinta Mountains	"	. . . .	"	90.13	und.	tr.	. .	. .	tr.	. .	. .	. .	0.11	Carbonaceous matter. 6.10	96.34
107	West Ridge, Battle Mountain	Carboniferous	Upper Coal Measures	"	75.32	15.19	3.30	. .	. .	2.41	0.31	0.22	. .	1.[illegible]8	. . . . .	98.73
108	Cabin Quarry, Upper Weber	"	" "	"	Insol. res.[1] 66.74; Sol. $\ddot{\mathrm{Si}}$ 0.19	1.76	1.72	. .	13.23	2.54	. .	. .	11.11	1.38	PO^5 0.74	99.41
109	Top of Parley's Peak, Wahsatch Mountains.	"	" "	"	Insol. res.[2] 60.75; Sol. $\ddot{\mathrm{Si}}$ 0.21	2.29	2.58	. .	16.00	2.99	. .	. .	12.64	1.99	. . . . .	99.45

(1)

SiO^2	59.56
Al_2O_3	6.83
MgO	0.34
	66.73

(2)

SiO_2	53.99
Al_2O_3	6.52
MgO	0.23
	60.74

TABLE OF CHEMICAL ANALYSES. VII.—B.—UNITED STATES GEOLOGICAL EXPLORATION OF THE FORTIETH PARALLEL.

SEDIMENTARY ROCKS.

Quartzites, Sandstones, and Associated Occurrences—(Continued.)

Number of analysis.	Locality.	Formation.		Analyst.	$\ddot{Si}$	$\overline{\dddot{Al}}$	$\overline{\dddot{Fe}}$	$\dot{Fe}$	$\dot{Ca}$	$\dot{Mg}$	$\dot{Na}$	$\dot{K}$	$\ddot{C}$	$\dot{H}$		Total.
110	Pilot Peak, Ombe Range, Nevada -	Carboniferous	Weber Quartzite - -	B. E. Brewster -	94.93	und.	und.	. .	. .	. .	. .	. .	. .	0.17	. . . . . .	95.10
111	Big Cottonwood Cañon, Wahsatch Mountains.	"	" " - -	" -	95.81	und.	und.	. .	und.	. .	. .	. .	. .	0.28	. . . . . .	96.09
112	Weber Cañon - - - - - - - -	"	" " - -	" -	82.99	tr.	tr.	. .	und.	und.	. .	. .	. .	5.47	. . . . . .	88.46
113	Point Carbon, East Fork of Du Chesne	"	" " - -	" -	97.63	und.	und.	. .	. .	tr.	. .	. .	. .	0.58	. . . . . .	98.21
114	Agassiz Amphitheatre - - - - -	"	" " - -	" -	98.58	und.	und.	. .	. .	. .	. .	. .	. .	0.17	. . . . . .	98.75
115	Carico Peak, Nevada - - - - -	"	" " - -	" -	97.59	und.	und.	. .	. .	. .	. .	. .	. .	0.18	. . . . . .	97.77
116	Bear River, Geodetic Point - -	"	" " - -	" -	87.47	7.47	0.26	. .	. .	0.20	1.30	2.53	. .	0.56	. . . . . .	99.79
					87.42	. .	. .	. .	. .	. .	1.09	2.73	. .	0.45	. . . . . .	. .
117	Ogden Cañon, Wahsatch Mountains	Devonian -	Ogden - - - - -	" -	97.79	und.	tr.	. .	. .	. .	. .	. .	. .	0.15	. . . . . .	97.94
118	American Fork Cañon, Wahsatch Mountains.	" -	" - - - - -	" -	89.75	. .	. .	. .	. .	. .	. .	. .	. .	2.38	. . . . . .	92.13
119	Three Lakes, Wahsatch Mountains	Cambrian -	- - - - - - - - -	" -	59.96	und.	tr.	. .	. .	tr.	. .	. .	. .	3.16	. . . . . .	. .

Iron-stone.

Number of analysis.	Locality.	Formation.		Analyst.	$\ddot{Si}$	$\overline{\dddot{Al}}$	$\overline{\dddot{Fe}}$	$\dot{Fe}$	$\dot{Ca}$	$\dot{Mg}$	$\dot{Na}$	$\dot{K}$	$\ddot{C}$	$\dot{H}$		Total.
120	Near Carbon, Wyoming - - - -	Cretaceous -	Colorado - -	" -	9.74	5.57	1.93	38.67	7.64	1.20	0.46 (Na and K together)		32.04	. .	Mn O 2.38	99.63

Infusorial Earths.

Number of analysis.	Locality.	Formation.		Analyst.	$\ddot{Si}$	$\overline{\dddot{Al}}$	$\overline{\dddot{Fe}}$	$\dot{Fe}$	$\dot{Ca}$	$\dot{Mg}$	$\dot{Na}$	$\dot{K}$	$\ddot{C}$	$\dot{H}$		Total.
121	Little Truckee River, Nevada - -	Miocene - -	Truckee - - - - -	R. W. Woodward	91.43	2.89	. .	0.66	0.36	0.25	0.63	0.32	. .	3.80	. . . . . .	100.34
					91.51	2.95	. .	0.63	0.39	0.20	0.59	0.?3	. .	3.79	. . . . . .	100.39
122	Fossil Hill - - - - - - - - -	" - -	" - - - - -	"	86.70	4.09	. .	1.26	0.14	0.51	0.77	0.41	. .	5.99	PO^5 und.	99.87
					86.91	4.00	. .	1.22	0.11	0.51	0.80	0.36	. .	5.89	PO^5 und.	99.80
123	Fossil Hill - - - - - - - - -	" - -	" - - - - -	B. E. Brewster -	98.06	. .	. .	. .	. .	. .	. .	. .	. .	0.62	. . . . . .	98.68

Green Earth.

Number of analysis.	Locality.	Formation.		Analyst.	$\ddot{Si}$	$\overline{\dddot{Al}}$	$\overline{\dddot{Fe}}$	$\dot{Fe}$	$\dot{Ca}$	$\dot{Mg}$	$\dot{Na}$	$\dot{K}$	$\ddot{C}$	$\dot{H}$		Total.
124	Grizzly Buttes, Bridger Basin - -	Eocene - -	- - - - - - - - -	R. W. Woodward	66.17	14.95	2.76	1.95	3.89	1.88	2.84	3.77	. .	2.61	{Mn O, Li O, SO^3} trace.	100.82
					66.42	14.73	2.82	1.93	3.89	1.97	2.97	3.61	. .	2.57	{Mn O, Li O, SO^2} trace.	100.91

of the Tertiary, a total thickness of about 77,000 feet of beds. About 19,800 feet are limestone, while the rest is purely detrital.

In the Cretaceous and Tertiary a considerable chemical proportion of the detrital beds is lime, but they are distinctly detrital formations, and the lime is the disintegration of already crystallized limestone. Embraced within the 19,800 feet of limestone are 1,500 feet of calcareous shales and shaly limestone of the Green River middle Eocene group.

The great Pogonip Cambro-Silurian bed of 4,000 feet is prevailingly siliceous, and is characterized by a small, variable percentage of magnesia.

The Wahsatch limestone, 7,000 feet thick, the greatest single calcareous body in the series, is for the most part a normal limestone, mechanically impure at a variety of horizons by the inclusion of siliceous or argillaceous particles, and in the lower beds, especially in the region of the Waverly and parts of the Devonian horizons, chemically impure by the admixture of carbonate of magnesia.

True dolomites in thin sheets are found in both the Pogonip and Wahsatch bodies, but neither chemical nor microscopic analysis discovers a considerable general distribution of magnesia in these two great series.

The Upper Coal Measure limestone, 2,000 feet thick, is comparatively pure, its chief admixture being argillaceous and siliceous sediments.

The series of intercalated limestone beds, amounting in all to about 5,000 feet in the Alpine Trias of western Nevada, is noticeable for the large amount of carbon which it contains, the comparatively small amount of magnesia, and the constant, but slight, proportion of quartzose and aluminous sand.

Above the limit of the upper Trias, throughout the entire Cretaceous and Tertiary, the limestones are all fragmentary and are simply the pulverized sands which are worn down from the neighboring limestone mountains.

15,000 ft.	CENOZOIC.	QUATERNARY	Upper Quaternary		Gravels and loose subaerial detrital material.	
			Lower Quaternary		Fine muds and silts.	
		TERTIARY	Pliocene	Wyoming Conglomerate.	Coarse structureless conglomerate.	
				Niobrara	Coarse and fine friable sandstones, and siliceous limestones; horizontal where observed.	
				Humboldt	Generally siliceous, fine-grained, friable beds; frequently volcanic tuffs; undisturbed.	
				North Park	Drab sandstones and limestones, loosely agglomerated; undisturbed.	
			Miocene	Truckee	Fossiliferous limestones, gravels, and volcanic (palagonite) tuffs; upturned.	
				White River	Fine light-colored sandstones, with clays interstratified.	
			Eocene	Uinta	Coarse and fine pinkish sandstones, gravel conglomerates, and argillaceous beds.	
				Bridger	Drab thin-bedded sandstones, and green marls, rich in vertebrate remains; slight development of limestones.	
				Green River	Thin calcareous shales, with fishes and insects; buff calcareous sandstones, and lignite toward the base.	
				Vermilion Creek	Coarse pink and chocolate-colored sandstones, with large development of conglomerates. *Coryphodon* beds.	
30,000 ft.	MESOZOIC.	CRETACEOUS		Laramie	Coarse white and reddish sandstones, heavily bedded, with large development of coal seams. Fossils marine and brackish-water. Unconformable with foregoing series.	
				Fox Hill	Coarse white sandstones, heavily bedded; few coal seams; less iron than former; fossils marine.	
				Colorado	Mostly blue and yellow clays and marls, with thin sandstones. Coal. Fossiliferous.	
				Dakota	Sandstones and characteristic conglomerate.	
		JURASSIC			East of Wahsatch. Clays and limestones; fossiliferous; small development. In Nevada. Heavy limestones, shales, and argillites; greater development.	
		TRIASSIC	Red Beds	Star Peak	Heavy-bedded, fossiliferous blue limestones, interstratified with quartzitic schists and slates.	The Red Beds, which represent the entire development of Triassic rocks east of the Wahsatch, consist mainly of coarse, heavily-bedded sandstones, of prevailing red color, sometimes white or buff, with some clays, thin limestone beds, and frequent deposits of gypsum. Almost barren of fossils.
				Koipato	Quartzites, argillites, and porphyroids.	
32,000 + ft (Wahsatch section).	PALÆOZOIC.	CARBONIFEROUS	Permo-Carboniferous		Clays and argillaceous limestones, with ripple-marks.	
			Upper Coal Measures		In general, light-colored blue and drab limestones, more or less siliceous, and passing in places into sandstones; generally fossiliferous.	
			Weber Quartzite		Compact sandstones and quartzites, frequently of reddish colors, with local developments of interstratified calcareous and argillaceous beds and conglomerates; non-fossiliferous.	
			Lower Coal Measures	Wahsatch limestone.	Heavy-bedded blue and gray limestones, with some interstratified quartzites, more frequently in the upper part of the series. Lower beds siliceous at times. Fossiliferous.	
			Sub-Carboniferous			
		DEVONIAN	Nevada Devonian			
			Ogden Quartzite		White saccharoidal quartzite, pink tints; conglomerate with flattened pebbles.	
		SILURIAN	Ute-Pogonip limestone		Compact blue limestone, with included argillites, passing into calcareous shales. More largely developed in Nevada, where the limestone carries primordial fossils at the base.	
		CAMBRIAN	Pogonip			
					Generally white quartzites, more or less iron-stained, with some development of micaceous beds, and heavy dark-blue argillites.	
50,000 + ft.	ARCHÆAN.	HURONIAN			Plagioclase-hornblende granites, diorite-gneisses, argillites, limestones, and quartzites.	
		LAURENTIAN			Coarse red orthoclase-mica granites, mica-gneisses, and schists, with deposits of ilmenite and graphite.	

CHAPTER VII.

TERTIARY VOLCANIC ROCKS.

SECTION I.

PROPYLITES AND QUARTZ-PROPYLITES.

It is the purpose of this chapter to assemble the more important facts accumulated by our Exploration relating to the Tertiary volcanic rocks, their sequence, geological dates, mode of occurrence, reciprocal relations, and petrographic* distinctions, and to offer an hypothesis which it is hoped may serve to advance our knowledge of the genesis and classification of volcanic species. The material will be classed under three groups:

First, the detailed occurrence of species, covering sections I. to V., inclusive; and in this the past method of treatment will be continued, namely, to begin with the earliest form and describe its special occurrences, passing always from east to west.

Secondly, the larger laws of occurrence contained in section VI., the relations of each rock to the orographical actions which brought it to the

*All purely microscopic details are hereby credited to Vol. VI., by F. Zirkel.

surface, with such generalizations as seem to be warranted as to synchronous extravasation of each species, and the superposition and succession of all the species.

Thirdly, in Section VII. the origin of igneous fusion and the genesis and petrological classification of volcanic rocks.

The area of the Fortieth Parallel has proved exceedingly rich in volcanic rocks. Although but a small part of the actual surface is covered with ejecta, yet, as compared with other wide regions, it is distinguished by the presence of a very great number of volcanic outbursts. Were the Quaternary valley deposits removed, together with a considerable portion of the most recent Pliocene, the area of volcanic rocks would be greatly enlarged over the western part of Nevada. Reference to Analytical Map VII., at the close of this chapter, will show at a single glance the area covered and the distribution of species.

At the close of the Jurassic age, a powerful mountain-building period was characterized in Nevada and Utah by scattered ejections of middle-age eruptive rocks, including diorite, diabase, felsite-porphyry, and hornblende-porphyry, together with rare melaphyres. That these rocks were post-Jurassic is clear from their covering Mesozoic strata in western Nevada and California. All over the Cordilleras, so far as we know, the entire span of the Cretaceous age was one of orographical calm, undisturbed either by important mountain flexures, perceptible dislocations, or the ejection of igneous material. The changes of level which may be assumed to have taken place were altogether the subsidences of sedimental areas.

East of Wahsatch Range, the entire Cretaceous series, having a maximum thickness of 12,000 feet, are strictly conformable, and are characterized by detrital material, and there are no traces anywhere of sediments which may be referred to active eruption. The same is true on the west coast of California. The marine Cretaceous which skirts the western flank of the Sierra Nevada, and has more recently been upheaved in the system of Coast ranges, shows an enormous thickness of pure detritus. So far as our observation goes, the land-mass which lay between the eastern and western oceans, bounded on the east by the Wahsatch and on the west by the Sierra Nevada, has no traces of Cretaceous accumulations, either subaerial or stratified. We have looked in vain for fresh-water Cretaceous lakes or for early massive eruptions. All the indications we have yet been able to obtain, point to the fact that this Cretaceous continent had free drainage to the sea, was characterized by the absence of all considerable lakes, and was eroded to an enormous extent, but never built up by volcanic material. It is not improbable that sooner or later the traces of small fresh-water lake deposits may be found. It would, indeed, be surprising if such lakes did not exist of sufficient size to have withstood the subsequent erosion throughout the Tertiary and Quaternary periods. The value of such deposits, could they be found, can hardly be over-estimated, as this land area must have been the habitat of the progenitors of Eocene mammals. Such lakes would also, perhaps, solve the question whether over the land areas there are any ejections. Until such data shall be discovered, we are warranted in assuming that the Cretaceous was a period free from either considerable orographical motion or the coming to the surface of any igneous rocks.

The relations of volcanic material to the surrounding sedimentary rocks are always among the most perplexing problems offered to the field geologist. In the case of the Fortieth Parallel area, after the greatest pains-taking, we are still unable definitely to fix the era of the resumption of igneous activity. In the extreme east of our area, on the divide between North and Middle parks, as also upon Steves' Ridge in the Elk Head Mountains, occur two families of rocks which may not improbably be hereafter referred to one group. Those upon Steves' Ridge have been referred by Professor Zirkel to the trachytes. They are quartziferous trachytes, composed of sanidin, quartz, biotite, a little plagioclase, and rare hornblende, titanite, and apatite. The sanidins are among the most remarkable ever observed in volcanic rocks. The crystals are all completed and attain the size of an inch cube, and present many of the rare faces which are characteristic of the older orthoclases of granite-porphyry. All the quartz appears in macroscopic grains the size of a pea, which are rich in glass inclusions.

The strikingly similar granite-porphyry from Good Pass, east of Park

View Peak, between North and Middle parks, is fully described on pages 68 and 69, Vol. VI. Large orthoclases, possessing the same rare planes as in the trachytes just mentioned are associated with quartz grains, a few plagioclases, strongly fibrous hornblende, a little epidote, apatite, and titanite. The chief difference between these two types of rock is, that in the so-called granite-porphyry the quartz contains fluid inclusions, which also occur in the fresh portions of the feldspars. Glass inclusions are wanting in the Good Pass rock. Otherwise they are strikingly similar, and they are totally unlike any other eruptive rocks within our field. Through the kindness of Major Powell and Mr. G. K. Gilbert, I have been permitted to look at a series of absolutely identical rocks from Henry Mountains, Colorado Plateau. Several slides from this latter locality were subjected to microscopic analysis, when it was seen that the hornblende contained beautiful glass inclusions, while certain of the quartzes contained fluid inclusions with moving bubble. The feldspars were the same remarkably developed orthoclases, with the rare planes mentioned by Zirkel, and associated with a few brilliantly striated plagioclases. In other words, in the Henry Mountain groups, both the types—that of Steves' Ridge, which Professor Zirkel had called trachyte, and that of Good Pass, which he referred to the granite-porphyries—were found associated. It is further of great interest that in all three of these localities the eruptive rocks are either connected with or subsequent to the upheaval of Cretaceous strata.

Tertiary rocks have not been observed in immediate contact with them in our area, and consequently our only clew to their date is, that they are subsequent to the deposition of the Cretaceous. From every geological analogy we are led to believe that the disturbance of the Cretaceous connected with the ejection of these peculiar rocks was a part of the general disturbance which took place during or posterior to the Eocene. It is indeed possible that the occurrence of these rocks will finally be proved to be pre-Eocene; but from the present geological indications we can only class them as post-Cretaceous and not improbably connected with the immediate close of the Eocene period. At the first two localities mentioned they partake, on the one hand, of the nature of trachyte, and on the other of granite-porphyry. In the Henry Mountain rocks some of the specimens show a clear predominance of plagioclase and hornblende over orthoclase and mica. With these forms are associated quartzes containing moving bubbles.

Taken together, the three occurrences show a series of rocks having remarkable physical similarity, yet when subjected to microscopical analysis showing an approach to the diorites, to the granite-porphyries, and to the trachytes. It is not a little singular to see this surprising divergence of interior constitution with such evident physical similarity and the common characteristic of large, highly developed orthoclase crystals. At the present writing I am inclined to group these rocks under one head and refer them to a point of time within the Tertiary period, and to insist that they show all the specific divergences which will afterward be traced in some of the later groups of volcanic rocks. In both cases the geological mode of occurrence of these rocks is obscure in the territory of the Fortieth Parallel. They accompany the dislocation and upheaval of thick bodies of Cretaceous strata. They cut the latter in dikes, and appear as heavy extrusions. The country in both cases is so much covered with soil, the soft Tertiary strata are so generally removed, and there is such a dense growth of forest, that the unravelling of the exact geological relation is very difficult, so that we are obliged to look to Mr. Gilbert's forthcoming memoir * for all the particular geological relations of this interesting group.

I have mentioned these in this connection simply to show that the dawn of volcanic action is at present not fixed by rigid geological dates. With the exception of this group of rocks, which is either to be placed at or since the close of the Cretaceous, all the other volcanic series are referable directly to the Tertiary.

The remarkable natural sequence of volcanic rocks brought to light by the admirable researches of Richthofen has been in every way corroborated by us. About the time of the appearance of Richthofen's memoir it was the writer's good fortune to geologize with him in the complex field of Washoe, where, more interestingly than anywhere else within the Fortieth Parallel area, the various families of volcanic rocks were displayed. From that time to the close of our Exploration I devoted much

* Report on the Geology of the Henry Mountains, by G. K. Gilbert.

time to examining the geological relations and superpositions of volcanic products, and came without hesitation to accept as law the order of sequence laid down by him, which is as follows:

1. Propylites.
2. Andesites.
3. Trachytes.
4. Rhyolites.
5. Basalts.

PROPYLITE.—Wherever we have been able to observe propylite in juxtaposition with others of these five eruptive groups, it is invariably the oldest. At the southern base of the Mount Davidson group in Washoe the great flood of propylitic rocks which deluged the whole declivity was outpoured beneath the waters of a Tertiary lake. The material in the region of the Daney Mine, and for a considerable distance east and west and down toward the valley of the river until it passes beneath the soft Pliocene strata, is composed of propylitic tuff, partly arranged by water into truly stratified beds, and partly bedded in a loose manner, as if it flowed down in vast fields of thick mud. The tuff specimens of these muddy bodies are characterized by the presence of numerous leaves, chiefly willow, which have been pronounced to be Tertiary. But we have learned to be a little cautious about accepting the evidence of leaves, since the history of the assignment of horizons upon plant evidence alone in Utah, Wyoming, and Colorado has revealed a series of professional disasters. This is the only direct evidence connected with the propylites themselves.

The science of petrography offers no more interesting example of the delicate shades on which lines may be successfully drawn than the case of this rock. Richthofen's subtle observation and great practice as a field geologist enabled him to detect the essential characteristics of the habitus of this rock, while at the same time he clearly saw its relations to the other hornblende-plagioclase species. The subsequent microscopic analysis of the rock by Zirkel has firmly established its independence as a species. The English petrographers especially have been inclined to deny its existence; but the shade of habitus upon which Richthofen founded his first assertion of the species is so evident in the field of the Fortieth Parallel Exploration that there has never been the slightest doubt on the part of Messrs. Emmons and Hague and myself as to the identity of propylite. When the large collection of specimens brought in by us came to be studied microscopically by Zirkel, it was found that we had never wrongly assigned a specimen to propylite. In certain instances the microscope revealed the presence of minute grains of quartz, and the rock thus characterized came to be classed as quartz-propylite; but there was never any doubt as to the generic nature of the rock. There was not a solitary instance in which the rock by us called propylite proved to be either diorite, andesite, or plagioclase hornblende-trachyte. I am careful to mention this fact, not as a guarantee of the correctness of our determinations, for that has been placed beyond question by the microscopical analyses of Zirkel, but because later in this chapter I shall have occasion to discuss what constitutes a species of volcanic rock, and the factor which habitus must necessarily play in classification.

Whether we regard the actual number of exposures or the total area of the propylite, this rock is of the least geographical importance. In all cases it is associated with later volcanic rocks, and the paucity of its exposures and its restriction of area are doubtless in great measure owing to overflow by the later species. From the few exposures in our area, we have every reason to believe that if the later volcanic rocks had not overwhelmed them, the outcrops of propylite would be more frequent and extensive.

Within the Fortieth Parallel area this rock is confined to the region west of the 116th meridian, appearing only in the basin of Nevada—in other words, within the boundaries of the Miocene lake. The most eastern propylites in our field are found on the meridian of 116° 15′, and a little north of the parallel of 41° 15′, in the region of Tuscarora. Here a region from three to four miles north-and-south by two miles east-and-west, the whole lying north of Tuscarora, is composed of propylite. The surface is almost altogether decomposed, and solid outcrops are rare. It is overlaid by rhyolite on the north, northwest, and northeast, and at the extreme southern end of the outcrop, in the region of Tuscarora, it is covered by the thick Quaternary beds of Independence Valley. Upon the whole it is, as an outcrop, rather obscure and unsatisfactory. The surface, to a depth of three or four feet, is a loose propylitic earth which has been worked for placer gold. The solid, normal portions of the rock are light greenish-gray, decidedly porphyritic, with a general earthy texture and rough trachytic surface. The predominating mineral is fibrous green hornblende of a light-olive tint. Plagioclase decidedly exceeds the few decomposed orthoclases which are present. Besides the fibrous green hornblende, there are dark solid prismatic hornblendes scattered at intervals through the mass.

Farther south, at Wagon Cañon, in Cortez Range, a little hill to the north of the pass, in the midst of quartz-propylites, shows a greenish earthy body, of which the hornblende is almost entirely decomposed, and the large, dull plagioclases are chiefly kaolinized. A few rather fresh monoclinic feldspars occur, besides which the microscope reveals apatite and a little biotite. This occurrence comes to the surface as an island in a broad field of distinctive quartz-propylite.

In the Fish Creek Mountains, at the western base of Mount Moses, a belt of granite overlaid by Triassic strata forms the foot-hills, which to the north and south are overwhelmed by the enormously thick accumulations of rhyolitic eruptions. Where the Triassic rocks pass underneath the rhyolites are a few limited masses of propylite which the most recent erosion of the rhyolite has laid bare. The hills directly north of Storm Cañon show excellent outcrops of the propylite, which is here made up of hornblende, frequently fresh and well preserved, built (as is the rule in the propylites) of thin, staff-like microlites impregnated with small, black grains. Zirkel found the hornblende in places considerably decomposed, resulting in calcite, epidote, and viridite. The feldspars are often fresh and quite large, a majority bearing distinct triclinic striations, with a few pale, small orthoclases. Brown mica occurs sparingly, and besides hornblende the rock contains an inferior amount of yellowish-green augite.

In Toyabe Range, near Boone Creek, the prominent ridge of quartzite is enclosed on the east and west by rhyolitic rocks, the latter breaking through upturned Miocene strata. Near the junction-line, where the quartzite passes under the rhyolite, are two rather obscure outcrops of normal hornblende-propylite. The surface is much decomposed, and there is very little of the hard material that can be observed; yet the chips with which the surface is covered are characteristically of the normal green hornblendic propylite. It decomposes in soft, earthy, olive-colored slopes, which are overlaid by both rhyolite and basalt. The outcrops are too obscure and too limited to be specially instructive.

An interesting locality of propylite is that at Kaspar's Pass, north of Hot Springs Station, at the southwestern end of Montezuma Range. The termination of the Montezuma is a deeply scored mass of rhyolite, overflowed by basalts which chiefly cover the southern slope of the hills. The base of the range, from the northern edge around as far as White Plains, is completely surrounded by outcrops of Truckee Miocene, which are inclined toward the range until in the neighborhood of the rhyolites they are thrown into irregular dips, having been burst through and overflowed by the rhyolitic bodies. These Miocene strata are more or less covered by accumulations of Quaternary. Through Quaternary, immediately in the vicinity of Kaspar's Pass, comes to the surface a body of propylite which occupies the whole of the Pass from the rhyolitic foot-hills on the east to an oval body of basalt which forms the western side of the valley. The basalts on the west, and the Montezuma rhyolites, clearly overlie the propylite; and although the relation between the Miocene and the propylite is obscured by Quaternary, all the appearances tend to the belief that the Miocene beds abut unconformably against a preëxisting body of propylite. This is rendered very probable by the material of the Miocenes, which is here altogether of the upper or trachytic tuffs. The surface of the propylite is much weathered, resulting in soft olive earth, with predominating propylitic chips. It consists of hornblende and triclinic feldspars, more or less altered, and epidote, a pseudomorphous product after hornblende. The microscope reveals, as Professor Zirkel describes,* all the pseudomorphic changes between hornblende and epidote.

The lower Truckee Cañon, from about two miles above Wadsworth, for six miles up the cañon, has its bottom largely occupied by propylite. It is entirely unconnected with any stratified rocks, and no clew is offered to the orographical disturbances related to its ejection. It occupies only the

* United States Geological Exploration of the Fortieth Parallel, Volume VI., page 114.

low land at the bottom of the valley, and is covered upon either side by more recent trachytes. A mass of diorite upon the river bank about four miles above Wadsworth is the only older rock in the neighborhood, being a hard, fresh boss of well preserved rock, around which the soft, earthy propylite has flowed. The propylite is of a dull olive-green, and is much decomposed, the feldspars reduced to soft, kaolinic masses, of which even the crystalline forms are chiefly lost. The groundmass is reduced to an almost amorphous paste, and there is a good deal of partially decomposed brown mica. The rock is full of dark green waxy spots, which, in favorable instances, were seen to retain the distinct form of augite. It is clearly an augite-propylite, similar to that discovered by Richthofen at Silver Mountain, which is here in the last stages of decomposition. It is of interest in this connection because this is the only locality of augite-propylite within the Fortieth Parallel area. It is overflowed by peculiar augitic trachytes, by light rhyolites, and finally by basalt.

A few miles north of Truckee Cañon, at Berkshire Cañon, a gorge eroded down the eastern flank of Virginia Range, occurs a fine association of volcanic rocks which have burst out in immediate contact with a body of older melaphyre. The propylite forms the earliest of the volcanic series, and occurs in a body of purple rock lying along the eastern flank of the lofty mass of melaphyre. It is invaded by quartz-propylite and by andesites, and is overflowed at the northern end by trachyte, which, in its turn, is covered by rhyolite, and that is succeeded by basalt. It is a rather earthy, compact propylite, composed of triclinic feldspar and greenish-purple hornblende, with a little magnetite, apatite, and occasional grains of mica. The outcrops are very limited, and for the most part covered with soil and overwhelmed by later ejections.

In Steamboat Valley, a little south of the west end of Map V., there is in the low lands a considerable development of hornblendic propylite, in which decomposition has reached an advanced stage. The staff-like growth of the hornblende is traceable in some of the better preserved crystals, the nature of the groundmass is totally obscured, and the feldspars are altogether kaolinic.

At all the localities heretofore mentioned, the propylite is displayed sufficiently for identification, and in nearly all cases for determining its age relatively to the surrounding eruptive rocks; but for minute study of the rock itself the occurrences are usually too disintegrated and altered for the collection of really specific types. They are all very restricted localities, and all occur at rather low altitudes, and offer none of the bold characteristic outcrops which mark the high parts of Virginia Range. So far as I have seen, from Pyramid Lake southward to its junction with the Sierra Nevada, Virginia Range shows at frequent intervals enormous fields of propylitic rock. South of Carson River it recurs at intervals for many miles, and in the Washoe mining district is displayed on a scale which is unsurpassed anywhere in the United States Cordilleras. In Volume III., "Mining Industry," page 25 *et seq.*, a detailed account is given of its mode of occurrence. Again, in Volume VI., "Microscopical Petrography," page 110 *et seq.*, Professor Zirkel has rehearsed the prominent features of that classic propylite locality.

Without repeating here what was said there, it seems necessary to recapitulate the broader facts of its mode of ejection and the leading petrographical characteristics of the rock. Prior to the propylite period, Virginia Range consisted of upturned sedimentary rocks—slates, limestones, nodular schists, and quartzites—whose original disturbance was connected with intrusions of true granite. Through these had outburst great dioritic masses whose hard summits had withstood erosion and formed culminating points of the range. The propylitic ejections took place from a series of fissures running longitudinally with the range and extending from summit to base on both sides. The diorites of the Mount Davidson ridge are cut by broad propylitic dikes, and similar lines of fracture may be traced north and south along the summit of the range for many miles. Down the south and east sides of the ridge the propylitic rocks poured quite to Carson Plain, and upon the west to the level ground of Steamboat Valley. Only the highest portions of the diorite summits were lifted above the enormous floods of propylite which poured out from these longitudinal fissures. The eruption was not continuous, but clearly intermittent, as is shown by the manner in which later propylite dikes cut through the heavy flows of the earlier ejections.

There is no evidence of the propylite having flowed in the sense of an andesite or a basalt. It never extended in thin sheets, but was evidently ejected in a viscous condition, accompanied (if we may judge from the present aspect of its areas) by enormous amounts of water, and developed a sluggish flow down the rather steep slopes of the range. The first eruptions were of normal crystalline propylite, uniformly porphyritic, and almost wholly of olive-green colors. The second ejection, which had its centres of eruption north and south of Mount Davidson, was of a coarse, propylitic breccia, which contained fragments as large as a foot in diameter, enclosed in an ordinary propylitic matrix, the breccias varying from green to purple. The third period of eruption was in the form of narrow dikes without any considerable outflow. They cut the main body of the propylites and the overlying breccias in the north-and-south lines, the dikes varying from six to thirty feet in thickness. Near Geiger Grade, north and west of Virginia City, may be seen the relics of these hard, crystalline dikes, which have withstood erosion better than the soft breccia, or even than the main porphyritic eruption. In consequence, they stand up in bold remnants of sheets which once formed the dike, towering thirty or forty feet above the surface.

In immediate contact with the diorite, some of the early ejections were of an exceedingly fine, compact texture, developing a fissile structure resembling some fine hornblendic slates. Above the level of Comstock Lode the propylite is altogether unaltered, but east of it the whole propylitic region is more or less wackenitic from solfataric action. At the lower levels, near Carson Valley, the ejections, as has been heretofore mentioned, were sublacustrine, resulting in rudely stratified, muddy tuffs. These extend about 600 or 700 feet above the present level of the river. The belt of middle altitudes below the level of the Comstock Lode is an area of earthy soft rock, frequently decomposed into white, yellow, and red clays, in which the original structure of the propylite is only indicated by soft, kaolinic white spots, the relics of the feldspars.

The eruptions through which the upper Crown Point and Ophir ravines are eroded offer the best examples of fresh, unaltered rock. Specimens collected from these two localities are seen to be composed of a light greenish or olive groundmass, which is made up of fine triclinic feldspar and the fibrous dust of green hornblende. In this characteristic groundmass are plagioclases of pale gray, white, and greenish-gray colors. Like the feldspar of the groundmass, these crystals are throughout impregnated by a dust of feldspar microlites. The hornblende, which is of green and olive colors, is seen even with the loupe to be made up of individualized hornblendic fibres. This observation was first made by Richthofen, and was subsequently sustained under rigid microscopical analysis by Zirkel. A characteristic of the rock is the tendency of this fibrous hornblende to become altered into epidote, a very large amount of the Washoe propylite showing the apple-green color due to this pseudomorph. Besides these characteristic minerals, there is always a little orthoclase, and not infrequent augite crystals. The microscope also reveals apatite and magnetite. In the normal propylites there is often a little accidental quartz, but never a well established transition between the hornblende-propylite and the true quartz-propylite.

Of all volcanic rocks, propylite is most readily decomposed; the peculiar character of the fibrous hornblende offers easy avenues for mineral solutions or gases. And this is true not only of the complex hornblende crystals which are made up of staff-like microlites, but also of the feldspar of the groundmass and of the larger feldspar crystals themselves, which are permeated in every direction by the fibrous hornblende. As a consequence, nearly all the propylite observed by us is decomposed. The entire absence of glassy base is one of the features which render the field aspect of the rock different from the family of andesites. There is never any of that subtle reflection of light which is one of the characteristic appearances of the andesitic surfaces. The propylites, on the contrary, are even duller and deader than the older diorites. From the latter they may be easily distinguished in the field by the behavior of the superabundant hornblende, which in propylite always presents a dull, velvety appearance.

Quartz-Propylites.—That part of Cortez Range which lies south of Humboldt River describes a curve, with its convexity to the southeast. It is composed of older masses of Carboniferous and granitic rocks, associated with diorite, upon which are piled up complicated occurrences of volcanic rocks. The earliest of these is a small mass of propylite already described in Wagon Cañon. After this come the quartz-propylites, the most important mass of which forms the summit of Cortez Peak, next to Tenabo the highest point of the range. The granite body that forms the northern foot-hills south of Granite Creek, gives way in the higher part of the range to a bold mass of quartz-propylite which has a general oblong form, being three or four miles across the range and extending northeasterly on the strike of the ridge about eight miles, forming a rude parallelogram. Upon the south and west the quartz-propylites overflow a heavy body of quartzite, which has been referred to the Weber period of the Carboniferous. Westward they overlap the old granites, and to the east and north they are capped by the more recent members of the volcanic series. The exposure is such that we have no distinct clew to the rocks through which the quartz-propylite came to the surface; but from the structure and appearance of the granite it seems most probable that it came through a broad fissure in the granite itself. At all events, it occupies a position high in the centre of the range, its present highest point reaching an altitude of 8,383 feet. To the north the slope of the ridge passes underneath a body of rhyolites which occupy the mountain summit for about eight miles in a northeasterly direction.

At Papoose Peak the underlying quartz-propylites again come to the surface and continue northward for about eight miles, where they pass beneath a flow of dacite. There is little doubt that the masses of Papoose and Cortez peaks form one body, whose continuity is only masked by the overlying rhyolites. Here, as at Washoe, they come to the surface not far from the earlier eruptions of diorite. As to the actual date of the eruption, the locality of Cortez Peak affords no clew whatever. When it is remembered that in the whole Great Basin, which, with the Sierra Nevada, proves to be the great volcanic field of the Cordilleras, there are only a few obscure and isolated outcrops of Eocene, and that the characteristic exposures of Miocene are confined to a few localities in western Nevada, it is not surprising that the data for determining the actual ages of the earlier volcanic products are so few and imperfect.

Toward the northwest the quartz-propylites of Cortez Peak offer rough, craggy terrace-slopes, exposing a great deal of solid rock, which displays exceedingly broken, irregular forms, the fracture being always rounded. There are certain broad, horizontal divisions which seem to represent heavy, single ejection-beds, varying from ten to fifty feet in thickness, as if an exceedingly viscous body had poured out with extreme slowness and become rigid upon the steep front. The abrupt slopes do not seem to be altogether the result of erosion, but partly at least of the rude piling up of these thick, viscous beds, the result of single throes of eruption. The general color of the natural surface of the rock is a soft gray, pinkish, and salmon-color, which is locally varied by green and olive hornblende. The groundmass consists of clear, dark plagioclase, more or less altered fibrous hornblende, and purely microscopic quartz, the latter containing fluid inclusions with (in some instances) included cubes of salt. The hornblende, as described by Zirkel (Vol. VI., page 119), is clearly made up of prismatic staffs characteristic of the propylite family, which distinguish it from the andesites and dacites. The microscope also showed the usual titanites. An incomplete analysis of this rock appears in the table of analyses, No. VIII. The larger feldspars are all dull and slightly kaolinized, but under the microscope show feeble traces of former triclinic striation.

The northern continuation of this quartz-propylite body, in the neighborhood of Wagon Cañon, is an almost precisely similar rock, the microscope showing the same fluid inclusions in the quartz, and, in addition to the minerals of the Cortez Peak rock, a few laminæ of brown mica, which, curiously enough, contain thin layers of pellucid calcite.

The Cortez Peak mass, besides the overlying rhyolites at the north, is further masked by a broad field of basalt which skirts it along the east, the sequence of eruptive rocks here being granite, diorite, quartz-propylite, rhyolite, and basalt.

At Papoose Peak the quartz-propylite is overlaid by a narrow band of normal trachyte, which in its turn is overlaid by a line of rhyolitic hills that separate it from the plain. Along its eastern side the body of quartz-propylite, from Wagon Cañon to Papoose Peak, is further overlaid by dacite. The quartz-propylite has the appearance of having been erupted in an almost solid condition, showing no tendency to spread out into thin sheets. The lower exposures contain no biotites, and both hornblende and plagioclase closely resemble those of Cortez Peak. Biotite seems to be characteristic of the last ejections. A similar sequence will be noticed later in the chapter at Berkshire Cañon. It has always appeared to be the rule among trachytic rocks, so far as our observations go, that the biotite-bearing sanidin variety immediately succeeds the gray variety, which carries a large amount of hornblende and plagioclase, and which really seems to be an intermediate rock between the true trachytes and true andesites. Here, again, in the quartz-propylites, is repeated the same condition, a mica-bearing rock succeeding a hornblende-bearing rock. Among the curiosities of decomposition is the fact that the hornblende is far more changed than the feldspar, while at Cortez Peak the reverse is true. The actual proportion of biotite in the latest outburst at Papoose Peak is really very small, but it is a very conspicuous mineral on account of its large, irregular flakes, which seem to have a parallel arrangement. With these minor differences the rocks of Papoose and Cortez Creeks are the same.

Between the stations of Iron Point and Golconda, Humboldt River cuts a narrow, rather sharp cañon diagonally across a chain of hills which diverge from Havallah Range in the neighborhood of Cumberland and extend northeasterly. In the region of Cumberland these hills are formed of granite, which a few miles to the north is overlaid by sedimentary beds that from their lithological character and stratigraphical peculiarities have been referred to the Trias, although no fossil remains were found. South of the river these rocks develop a well defined synclinal, in the axis of which is a limited body of quartz-propylite that possesses the trend of the axis, north-northeast, extending for about two and a half miles, its transverse breadth being very slight, not over one fourth to one half of a mile. On the little map at the close of this chapter it is erroneously colored as propylite. In a yellowish-gray groundmass appear large, clear quartzes, and dull, opaque, white feldspars; the latter, like the groundmass, having suffered considerable decomposition. As throughout the propylite family, the hornblende is made up of acicular hairs which also permeate the groundmass and the feldspars, greatly facilitating their decomposition. Among the curious things developed by the microscope is carbonate of lime incrusting

Number of analysis.
125
126
127
128
129
130
131
132
133

PROPYLITES AND QUARTZ-PROPYLITES.

Propylites.

Number of analysis.	Locality.	Analyst.	Si	Al	Fe (ferric)	Fe	Mn	Ca	Mg	Na	K	Li		Ignition.	Total.	Specific gravity.	Oxygen ratio of— R	R (triatomic)	Si	Oxygen quotient.
125	Washoe (Virginia City) - - - -	W. G. Mixter -	58.66 31.28	17.90 8.34	. . . .	4.11 0.91	. . . .	5.87 1.67	2.03 0.81	2.07 0.53	3.19 0.54	. . . .	. . . . . .	6.53 . .	100.36 . .	2.65 . .	4.46 3.55	8.34 9.71	31.28 31.28	0.409 0.423
126	Connection between Truckee and Montezuma ranges.	R. W. Woodward	60.33 32.17	19.74 9.13	0.70 0.21	2.50 0.55	tr. . .	3.73 1.06	4.01 1.60	4.36 1.12	1.62 0.27	. . . .	. . . . . .	3.13 . .	100.12 . .	2.6, 2.7 . .	4.60 . .	9.40 . . .	32.17 . .	0.447 . .
127	Storm Cañon, Fish Creek Mountains.	"	60.55 32.29	17.43 8.12	3.07 0.92	2.54 0.56	tr. . .	3.87 1.10	2.65 1.06	3.39 0.87	4.46 0.76	tr. . .	CO^2 trace. . . .	2.23 . .	100.19 . .	2.6 . .	4.35 . .	9.04 . .	32.29 . .	0.414 . .
	" " "	"	60.58 32.30	17.52 8.16	2.77 0.83	2.53 0.56	tr. . .	3.78 1.08	2.76 1.10	3.30 0.85	4.46 0.76	tr. . .	CO^2 trace. . . .	2.25 . .	99.95 . .	. . . .	4.35 . .	8.99 . .	32.30 . .	0.413 . .
128	Cross Spur, below Grave-Yard, Washoe.	W. G. Mixter -	60.82 32.43	17.54 8.17	. . . .	5.42 1.20	. . . .	5.65 1.61	1.76 0.70	3.71 0.96	1.41 0.24	. . . .	CO^2 1.41 . . .	2.31 . .	100.39 . .	2.66, 2.68 . .	4.71 3.51	8.17 9.97	32.43 32.43	0.397 0.415
129	Virginia Range, Sheep Corral Cañon	Prof. Wiedermann	64.62 34.46	11.70 5.45	. . . .	8.39 1.86	. . . .	8.96 2.56	1.18 0.47	3.13 0.81	1.95 0.33	. . . .	PO^5 trace. . . .	1.02 . .	100.95 . .	. . . .	6.03 4.17	5.45 8.24	34.46 34.46	0.333 0.360

Quartz-Propylites.

Number of analysis.	Locality.	Analyst.	Si	Al	Fe (ferric)	Fe	Mn	Ca	Mg	Na	K	Li		Ignition.	Total.	Specific gravity.	Oxygen ratio of— R	R (triatomic)	Si	Oxygen quotient.
130	Hills east of Havallah Mountains -	W. Kormann -	66.34 35.38	14.80 6.90	4.07 1.22	. . . .	. . . .	2.99 0.85	0.92 0.37	5.16 1.33	3.19 0.54	. . . .	CO^2 1.03 . . .	2.31 . .	100.81 . .	. . . .	3.90 3.09	6.90 8.12	35.38 35.38	0.305 0.317
131	Hill west of American Flat, Washoe	W. G. Mixter -	68.44 36.50	14.86 6.92	. . . .	3.80 0.84	. . . .	1.90 0.54	. . . .	3.22 0.83	5.08 0.86	. . . .	CO^2 0.94 . . .	2.26 . .	100.50 . .	2.63, 2.67 . .	3.07 2.23	6.92 8.19	36.50 36.50	0.273 0.285
132	Mullen's Gap, Virginia Range - -	R. W. Woodward	68.46 36.51	16.85 7.85	1.43 . .	 0.32	tr. . .	2.92 0.83	0.75 0.30	3.60 0.03	3.98 0.67	tr. . .	CO^2 0.59 . . .	1.45 . .	100.03 . .	2.38, 2.44 . .	3.05 2.73	7.85 8.33	36.51 36.51	0.298 0.303
133	Foot-hills, Virginia Range, Sheep Corral Cañon.	"	74.41 39.68	2.84 1.32	. . . .	13.30 2.95	. . . .	0.40 0.11	. . . .	1.28 0.33	6.02 1.02	. . . .	. . . . . .	1.79 . .	100.04 . .	2.4 . .	4.41 1.46	1.32 5.75	39.68 39.68	0.144 0.181

in a crystalline dust the more decomposed feldspars, and there are the usual fluid inclusions in the quartzes. These, however, are varied by the occurrence of double inclusions of liquid carbonic acid and water. The rock has the usual field habit of all the quartz-propylites—a very roughly fractured exterior, dull, lustreless surface, and the peculiar half earthy look produced by the partial decomposition of the groundmass. This little isolated body of quartz-propylite is not immediately associated with any other volcanic rocks. Two miles to the east, at the base of the hills, there is a slight development of basalt; and west of Rocky Creek, in the neighborhood of Golconda, there are powerful ejections of rhyolite.

The following table, No. VIII., gives the constitution of several of the most important occurrences of propylite and quartz-propylite.

SECTION II.

ANDESITES AND DACITES.

Andesitic rocks have a somewhat wider distribution than propylites, but within the Fortieth Parallel limits they hardly cover a greater topographical area. Together with their related dacites (the quartziferous species), they are scattered in limited exposures from Cedar Mountains, in the Great Salt Lake Desert, to California. In general they occupy subordinate topographical positions, and with the exception of a few points in the Sierra Nevada, beyond the western limits of our work, they appear altogether as massive eruptions. Andesitic volcanos probably contemporaneous with the massive eruptions of Nevada and Utah, are placed at intervals along the axial line of the Sierra Nevada and Cascade Range, both hornblende and augite-andesite occurring there as true volcanos. The relics of an enormous extinct crater at Lassen's Peak mark an andesitic volcano of the first order. Much of the crater wall, however, has been engulfed, and its place is occupied by modern trachytic and rhyolitic cones. The andesites of the Fortieth Parallel are never extensive outbursts, or rather the present exposures are never extensive. How far they may be covered up by succeeding outflows can not be determined. The most eastern exposure is in the Traverse Mountains, a small group of hills which extends westward from the base of the Wahsatch, connecting that range with the Oquirrh.

Hornblende-Andesite.—On the divide between Gosiute Valley and that of Deep Creek, among outcrops of rhyolite which are separated from each other by accumulations of Quaternary, rises an isolated hill of andesite. The exterior surfaces which have been subjected to weathering are of a pale-grayish mauve, almost a lavender-color; but the fresh fracture shows a dark-brownish, compact rock of felsitic habit, with a remarkably homogeneous, half glassy matrix, including small white crystals of plagioclase, occasional brown micas, and the normal andesitic hornblende, together with a few rounded grains of quartz. The hornblende shows the exterior modification described by Zirkel as one of the constant microscopic peculiarities of andesitic hornblende. The quartz, which occurs in detached cracked granules, does not appear to be a constituent of the groundmass, but occurs as an accidental accessory constituent, after the manner of certain quartziferous trachytes. The rock could not be at all classed as a dacite, in spite of the presence of these accessory quartzes.

South of Palisade Cañon, facing the Cluro Hills, along the western side of Cortez Range, is a rather obscure, dark, even-grained andesite, evidently later than the porphyry and syenite which come in contact with it on the west, and probably earlier than the dacite which lies east of it, though their relative ages have not been satisfactorily made out. Although it contains but little hornblende, the absence of augite probably refers it to the hornblende-andesite.

Cortez Range is one of the most broken up and geologically complicated of any in the Great Basin. It exhibits andesites from the region of Tuscarora at intervals as far south as Papoose Peak, some distance south of Humboldt River. Breaking through and overlying the propylite of the Tuscarora region, is a limited body of andesite, which is overlaid on the west by rhyolites. It is a dark, compact rock, rather reddish on the weathered surface, and shows to the unaided eye small brilliant plagioclases and black hornblende crystals in a dark greenish-gray groundmass. Under the microscope, Zirkel found the hornblende green, and more or less fibrous. Its geological habit also inclines toward the propylites, which it somewhat resembles as to the character of the hornblende.

At Carlin Peaks, in Cortez Range, latitude 40° 45′, the summits of the Lower Coal Measure limestone are flanked on the west by a small body of andesite, which is surrounded on the north, west, and south by subsequent rhyolite. The andesite is piled up in a mass, rising about 1,200 feet above the surrounding rhyolites. It is a dark-gray, compact rock, very rich in hornblende, although carrying a good deal of yellowish-brown augite and a little apatite. Besides the predominating plagioclases, there are some schistiform sanidins. A few miles to the south, where the Emigrant Road crosses Cortez Range, is a second body of andesite, overlaid by trachytes on the south, but surrounded on the east, west, and north by rhyolite. It is unimportant geologically, and possesses no petrographical differences from the rock mentioned at Carlin Peaks.

Above the head of Clan Alpine Cañon the summits of Augusta Range are formed of andesite masses, the crests of an earlier topography, which have remained lifted above the later floods of rhyolite, or perhaps which erosion has recently exhumed from the overlying acidic rocks. The andesites have a rudely columnar structure, and are made up of plagioclase and hornblende, the latter showing the characteristic black boundary, and the groundmass is distinctly made up of microlitic particles of the two minerals. The long hornblende prisms are noticeable for a rude parallel arrangement. A few miles north, the region around Crescent Peak and the head of Augusta Cañon shows a considerable field of andesite, which has broken through and overflowed the Mesozoic limestone, in turn overlaid by trachytes and rhyolites in the order mentioned. The groundmass of this rock has a prevailingly earthy character, owing to the varying decomposition of the hornblende.

Zirkel calls attention to the interesting manner in which the hornblende crystals of this locality, viewed with the microscope, are seen to have been ruptured and the particles moved away from one another. In some cases nearly all the fragments of the crystal remain embedded in the groundmass within the field of view, when the eye readily reconstructs the form of the original crystal. At other times detached fragments not traceable to the parent crystal are seen. There are certain very distinct instances of fluidal motion, the chips of a crystal being thrown into wavy lines like the figures of marbled paper.

The little group of Kamma Mountains, lying west of Montezuma Range, in latitude 40° 45′, forms an isolated series of hills rising about 2,000 feet above the desert. The southern portion of the group and a few detached outliers in the lowland south of the main group are made up of hornblende-andesites. The outcrops toward the summits of the mountains form jagged, prominent peaks, with considerable exposures of bare rocks. Farther down the slopes there seems to be a distinctly bedded structure with an inclination of the sheets to the east. Still farther, the low hills are mostly covered by recent detritus and afford no very characteristic exposures. This rock is a true hornblende-andesite, the groundmass consisting chiefly of plagioclase containing a high proportion of black opacite grains. All the andesites of this region south of Lander Spring have a more or less trachytoid habit, the weathered surfaces having almost the roughness of trachyte, quite that of the dacites. There is a noticeable amount of sanidin in the composition of the rock, which doubtless accounts for the peculiar roughness of the texture.

The little group of andesitic hills a few miles north of Kamma Range, at Indian Springs, show a somewhat similar superficial roughness, and upon closer examination the rock, although a true andesite, is seen to contain an unusual proportion of large crystals of sanidin, together with decomposed hornblendes, in a compact close-grained, greenish-gray groundmass. There is nothing in the geological occurrence of the andesites of this region to distinguish them specially. They are the oldest eruptive rocks of the neighborhood, with the exception of the small body of middle-age diorites. The relation between the detached small bodies of andesite lying south of the main Kamma Mountains and the slightly inclined Miocene beds does not appear, the superficial Quaternary preventing any true solution of their position. Taking the outflows of these andesites as a whole, they seem to be related to the western margin of the great body of Jurassic slates which form the western flank of the northern part of Montezuma Range. Where those westerly dipping slates finally disappear beneath the low desert country, is doubtless the mountain fracture which gave vent to the andesites.

From the valley of Glen Dale eastward, Virginia Range is cut directly across by the cañon of Truckee River. At the western or upper entrance of the cañon the hills on either side rise from 1,500 to 1,800 feet above the level of the river. Those to the south are formed of thickly bedded andesites and andesitic breccias of prevailing grayish-brown, reddish-brown, and chocolate-brown colors. There cannot be less than a thickness of 1,200 or 1,400 feet of accumulated beds, showing every variety of texture, from a rough, loose, trachytic, porous mass to an extremely compact, highly crystalline body resembling the best preserved porphyritic andesites of Washoe. The beds all incline toward Truckee Cañon. The lowermost members of the series are of compact reddish-gray and olive-gray flows, with a gray microcrystalline groundmass, in which hornblende and triclinic feldspar and a few large, conspicuous crystals of augite are seen. Over these, forming by far the greater portion of the series for a thickness of not less than 1,600 feet, are reddish-brown, highly cellular, almost scoriaceous andesites, containing both hornblende and augite, with a decided predominance of the latter, the whole overlaid by a thick series of andesitic breccias, of which most of the fragments contain augite to the exclusion of hornblende. Much of the breccia is decomposed, leaving earthy masses of which the hornblende crystals are decayed past recognition. Although distinctly a massive eruption, the physical character of these andesites partakes much more of the andesitic lavas of a true volcano. They were evidently ejections from a deep fissure, coming to the surface near the summit of the range, and pouring down one over the other, exactly as upon the flanks of a true volcano; and the loose, scoriaceous habit of a large part of the middle series closely corresponds with the andesitic material thrown out from the ancient crater of Lassen's Peak. With this exception, all the andesites of the Fortieth Parallel are decidedly compact, having the habit of ordinary massive eruptions. It is not at all impossible that the inclined beds represent the fragmentary remains of some old andesitic volcano, most of whose body is now covered by the later eruptive rocks of the neighborhood.

The narrow andesite body which lies along the eastern flank of the melaphyres of Berkshire Cañon in Virginia Range has an east-and-west breadth of not more than a quarter of a mile, but extends about six miles north-and-south. Like the neighboring propylite, it is wonderfully trachytic in appearance. The groundmass is a grayish-brown feldspathic body with but little brown hornblende distributed through it. The large crystals and fragments of crystals of hornblende, however, which lie porphyritically embedded in it, are arranged with a certain degree of parallelism. This rock most closely resembles those earlier trachytes of the Washoe region which underlie the sanidin varieties, and which by their high proportion of black hornblende and plagioclase closely approach the andesites The middle ground between the andesites and trachytes is occupied by a gray or grayish-brown rock, carrying a predominance of hornblende over biotite, with plagioclase and sanidin in about equal proportion. When the texture of the groundmass is rendered trachytic by a high proportion of hornblende, the habitus of the rock inclines obviously to the trachyte family. But when the groundmass is composed predominantly of feldspars, and of those feldspars the plagioclases equal or exceed the orthoclase, the habit of the rock becomes truly andesitic. Out of this middle region, therefore, between the two species, when, as is often the case, one cannot decide upon the predominance of included orthoclase and plagioclase, the habitus of the groundmass gives a pretty sure indication of the general group it belongs to.

Dacite.—The eastern half of Cortez Range, from four or five miles south of Papoose Peak nearly up to Humboldt Cañon, a distance of fourteen or fifteen miles, is composed mainly of a continuous field of dacite, which seems to prolong the line of eruption determined by the quartz propylite of Cortez and Papoose peaks. As an eruption, it shows no tendency to form sheets or extend itself laterally from the region of fissure. On the contrary, it behaves like granite or the least fluid of the trachytes. It is essentially a massive eruption, and north of Wagon Cañon shows a thickness of at least 1,200 or 1,500 feet. Like the andesites, its surface is very easily decomposed, the prevailing character of the rock is rather earthy, and the colors vary from purple to chocolate and brown, the later eruptions north of Wagon Cañon growing pale and approaching grays and olives. At the southern end the mass is overlaid by high piles of rhyolite, and the eastern base for many miles, as the map shows, is overlaid by basalt. Along its eastern line it quite distinctly overlaps the quartz-propylite, and is therefore later. North of Wagon Cañon the basalts give way, and the Pliocene strata of Pine Valley come directly in non-conformable contact, abutting against the slopes of dacite. The field habit of this dacite is decidedly more propylitic than andesitic. There is a lack of the resinous lustre and the easy, glassy fracture of hornblendic and augitic andesite. In the field and in hand specimens we were often unable to distinguish between it and quartz-propylite. But in the case of this outburst it might readily be mistaken for the neighboring quartz-propylite. The chocolate-colored and purple groundmass encloses peculiar white kaolinic crystals of feldspar, which in the least decomposed portions show under the microscope triclinic striation, and numerous black and glittering quartzes. The rock is really a dacitic breccia, since the groundmass contains numerous fragments, both angular and sub-rounded, of a similar purple dacite, whose only difference from the enclosing material is, that the kaolinized crystals of plagioclase are much smaller than those secreted in the matrix. The microscope shows that the kaolinized feldspars are penetrated by fine crevices carrying chalcedony. In various directions through the rock are late fissure-lines, which may be traced by a rusty ferruginous color penetrating the purple groundmass a short distance on either side of the crack, resulting no doubt from the decomposition of the hornblende. Those hardly perceptible traces of motion which indicate to the eye whether the viscous movement of the body has been in horizontal beds or simple vertical planes, show in this instance that it was vertical.

North of Wagon Cañon, where dacite forms the crest of the ridge, the rock is decidedly less brecciated than to the south. It is purplish-green, and is very noticeable for large, opaque, triclinic feldspars. The hornblende is fresh and brownish, and there are a few flakes of biotite in the microfelsitic groundmass. Throughout this whole mass the quartz crystals are all very dark, and but rarely visible macroscopically. The microscope reveals their abundant presence everywhere, and it also shows that the glass base is of the gray type.

At Shoshone Peak, the culminating point of Shoshone Range, in the midst of a broad area composed of Carboniferous quartzites, dacite forms a small, insular mass, its overflow making the highest point of the range at Shoshone Peak, 9,760 feet above sea-level. This outburst has occurred on the line of a flexure in the quartzites which still earlier was marked by a small eruption of diorite in a cañon north of Shoshone Peak. It is at once the most elevated and most interesting outburst of this rock within the limits of our survey. Petrographically it is of importance as including the largest quartz grains of any Fortieth-Parallel dacite, many reaching the diameter of an eighth and some a quarter of an inch. The general color of the rock shades from purple to green. Not a little of it in the lower exposures, indicating the earlier stages of the eruption, is rudely brecciated. Between the dacite breccia and the compact, uniform rock, there is every transition, some hand specimens showing a single included angular fragment not larger than a pea. The most important structural characteristics of this exposure are the powerful vertical jointing-planes which in some places approach the regularity of a columnar structure. The groundmass is often so coarse that the particles of triclinic feldspar and fresh hornblende may be seen by using the loupe, and occasionally with the unaided eye. Toward the east the cliffs of dacite are eroded down sharply in cañons, modified, if not determined, by glacial action. The bold, rocky fronts of the spurs and the flanks of the cañons offer admirable exposures of the rock, the slight accumulation of soil and the absence of forest trees combining to make it the most imposing exposure of dacite in the Fortieth Parallel area. In weathering, the groundmass, feldspars, and hornblendes wear down pretty evenly, leaving the crystals of quartz, which are often dihexahedral forms, standing out along the surface. The geological aspect in the field of this and of the other dacites often resembles certain metamorphic quartz-porphyroids. The surface is exceedingly rough, the fracture more like that of propylite, the low proportion of the glass base rendering the lustre dull and very different from the resinous brightness of the quartzless andesites.

Virginia Range, so justly noted for its varied and extensive display of volcanic species and varieties, exhibits typical dacites at three points within the limits of our Exploration. Abreast of the southern end of Pyramid Lake the range is severed by the deep pass of Mullen's Gap. The hills both north and south of this depression, ascending to considerable heights, are composed of a gray dacite, which weathers in rough, rounded forms, and is conspicuous by a very dull surface, resembling the propylites. It varies from gray through several olive-greens to purple, and in all hand specimens shows more or less distinctly striated plagioclase and macroscopic quartz. The latter, as described by Zirkel in Volume VI., page 139, carries distinct fluid inclusions. The hornblende also is of the true andesite-dacite type, and not the polysynthetic propylite variety. Of all the dacites, in external habitus this most closely resembles the propylite type, and it is by mistake colored upon our geological map as quartz-propylite, close examination having been made too late for a change. The rounded or rudely crystalline grains of quartz are brilliantly vitreous, and are fissured in every direction by innumerable cracks, closely resembling the rhyolitic quartzes, with the exception that the latter almost never contain fluid inclusions. For analysis of this, see table of analyses No. IX.

Throughout this northern portion of Virginia Range there are no ante-Tertiary rocks, except the limited development of melaphyres in the region of Berkshire Cañon. The relation of the overflow of Tertiary ejecta to the earlier range cannot here be made out. Farther to the south, Archæan, Mesozoic, and middle-age eruptive rocks form the distinct body and core of the range, over which the Tertiary species have poured. In the northern portion now under consideration, although the heights are maintained up to 8,000 and 9,000 feet, the entire range is masked by enormous floods of trachyte and basalt. It is only in the lower portion of the hills, however, that the earlier Tertiary eruptive species come to the surface. Along the eastern flank, at Berkshire Cañon and for about four miles northward and the same distance southward, the andesites and propylites which lie along the eastern base of the melaphyres are broken through by repeated flows of dacite, the latter extending southward to the mouth of Sheep Corral Cañon and forming a distinct foot-hill region, noticeable for its purple and green colors. The mode of weathering of this rock resembles that of the older diorites. It appears in low, rounded hills, exposing considerable stretches of smooth, rocky surfaces not covered by earth or recent débris. The harder quartzes frequently stand out prominently upon the surface.

Very considerable portions of this outflow are of a fine-grained, purple groundmass, with no included crystals recognizable to the unaided eye. From this fine microcrystalline condition it passes into a more coarsely crystalline groundmass, in which triclinic feldspar and more or less brown hornblende are easily detected. Through these earlier purple dacites have broken large volumes of dacitic breccia, which carries a great deal of dark, bronzy-brown magnesian mica. The percentage of free quartz crystals is also higher than in the earlier outflow. Last of all, and closing the dacite period in this neighborhood, came a pale, apple-green dacite, richest of all in quartz. It is interesting for the decomposition of the feldspars and their conversion into carbonate of lime and kaolin. As in the dacites of Shoshone Peak, which these often closely resemble, the quartz grains are frequently dihexahedral. The anomalous position of a crystal of quartz containing fluid inclusions in a glass-imbued groundmass is difficult to explain, unless it may be an ingredient of an older rock, which has escaped fusion.

Augite-Andesite.—The limestone body of Cedar Mountains, a detached range southwest of Salt Lake, is accompanied by outbursts of volcanic rock. The oldest of these is at a remarkable bend in the range, near its southern extremity, a little north of latitude 40° 15′. The limestones, which have stretched southward from the northern portion of the range for about thirty miles, suddenly bend off to a southeast strike. Directly at the intersection of these two strikes, where a very great strain must have occurred in connection with the flexure of the strata, there is an outburst of andesite which occupies the angle of the range. The desert Quaternary deposits rise high upon its flanks, and probably cover a considerable portion of the andesite flows. Four or five miles to the southwest, a small isolated butte of andesite rises out of the Quaternary, and is evidently separated from the main mass by a thin blanket of loose soil. The external appearance of these andesites is quite like that of basalt. Its structure is that of thin sheets, which often display a rude, columnar jointing. The reddish weathered surfaces also resemble some of the thinly bedded basalts. Upon fracture, the rock is seen to contain considerable pale-gray glass, the larger crystalline secretions being plagioclase, augite, and a few hornblendes, together with a little brown biotite. Augite predominates over hornblende.

An interesting group of andesites occurs on the northeast base of the Wachoe Mountains, longitude 114° 30′. The hills consist of a granitic core against which rest considerable bodies of limestone belonging to the Lower Coal Measure series. Diorites and felsite-porphyries are connected with the disturbances of the middle age, and andesites and rhyolites form the features of Tertiary eruptive activity. The andesites are all seen along the northeast base of the group; and with the exception of a small, isolated hill south of Last Chance Spring, are all overlaid by rhyolite. The andesites at the mouth of Spring Cañon, as exposed where the rhyolites have been eroded away, together with the butte south of Last Chance Spring, exhibit a dark gray, rather compact groundmass, which the microscope shows to possess a pale gray glassy base. Besides plagioclase and augite, which are the predominating crystalline secretions, there are a few hornblendes and a little sanidin. The eruption of these andesites is of the usual massive type, spread out in rather thin sheets. Although the outflows are arranged on a northwesterly trend, yet the northernmost outcrops, north of Melrose Mountain, are of a different petrographical nature. The groundmass is dark, steely gray, the crystalline secretions being a little orthoclase, fine, brilliant crystals of plagioclase, predominating biotite, and a few broken, acicular hornblendes. It is classed by Zirkel as the mica equivalent of hornblende-andesite. Externally, with the exception of the evident mica, the rock has the same geological habit and aspect as the Spring Cañon outcrops. Like that, it is surrounded and in great part covered by rhyolite, and presents the ordinary characteristic dull-red surfaces of weathered andesite. Under the hammer it breaks with sharp fracture and shows the resinous lustre of semi-vitreous rocks.

The River Range lying north of the Humboldt, in middle Nevada, is suddenly cut off a few miles north of Penn Cañon. The range, which has been a well defined quartzite ridge for fifty miles, suddenly plunges down beneath a broad flood of rhyolitic and andesitic rocks. There is no doubt that this break in its continuity is due to a fault, and that the andesite has come up in the fracture-region.

The North Fork of Humboldt River flows through the horizontal Pliocene of Bone Valley, and then cuts a sharp gorge, to which Mr. Emmons gave the name of Egyptian Cañon, through a field of andesite For about eight miles along the cañon, by four or five miles in width, is exposed a body of andesite which is overlaid by the horizontal Humboldt Pliocene strata of Bone Valley on the north and similar beds at the lower end of Egyptian Cañon. East and west it is overlaid by fields of rhyolite. The physical habitus of this rock, in a broader sense, is strongly like that of basalt. It is composed of tabular layers, which along the walls of Egyptian Cañon show a rude columnar structure, in which the columns are cylindroids rather than prisms. There is also a tendency to split into plates perpendicular to the axis of the cylinders. It is to those two sets of fissurings that the peculiar architectural aspect of the region is due—an effect resembling ruined columns of an Egyptian temple. Under the hammer the rock has the usual flinty fracture, totally different from the rough, ragged fracture of basalt. A specimen from the lower end of the cañon shows a groundmass entirely made up of microlites and grains of plagioclase and augite, free from olivine; the only larger crystalline secretions being small, pellucid plagioclases. Near the upper end of the cañon is a very remarkable variety of the rock, having a dark, brownish-gray groundmass which carries sanidin crystals half an inch in length, and a few cracked and rounded granules of quartz, altogether similar to those in the augite-andesites of Cedar Mountain; the main ingredients, however, being plagioclase and augite. Like the specimens collected at the lower end of the cañon, it contains no olivine. The microscope shows considerable quantities of apatite. Between the basalts, which want olivine, and the augite-andesites, which are totally free from hornblende, it is not easy to determine, either by microscopic analyses or by examination of hand specimens. The question of devitrification of the glassy base is not in itself sufficient ground for a distinction between the two species. At the time Professor Zirkel's examinations were made, the field-notes were not written out, and he was not informed as to the condition in the field. The rock is earlier than the Pliocene and surrounding rhyolites, and its habits are altogether those of andesite. For this reason we have decided to class it among the andesites.

A few miles south of Tuscarora is found a small body of augite-andesite, entirely surrounded by rhyolites. It is of no particular importance, except for the extremely fine development of augites and the fact that the plagioclases, which reach the size of a hazel-nut, are extraordinarily rich in inclusions of yellow glass.

The valley of Susan Creek is occupied by horizontal Pliocenes which continue southward from the valley of the North Fork of the Humboldt, forming a narrow strip between the rhyolite hills of Seetoya Range. On the east side of Susan Creek Valley, about abreast of Maggie Peak, between the creek and River Range, is a small body of augite-andesite coming to the surface under trachytes and rhyolites. The weathered surfaces have a pale greenish-gray color, but the fresh fracture is very dark brown, almost black, and possesses the brilliant resinous lustre characteristic of the family of andesites or of the most glassy basalts. Crystals of sanidin and plagioclase can be detected in the fine-grained groundmass, as well as clear, well shaped augites, the latter standing out prominently on the weathered surfaces. As usual, the rock contains no olivine.

Palisade Cañon is eroded through a body of trachyte, to be hereafter described. A prominent ravine, entering the cañon from the north, lays bare a body of andesitic rock of very peculiar constitution. It is a dark gray rock, having the characteristic fracture and surface of andesite, but the very fine-grained groundmass contains augite, plagioclase, biotite, and angular grains of quartz which, together with apatites, are found embedded in some of the larger feldspars. The association of augite and quartz renders the rock particularly interesting.

On the gentle eastern slope of Cortez Range, south of Wagon Cañon, a long, narrow exposure of augite-andesite comes to the surface, enclosed on all sides by dacite, which strongly resembles it in color, texture, and general geological habit. The two rocks disintegrate with about equal ease, and the earlier (for so it seems to be) andesite is probably a portion of a prior outburst, from which erosion has removed the covering of dacite. It is indeed possible that the andesite has broken up as a dike through the dacite, as data for their relative ages are wanting. The color of the mass varies from brown to purple, very much of the surface being covered with minute chips of the solid portions. The fresh fracture shows the usual resinous lustre due to gray glass, which constitutes the base of the rock. The groundmass is much discolored and decomposed, passing from the color of chocolate to a rusty iron-red, and at times pale yellow and brown. In it are plagioclases, more or less kaolinized, showing traces of zonal structure, yellowish augites, and occasional but rare flakes of biotite.

In the valley of Reese River, directly north of the little town of Jacobsville, is an isolated mass of hills connected with the southern part of Shoshone Range by a flow of rhyolite. The little group known as Jacob's

Promontory is made up largely of quartzites, considered to belong to the Weber period, which here have a very dark, ferruginous color. Through these, at the northern and southern foot-hills of the group, long anterior to the period of the trachytes and rhyolites, have burst out masses of dark augite-andesite with a distinctly columnar structure and a light-gray weathered surface. When broken, it has a sharp, conchoidal fracture and a distinctly resinous lustre, owing to the high proportion of glass base. The groundmass is composed of plagioclase and olive-colored augite. Besides these minerals, there is a little sanidin and a few irregular, broken crystals of hornblende, the latter having the appearance of a foreign ingredient. Under the microscope, the plagioclases are noticed by Zirkel as containing well defined inclusions of brown glass with thick bubbles, the augites also containing large glass inclusions which themselves contain augite microlites. This locality is of special interest, since here the augitic andesite is distinctly overlaid by basalt, the greater relative antiquity of the former rock being thus clearly demonstrated.

In the southern portion of the Augusta Mountains, south of Shoshone Pass, in the region of Crescent Peak, where the stratified Mesozoic limestones are overpoured by heavy masses of hornblende-andesite, the latter have been broken through and in turn overflowed by a highly glassy augite-andesite, resembling in external features and in geological habit the occurrence at Jacob's Promontory. At the head of Augusta Cañon, and over the ridge to the north, the augite-andesites superposed upon the hornblende variety are seen in distinct columnar structure, the individual prisms varying from a few inches to a foot or two in diameter, and commonly displaying a fairly regular pentagonal section. The exterior surface of the blocks, to the depth of about a tenth of an inch, shows a light grayish-green color, the result of the alteration of the groundmass. Directly beneath this altered layer is a dull-reddish, rusty zone, and then the dark, fresh, resinous, glassy material of the main mass. A few miles farther north, on the western side of the range, at Antimony Cañon, similar augite-andesites appear, which have broken through and overlaid brecciated hornblende-andesite, the latter overlying, as in the Crescent Peak region, masses of older hornblende-porphyry. In both of these latter localities the augite-andesite is of distinctly later origin than the hornblende-andesite, a fact which is elsewhere repeated, and to which the field observed by us offers no exception. It is also extremely important to note that the augite-andesites of the Augusta Cañon region are overlaid by the trachytes that form the extreme heights of the range. At Jacob's Promontory we saw that the augite-andesite was of earlier age than the basalt; here it is seen to be earlier than the trachytes. In other words, it belongs manifestly to the andesitic period, and since it clearly followed the hornblende-andesites, it may safely be held to close the andesite period. The rock, then, should be considered a true dependent of the andesite family, and not of the basalt family, to which its petrological features far more closely ally it. The importance of this region cannot therefore be over-estimated, as will be seen when we come to treat the natural classification of volcanic rocks.

In a side ravine of Truckee Cañon, three miles north of the main river, occurs a limited outcrop of dark rock resembling basalt in appearance and mode of occurrence. It is surrounded by rhyolites. Under the microscope appear both orthoclase and plagioclase in about equal proportions, green augites, and abundant olivine, the latter surrounded by an encircling band of green augite prisms arranged tangentially. It is classed by Professor Zirkel as an augite-andesite, the silica equivalent being far too high for the true basalts, to which its large tenure of olivine would naturally ally it. The silica equivalent is doubtless to be accounted for by the abundant presence of a highly acid glass which fills all the spaces between the crystals of the groundmass.

Directly south of Wadsworth are three detached hills of black rock, the northern one of the true basalt, the two farther south of augite-andesite. The groundmass is a dense aggregation of minute plagioclase, magnetite, and augite-microlites, in which are embedded sanidins and plagioclases in about equal proportion. Although augite is distinctly in excess, there is yet considerable light-brown hornblende with the characteristic black border of the andesite-hornblendes. Olivine is wanting.

In the rolling hills west of Steamboat Valley, Nevada, somewhat north of the group of springs, are augitic andesites composed of a very light grayish-green groundmass, in which are well defined green augites up to

T

Number of analysis.	
134	I
135	S
136	N
137	F
138	N
139	N
140	V
141	F
142	S

TABLE OF CHEMICAL ANALYSES. IX.—UNITED STATES GEOLOGICAL EXPLORATION OF THE FORTIETH PARALLEL.

ANDESITES AND DACITES.

Andesites.

Number of analysis.	Locality.	Analyst.	S̈i	Äl	Fe	Fe	Mn	Ca	Mg	Na	K	Li		Ignition.	Total.	Specific gravity.	Oxygen ratio of— Ṙ	R̈	S̈i	Oxygen quotient.
134	Ridge northeast of American Flat, Washoe.	W. G. Mixter -	58.33 31.10	18.17 8.46	. . . .	6.03 1.34	. . . .	6.19 1.77	2.40 0.96	3.20 0.82	3.02 0.51	. . . .	CO^2 2.85	0.76 . .	99.95 . .	2.72, 2.76 . .	5.40 4.06	8.46 10.47	31.10 31.10	0.445 0.467
135	Silver Terrace, Washoe - - - -	" -	59.22 31.58	18.20 8.48	. . . .	6.69 1.48	. . . .	5.51 1.57	2.90 1.16	3.31 0.85	1.39 0.24	. . .	. . . .	2.80 . .	100.02 . .	2.6 . .	5.30 3.82	8.48 10.71	31.58 31.58	0.436 0.460
136	Main Ridge, above Three Knobs, Cedar Mountains.	R. W. Woodward	60.71 32.37	16.00 7.45	2.09 0.63	3.87 0.86	. . . .	5.17 1.48	3.07 1.23	2.74 0.71	3.78 0.64	tr. . .	CO^2 1.01	1.48 . .	99.92 . .	2.6, 2.5 . .	4.92 . .	8.08 . .	32.37 . .	0.401 . .
137	First hill north of Gold Hill Peak, Washoe.	W. Kormann -	61.12 32.59	11.61 5.41	11.64 3.49	. . . .	. . . .	4.33 1.23	0.61 0.24	3.85 0.99	3.52 0.60	. . . .	. . . .	4.35 . .	101.03 . .	. . . .	5.39 3.06	5.41 8.90	32.59 32.59	0.331 0.366
138	North Pass, Cortez Mountains - -	R. W. Woodward	61.64 32.87	17.44 8.13	0.82 0.24	3.99 0.88	tr. . .	5.86 1.67	3.05 1.22	3.45 0.89	1.15 0.19	tr. . .	. . . .	2.64 . .	100.04 . .	2.6, 2.5 . .	4.85 . .	8.37 . .	32.87 . .	0.402 . .
139	North bank of Palisade Cañon - -	Reinhard - - -	62.71 33.44	12.10 5.64	14.79 4.43	. . . .	. . . .	8.34 2.38	1.31 0.52	0.73 0.19	1.15 0.19	. . . .	. . . .	. . . .	101.13 . .	. . . .	6.24 3.28	5.64 10.07	33.44 33.44	0.355 0.399
140	Wachoe Mountains - - - - -	R. W. Woodward	67.81 36.16	17.60 8.20	2.11 0.70	 0.47	tr. . .	3.15 0.90	1.08 0.43	2.97 0.77	3.85 0.65	. . . .	. . . .	1.57 . .	100.14 . .	2.5, 2.6 . .	3.22 2.75	8.20 8.90	36.16 36.16	0.316 0.322
	" " - - - - -	"	67.63 36.07	18.08 8.42	2.17 0.72	 0.48	tr. . .	3.16 0.90	1.14 0.45	2.87 0.74	3.86 0.65	. . . .	. . . .	1.49 . .	100.40 . .	. . . .	3.22 2.74	8.42 9.14	36.07 36.07	0.322 0.329
	Dacites.																			
141	Hills above American City, Washoe	C. Coüncler - -	69.3 36.96	17.9 8.34	. . . .	4.1 0.91	. . . .	1.6 0.45	1.3 0.52	2.0 0.51	3.6 0.61	. . . .	. . . .	2.1 . .	101.9 . .	. . . .	3.00 2.09	8.34 9.70	36.96 36.96	0.307 0.319
142	Shoshone Peak, Shoshone Range -	R. W. Woodward	70.17 37.41	14.53 6.77	2.54 0.76	1.74 0.38	tr. . .	2.29 0.65	0.93 0.37	3.25 0.83	3.35 0.57	tr. .	. . . .	1.53 . .	100.33 . .	. . . .	2.80 . .	7.53 . .	37.41 . .	0.276 . .
	" " " -	"	70.25 37.46	14.90 6.94	2.57 0.77	1.76 0.39	tr. . .	2.39 0.68	0.83 0.33	3.24 0.83	3.22 0.54	tr. . .	. . . .	1.51 . .	100.67 . .	. . . .	2.77 . .	7.71 . .	37.46 . .	0.279 . .

the size of a pea, feldspars, both orthoclase and plagioclase, of equal dimensions, a little sharply crystallized magnetite, and some apatite. Not a trace of hornblende was observed in this rock. The external appearance and habitus of this occurrence are distinctly andesitic, the bedded flows resembling those of the hornblende-andesites which overlie the propylites near Virginia City.

The following table, No. IX., gives analyses of several of the most important andesites and dacites.

SECTION III.

TRACHYTES.

We have seen that the propylites, quartz-propylites, andesites, and dacites occur very sparingly over the Fortieth Parallel field, and are altogether confined to the region west of Wahsatch Range, with their greatest concentration at the extreme western limits of our work. The trachytes which we are now about to consider, have a somewhat peculiar distribution. They occur chiefly in four well defined groups:

1. That of the Rocky Mountains, which consists of two main outbursts, one constituting the divide between North and Middle parks, the other in the Elk Head Mountains, directly west of Park Range. This forms an entirely detached group, with no trachytes over an interval of 4° of longitude westward.

2. The next group appears in the region of Wahsatch Range and Salt Lake. North of the railway, at longitude 109° and 109° 20′, several little dots have the characteristic trachyte color on the small map at the end of this chapter. But these are so colored to avoid the expense of another stone, and are really leucitic rocks, not to be confounded with the trachytes. The Wahsatch trachyte group consists of several outbursts, the most prominent of which lies between the western end of Uinta Range and Clayton's Peak in the Wahsatch. The line of fissure through which this ejection has taken place is a great fault, slightly diagonal to the axis of the Wahsatch, and its trend is defined by a line of trachytic outcrops shown on East Cañon Creek. At the western base of the Wahsatch, in the Traverse Mountains, directly opposite the broad field of trachyte east of Clayton's Peak, are two important bodies, one occupying the Traverse Mountains and the other the slopes of the eastern spurs of the Oquirrh.

3. Passing over an unimportant mass in the Tucubits Mountains in northeastern Nevada, the next considerable trachytic region is that of Piñon and Cortez ranges and their continuations to the north. Here, from the

southern limit of our map as far north as Nannie's Peak in Seetoya Range, are exposures of considerable masses of sanidin-trachyte.

4. The last noteworthy locality is that of Virginia and Lake ranges in the vicinity of Pyramid Lake, where large portions of the mountain bodies are composed of trachytes.

It is curious to observe that these four important groups are separated from each other by intervals of 4° of longitude.

The group in the Rocky Mountains is directly contiguous to important folds of Archæan rocks, a region which has been the theatre of orographical movements in very early times. The group of Wahsatch trachytes accompanies one of the most important geological centres of the whole Cordilleras, where the deepest stratified rocks are exposed, and where immense dislocations of the crust and excessive erosions have taken place. It is a region of exceptional geological grandeur and activity. Passing westward to the group of Cortez and Piñon ranges, we come again to a region of unusual geological conditions. It is here that the older Devonian and Silurian rocks are brought up from great depths to the surface, and evidence of remarkable faults in Tertiary times is not wanting. Again, as regards Virginia Range, it may be said that it is the most important of the meridional ridges which branch off from the northwest trend of the Sierra Nevada. It is a range in which perhaps a greater volcanic activity was maintained throughout the whole period of time covered by the Tertiary eruptions than in any other east of the Sierra Nevada.

During the period of the deposition of the Cretaceous, North and Middle parks were unquestionably one basin. The orographical movement which accompanied the close of the Cretaceous epoch threw up an east-and-west ridge, dividing the basin into two parts. The character of the disturbance of this ridge was very complicated, being something more than a mere anticlinal. Either then or later, there was a sudden fracturing uplift, accompanied by outpourings of great volumes of a peculiar rock, having certain affinities on the one hand with the family of trachytes, and on the other with the older granite-porphyries. The rock in question occupies a large portion of the surface of the ridge which culminates in Parkview Peak, a point rising more than 12,000 feet above sea-level. The exposures of the Cretaceous rocks indicate mere dislocated fragments wedged in between the enveloping flood of eruptive rocks, the blocks themselves being subsequently cut through by east-and-west dikes of similar volcanic material. Aside from the supposed Pliocene beds of the Park, evidently a very recent lacustrine series, there is no means of positively determining the age of this eruption. From its intimate relations with the broken, dislocated fragments of Cretaceous strata, it is evident that its eruption was contemporaneous with the fracturing and breaking up of the Cretaceous ridge. It is indeed possible that this took place during the Tertiary period, at the time of the general trachytic eruptions which we have seen reason to place within the Miocene. But it seems quite possible that this great disturbance of the Cretaceous was coeval with the formation of other similar Cretaceous uplifts, which in the Green River Basin are clearly seen to have preceded the earliest Eocene deposits.

Rocks similar to the trachytes of Parkview Peak are found along the Elk Head Mountains, and the identical species has been brought to light by the researches of G. K. Gilbert in the Henry Mountains. In all three of these places, facts necessary to fix the actual date are wanting. In each case this rock accompanies peculiar local disturbances of Cretaceous rocks. Its affinities with the older granite-porphyries, together with its peculiar relations to the Cretaceous, suggest that it is a special group long antedating the other trachytes, and to be assigned to the very dawn of the Eocene period. The east-and-west dikes which cut the blocks of Cretaceous strata, and the main fields of eruptive rock, have withstood atmospheric agencies remarkably well, and rise above the sandstone like stone walls.

East of Parkview Peak, near Middle Park Trail, are some isolated hills and cones which Professor Zirkel has described as granite-porphyries. These and the rocks from Parkview Peak are petrographically similar, although the field habit is like that of true trachytes. The yellowish-gray groundmass consists of orthoclase, quartz, and a little hornblende; it is extremely fine-grained and nearly homogeneous. The most remarkable lithological point is the occurrence of orthoclases in perfect individuals, presenting faces such as heretofore have only been found in middle-age granite-porphyries of Europe. Besides these orthoclases are a few small plagioclases, hornblende, apatite, titanite, magnetite, and pyrite, the latter having a brilliant, brassy color. From similar rocks at Steves' Ridge these are distinguished by the microscopic behavior of the hornblende, which gives the green sections characteristic of the older rocks, by the fact that the quartz contains fluid inclusions, but none of glass, and by the presence of pyrite and titanite; whereas the similar trachytes of Steves' Ridge contain ample glass inclusions in the quartz, and neither titanite nor pyrite, and the hornblendes have the usual brown sections. At the same time, the physical likeness of the rocks is wonderfully complete. The modes of occurrence are similar, both are involved in dislocated Cretaceous strata, and neither can be positively referred to a later disturbance than that which marked the close of the Cretaceous. Further, the Henry Mountain rocks, which according to the observations of Gilbert, cannot be earlier than the end of the Cretaceous, have also apatite, titanite, and fluid inclusions in the quartz, besides both green and brown sections of hornblende. Examination of several of these specimens shows the uniform presence of highly modified orthoclase, which in some cases has the glassy habit of sanidin and in others resembles that of granite and granite-porphyry.

From a geological point of view it seems to me most correct to refer this rock to a new group, for which I propose the name of *trachytoid-porphyry*, the group representing, both in geological date and in physical habits, the transition between the porphyries, whose occurrence in the Cordilleras has never been known to be later than the close of the Jura, and the Tertiary volcanic series. It is true that one extreme of the group is indistinguishable from the earlier granite-porphyries except by the trachytic mode of eruption, while the other extreme falls within the petrographical limits of true trachytes. The writer has examined specimens where the quartzes contained fluid inclusions with moving bubble, while the hornblendes contained ample glass particles.

There is a decidedly sudden change between the Parkview rocks and the summit south of Ada Spring, the former occurring as cones, sharp peaks, and long, irregular dikes, while farther west the region is a broad trachytic plateau with escarped faces. The rock south of Ada Spring is unmistakably a fine-grained, dark-gray trachyte, the groundmass consisting of sanidin, augite, hornblende, biotite, and apatite; the microscope showing the augite to predominate greatly over the hornblende. The main plateau shows everywhere dark-grayish and brownish-gray rocks of the same character, in which augite always predominates over hornblende or biotite, and sanidin over the small brilliant crystals of plagioclase. The ordinary rough trachytic habit is well displayed, and the rock in every way contrasts with the trachytoid porphyries of Parkview. The augitic rock is later, and doubtless belongs to the regular Miocene trachyte period.

The Archæan mass of Park Range suffers an important change of trend about the latitude of 41°, the neighborhood of Davis Peak being the region of deflection. Within this angle and west of the range are the Elk Head Mountains, a group whose position doubtless depended upon the Archæan angle. The eruptive rocks of this group consist of trachytes and basalts. The former occur close to the Archæan rocks, from Hantz Peak to Camel Peak, and thence extend southward from Steves' Ridge and Whitehead Peak in a broad field about thirty-five miles long. The highest summit is that of Hantz Peak, which reaches 10,906 feet, while the other three peaks mentioned are all over 9,000 feet, and Whitehead reaches 10,317. The greatest east-and-west expansion is a stretch of twelve or fourteen miles from Crescent Peak to Hantz Peak. The trachytic eruptions come to the surface through a preëxisting uplift of Cretaceous rocks of the Fox Hill and Colorado groups. As a whole, these rocks are all sanidin-trachytes. One type is made up of a rough, porous, crystalline groundmass, in which are large, highly modified sanidins, similar to those already mentioned at Parkview Peak. A prominent variety of the true trachytes of this region contains in the characteristic groundmass a great many brilliantly clear, rounded granules of free quartz, which are peculiarly cracked and riven, not unlike some of the quartzes of rhyolite. All the quartz is confined to these large macroscopical grains, the microscope showing none whatever in the groundmass. It is essentially an accessory mineral, like the tridymite of other trachytes. It frequently contains glass inclusions. Besides large sanidins and quartzes, the rock contains hornblende, a little mica, a comparatively high proportion of augite, and, in a few instances, olivine. The outcrops are generally in rounded dome-like hills and sharp cones, offering a great contrast with the more level plateaus of basalt to the west. It is probable that the high ragged cone of Hantz Peak formed one of the centres of eruption.

Crescent Peak with its southeast spur and Skelligs Ridge are interesting trachytic dikes rising above the neighboring Cretaceous strata, having from their more resisting nature suffered far less erosion than the enclosing sandstones. South of Whitehead Peak the trachytic ridge has a broad gentle slope, extending out to the edge of the valley of Yampa River. The rock of Whitehead Peak is a peculiar grayish-drab trachyte, having an unusual tendency to split into laminæ half an inch to an inch thick. In the purplish-gray, fine-grained groundmass are enclosed crystals of sanidin, hornblende, and augite, with large cracked globules of pellucid quartz, a few bronze micas, and numerous reddish-brown spots of serpentinized olivine. The large sanidin crystals, which frequently measure an inch or more in diameter, show a tendency to zonal decomposition.

The Sugar Loaf, an isolated trachytic mountain west of Elk River, is composed of a rock of massive habit, containing in a porous gray groundmass large, highly developed sanidin, hornblende, and black biotite, but none of the quartz which is characteristic of the main trachytic body to the north and west. Upon a spur extending northwest from Steves' Ridge, not far from Steves' Fork, is a very characteristic quartziferous trachyte, in which the sanidin crystals are often more than an inch long, associated in the groundmass with biotite and hornblende. Some of the earthy, soft varieties from this locality have an easily decomposed groundmass, from which the large, highly modified sanidin crystals may be readily separated. The surface of the rock here, like that upon Whitehead Peak, is peculiarly pitted where cracked granules of quartz have been weathered out. On the eastern spurs of Steves' Ridge, which project toward Park Range, occur further quartziferous trachytes containing considerable olivine, together with a free sprinkling of brownish mica. The trachyte of Crescent Peak is mineralogically like that of Whitehead, with the same peculiar habit of splitting into laminæ of an inch to an inch and a half in thickness.

Skelligs Ridge is one of the most interesting developments of trachyte in this curious region. The body of the dike, which is from twenty to fifty feet thick, rises out of the soft, grassy slopes of eroded Cretaceous sandstone to a height of 150 feet, and extends in a northwest direction, with a single considerable break, for five or six miles. The walls are nearly vertical, and the rock is composed of rude columns arranged horizontally. The weathered surfaces have a peculiar, pitted appearance from the dropping out of the rounded granules of quartz Mineralogically it is like the rock of Crescent Peak, and is doubtless a continuation of the same eruption. The western spur of Crescent Peak is peculiar from the absence of all crystallized secretions from the groundmass. It is an exceedingly compact, fine-grained, homogeneous mass, and the only included bodies are clear, brilliant granules of fractured quartz, which are often stained brown by the decomposition of the iron of the surrounding mass.

Camel Peak, which is the northernmost point of this great trachytic field, rises like a wedge for 2,500 feet above the valley. The groundmass of the rock is homogeneous, very fine-grained, and in general bluish-gray, containing besides the quartz grains only a few flakes of black mica with occasional hornblendes and augites, the microscope showing that the augites predominate. Upon the freshly fractured surfaces the globules of quartz stand out with a pale, earthy green coating closely resembling the delessite amygdules of basalt. Numbers of specimens collected between Steves' Ridge and Camel Peak are of this same type—dark, compact rocks, containing quartz and augite, with more or less olivine; a few specimens showing considerable biotite, a high proportion of augite, and but little olivine. Some forms approximate very closely to basalt, and it seems as if the whole northern region represented a sort of transition between the true trachyte period and that of the basalts, the genuine basalts breaking out later.

Hantz Peak, the dominating point of the region, shows about 300 feet below its summit the edges of sedimentary beds, chiefly of sandstones, which are highly altered and in some cases distinctly vitrified. Above these are the mauve-colored trachytes which are seen to split easily into laminæ that have generally a very felsitic appearance, the groundmass containing the usual rounded quartz, white, rather decomposed feldspar, a little black mica, and hornblende. The very summit of the rock, however, is made up of a white trachyte having some of the characteristics of rhyolite. But it is considered only a local deviation from the general trachytic type. The very sharp, isolated crest has been frequently struck by lightning, and is grooved out in radiating trenches by the force of the bolts.

On Slater's Fork, near its junction with Little Snake River, is seen a small outcrop of trachyte which the valley-erosion has exposed. It is a narrow body extending about a mile and a half east-and-west, passing under the basalts at its eastern termination. It is exceedingly compact, and the groundmass is cryptocrystalline, the eye detecting only flakes of brown biotite. The microscope shows predominating sanidin, plagioclase, abundant augite, and a few olivines, but neither quartz nor hornblende. There is, however, a little distinct nepheline.

The trachytes of this eastern Rocky Mountain province may be summed up under two distinct types: that which appears upon Steves' Ridge, and which in the crystalline form of its unusually large sanidins so closely resembles the highly modified orthoclase of granite-porphyries; and the remarkable family of quartziferous augite-trachytes, which are nowhere so well developed in the Fortieth Parallel area as here. Their peculiarity is, that the groundmass contains no microscopical quartz, while large globules, up to one eighth of an inch in diameter, remarkably split and cracked, are very prominent among the crystalline secretions. Olivine is of not infrequent occurrence, and augite always predominates over biotite and hornblende. Plagioclase is invariably present, but in smaller amounts than the sanidin. It seems to be a thorough mingling of the constituent minerals of basalt and rhyolite; there being present the sanidin, biotite, quartz, and occasional hornblende, characteristic of rhyolite; and the augite, triclinic feldspar, olivine, and magnetite of basalt.

In the northern angle between Green River and Bitter Creek, rising out of the plains of Green River Eocene strata, is a single isolated body of augite-trachyte, presenting abruptly escarped faces on all sides. The soft and easily eroded material around its base shows no traces of local disturbance. The recent washing and erosion of the Tertiary soil would naturally cover up any slight local disturbances, and it is therefore uncertain whether this isolated mass of trachyte has burst up *in situ*, or whether it is the sole surviving fragment of a flow. It is uncommon in the geology of the Cordilleras for jets of eruptive rock to burst up through horizontal strata without any orographical disturbance. At the same time it is common to find the fragments of a flow which have escaped general erosion; and in the case of Pilot Butte it is impossible to assert positively what its deeper relations may be. In composition it is an augite-trachyte, not unlike those of the Elk Head region.

Next to the Elk Head trachytes, the most extensive exposure within our area is that which lies along the eastern base of the Wahsatch, separating it from Uinta Range. A reference to geological Map III., on which the relations of the trachyte to the surrounding sedimentary rocks may be clearly seen, will show at a glance that the main line of the trachyte eruption has a north-and-south trend, that it breaks through the depressed region between Uinta and Wahsatch ranges, and in passing northward cuts a diagonal into the heart of Wahsatch Range. The most important body is that which overlies the Cretaceous and Eocene Tertiary in the neighborhood of Wanship, and extends thence southeastward for thirty-five miles, forming a belt that spreads out transversely eight or nine miles. The Jura, Trias, and Permian, and heavy masses of Carboniferous rock, dip eastward along the Wahsatch, and, passing under a synclinal, rise again upon the end of Uinta Range. From the relative position of the rocks on both sides of the synclinal, it is evident that there has been a fault, and that the end of the Uinta has been elevated above the corresponding horizons of Wahsatch Range. The fault which is thus defined through the older rocks projects southward through the Cretaceous and the overlying Eocene beds, the trachytic eruptions reaching their greatest elevation at the south at Heber Peak, where the altitude is 10,138 feet. North of the synclinal between the Wahsatch and the Uinta the trachytes had a wider spread, extending eight or ten miles northeast from the little town of Peoria. In a northwest direction they recur upon the north side of Parley's Park, and the northwest trend is continued in outbursts of trachyte which are seen in the valley of East Cañon Creek, at its bend ten miles north of

Parley's Park, and again at Richville. The entire length of this trachytic vent is therefore about fifty miles.

In Kamas Prairie and Provo Valley the Quaternary débris doubtless covers considerable portions of trachytic rock. Both in the region of Heber Peak and again north of Peoria, where an arm of the trachyte comes in contact with the Eocene rocks, it is distinctly later than the stratified sandstone. So, too, both the bodies which are seen in the valley of East Cañon Creek are plainly later than the surrounding Tertiaries. It is the Vermilion Creek or the lowest member of the Eocene with which they are found in contact. There must, however, have been a great amount of erosion along the drainage of East Cañon Creek before the ejection of trachyte, as it took place in the bottom of a well eroded cañon.

In middle Nevada, in the region of Dixie Valley, we have the next later member, the Green River group of the Eocene, overlaid by trachytes. The Bridger group has never been seen by us in contact with volcanic rocks, and the only time-fact about this great Provo trachyte field is, that it occurred either late in the Eocene or during the Miocene. The latter is known to be the age of the western Nevada trachytes, and there are no valid geological grounds for especially doubting that these are contemporaneous.

At the southern end of the outburst they appear to have overflowed the conglomerates of the Uinta group of Eocene, which here represents the same horizon as the Vermilion Creek beds to the north. The conglomerates, both north and south of the Uinta, in the immediate neighborhood of the trachyte, never contain any trachyte bowlders, which must necessarily have been the case if the ejection had been prior to the deposition of the Eocene sediments.

In several of the higher ravines in the neighborhood of Heber Mountains there are considerable accumulations of varied gravels and bowlders, among which are many fragments of trachyte. These probably belong to the Wyoming (Pliocene) conglomerate, which covers the neighboring ridges. Besides the superficial exposures, which are frequent over the whole trachytic field, good sections are obtained in Heber Cañon, in the valley of the Provo, on the heights on both sides of Weber River near Peoria, and throughout the valley of Silver Creek. In general, the whole eruption was quite free from breccia, and it is remarkable for so extended a field in that it is extremely rich in well crystallized minerals from one end of the exposure to the other. The exceptions to this are on the foot-hills northeast of the town of Medway, where there is a considerable deposit of stratified volcanic ash, indicating that during the early period of the eruption sands and rapilli accumulated in a small lake. The second exhibition may be seen in the valley near Silver Creek, above the head of Provo Cañon, where there is a light-gray, trachytic tuff, with a slighly decomposed groundmass and large sanidin crystals, with needles and flakes of mica.

On the cañon walls between Kamas and Provo are highly porphyritic forms, having reddish, purplish, and greenish groundmasses, containing brilliantly white sanidins, earthy-brown hornblende, and much specular iron, and, in a few instances, considerable bronze mica.

On the heights between Provo and the head waters of Silver Creek are some interesting purple and apple-green trachytes, having a groundmass especially compact and semi-vitreous, in which are abundant glassy sanidins; dark-brown, dark-purple, and black, more or less altered hornblende, with occasional flakes of biotite, and small, brilliant plagioclases, the microscope showing a dark-gray, globulitic base.

Farther down Silver Creek, near Kimball's, a similar trachyte was observed, very rich in sanidins, and having a good deal of plagioclase, hornblende, augite, tridymite, and apatite. And not far from Kimball's Station, directly north of the road, are trachytes of a rusty brick-red color, that have broken through the Cretaceous and Jurassic strata, which are more or less altered by contact with the trachyte. The only peculiarity of the rock is, that the hornblende is a little fresher than usual, and that besides the tridymite there is a large proportion of augite.

Comparison of a great number of specimens from the whole field of this extensive eruption shows a single prevalent type; a rather fine-grained groundmass plentifully imbued with a glassy base, which for the most part is devitrified, carrying predominating sanidin, few but brilliant plagioclases, hornblende (often decomposed), and sparing augite; exceptional specimens showing a high proportion of bronze mica. It is a normal sanidin-trachyte, in which hornblende exceeds biotite. North from Parley's Park, about half-way down to Morgan Valley, a body of trachyte occupies the hill slope on the right bank of East Cañon Creek for two or three miles. A rather abrupt slope is exposed, made up of distinct horizontal beds, the habit of the rock being decidedly like an andesite.

About four miles south of Weber Station, where East Cañon opens out into a broad valley, is the northernmost of this chain of trachytic bodies. It occupies a narrow area along the right bank of the stream, and is for the most part surrounded and covered by horizontal Pliocene strata. It consists of a very coarse groundmass of sanidin and biotite, with little or no glass base. In the groundmass are highly developed sanidins of brilliant, glassy purity, and shining black biotites. Although it precedes the Pliocene beds which clearly overlie it unconformably, yet a considerable part of this eruption appears in the form of a rough, gritty, trachytic tuff, which must have been ejected when Morgan Valley was eroded to nearly its present dimensions and contained more or less of a lake.

The great orographical feature of the Wahsatch is the line of fault and displacement which for a hundred miles has occurred through the heart of the range, severing it into halves, the western of which has been depressed to an unknown depth—certainly in the region of Cottonwood Cañon 40,000 feet—below the level of the eastern. Nothing is more natural than that this line should subsequently become the theatre of volcanic action. The smallness of the amount of actual ejecta is rather the most remarkable feature of the locality. This great north-and-south fault was crossed by a less powerful but remarkable line of east-and-west strain along the axis of the Uinta Mountains, the intersection of the two taking place in the granite region of the Little Cottonwood. It is here, in what are called the Traverse Mountains, that the most considerable trachytic eruptions have taken place.

South of the granitic body of Lone Peak, a spur of hills projects westward to the middle of Jordan Valley, and beyond the river rises against the foot-hills of the Oquirrh. In the immediate valley of the Jordan the volcanic rocks are covered by accumulations of Quaternary and the terraces of the Bonneville Lake period. The Traverse Mountains have a trend a few degrees south of west, or approximately at right angles to the northwest trend of the great trachytic series that lies along the eastern base of the Wahsatch. The fissure that permitted the escape of these rocks started out from the great Wahsatch fault where the Cambrian series comes in contact with the underlying Archæan granite, and continues through the unknown rocks deeply buried beneath the valley of the Jordan, finally cutting through the quartzites and limestones of the Oquirrh. The hills east of the Jordan rise about 1,200 feet above the level of the plain, and probably a considerable portion of their bulk is the continuation of the Archæan and granitic spur; but it is all covered now by the broad field of trachyte which occupies the whole surface. West of the Jordan the trachytic exposure is on a larger scale, the hills rise 2,000 feet above the valley, and the trachytes are seen abutting directly upon the Weber quartzites of the main ridge.

Along the eastern foot-hills of the Oquirrh, the trachytes extend northward as far as Bingham Cañon. Near the Wahsatch, on the eastern end of the group of hills, the trachytes are dark-bluish, reddish, and brownish rocks, composed of but a small amount of groundmass, in which sanidin and biotite are the principal secretions. There is so little groundmass that certain specimens have a granitoid look, suggesting some of the nevadites. While sanidin and biotite are the prominent constituents, there appear small plagioclases, unaltered hornblendes, and considerable olive-colored augite, and the microscope reveals apatite and magnetite. In immediate contact with the Lone Peak granite, the rock is an earthy, greenish-white mass, with the feldspars kaolinized and the groundmass decomposed beyond recognition.

The western body of mountains beyond the Jordan consists also of sanidin-trachytes, rich in glassy feldspar and bronze mica, and possessing a very little hornblende. Here at the northern limit of the main body, at Rose Cañon, hornblende and mica are more abundant and sanidin less. Throughout the middle of the group are dark, heavy, hornblendic trachytes, in which the proportion of plagioclase rises very nearly to equality with the sanidin, and the rocks approach the andesitic habit.

Near Salt Lake City, about two miles up the cañon of City Creek,

the hills on either side of the stream are for a short distance (not over a mile and a half) formed of dark, reddish-brown trachyte. All around the sides of the body the Eocene Tertiaries are extremely soft, and the earthy accumulations effectually hide the relative ages of the two. There is little doubt, however, that the trachyte, like that east of the mountain, is more recent than the Eocene beds. This outburst is directly on the line of the great fault, which to the south has cut off the ends of the Palæozoic and Mesozoic strata, and to the north has split down the body of Archæan rocks which forms the nucleus of the range. The rock shades from reddish-gray into light pinkish-gray, deepening in some cases into a dark chocolate. It has a rough, coarsely crystalline groundmass of feldspar, hornblende, and biotite. Among the macroscopical crystalline secretions are abundant sanidin and a high proportion of plagioclase, deep-brown hornblende with the characteristic black border, yellowish-brown mica, and pale-green augites. The microscope also shows an abundance of tridymite and quartz. An interesting microscopical peculiarity mentioned by Zirkel is the occurrence of minute fluid inclusions, with moving bubble, together with gas cavities in the pale, clear interior of certain hornblende sections. The augites contain none of the magnetite grains so common in basalts. Here again is one of those rocks which contain the minerals both of basalt and of rhyolite.

Partly on account of the great geological interest of the region and partly as a study of cañon erosion, I made in the year 1869 a short expedition from Camp Halleck, Nevada, northeastward, by way of Thousand Spring Valley, to the basin of Snake River. In the lower and western portion of the same great interior basin there is an abundant exposure of lacustrine Pliocene rocks rich in a fauna comprising mammals, fishes, and mollusks, and also charged with the remains of arborescent vegetation now silicified. One of the most interesting features of that region was the intercalation of sheets of basalt in the midst of the Pliocene series. This observation, hastily made in travelling by myself, was afterward confirmed by Prof. O. C. Marsh. Pliocene rocks in disturbed positions form the divide between the basin of Utah and that of the watershed of the Columbia. The western exposure of these rocks on the divide in the region of Toano and westward as far as Bone Valley, consisted, as was shown, of rhyolitic glassy tuffs. We have seen, when examining the Truckee Miocene strata of the Kawsoh Mountains in western Nevada, that in the process of upheaval the Miocene trachytic tuffs were invaded by rhyolites which accompanied the post-Miocene disturbances. The rhyolitic tuffs of northwestern Utah and northeastern Nevada, already proved to be Pliocene by carrying fossil vertebrate animals referred by Leidy to the age of the Niobrara Pliocene, are still further confirmed as such by the nature of their material, which belongs to the age of the rhyolites, which from the data in the Kawsoh Mountains we are able to place at the beginning of the Pliocene. We have, therefore, in the region of the divide between the Great Basin and that of the Shoshone, early Pliocene beds of volcanic origin, carrying the Niobrara fauna, and in Boise Basin two divisions of lacustrine Pliocene, both horizontal, one previous and one subsequent to certain of the basaltic eruptions. It is all but certain that the sub-basaltic Pliocenes are the equivalent in age of the rhyolitic Pliocene division of western Nevada. The post-basaltic Pliocenes of Boise Basin are to be directly correlated with those of the Humboldt valley and much of the Great Basin country.

The eastern portion of the Shoshone Basin has for its surface a broad, nearly level field of black basaltic beds which are seen by the magnificent exposures of Snake Cañon to overlie an undulating, hilly surface of prior trachytic eruption. In this portion of the basin no lacustrine sediments are seen, and it is evident that none were laid down here, since the underlying trachytes belong to an age prior to the earliest Pliocene deposit. Throughout the great basaltic plain is traced the sinuous line of the Shoshone cañon, a gorge cut sharply down through the volcanic beds from 400 to 700 feet.

Geologically and scenically the neighborhood of Shoshone Falls is the most interesting point of the cañon. Plate XVII. is a view taken from a point a little below the surface of the plain on the left bank of the river, looking east. The horizontal sky-line is seen defined by the basaltic tables and the middle of the field is occupied by a general view of Shoshone Falls. Plate XVI. is a nearer detailed view of the Fall itself plunging over a trachyte cliff 190 feet high. The volume of the river in its fullest stage

is far less than that of the Niagara, but the breaking up of the brink of the Falls by deep reëntrant angles, renders the cataract one of the most picturesque in the world Plate XVIII. is a view down the gorge looking over the top of the fall, and is of especial interest as showing the narrow, abrupt character of the cañon. Plate XIX. is a detailed bit on the left bank of the cañon, showing the light-colored, easily eroded trachyte mass, with a vertical exposure of about 200 feet, capped by the level sheets of basalt which extend down the river uninterruptedly for many miles.

From a few miles above the Shoshone Falls the river was followed for ten miles of its downward course, and although the exhibition of underlying trachytes was almost continuous for that distance, no variation in the type was observed. The chief interest of this region, besides the evident relations of the two types of the volcanic rocks, is the great horizontal extent of the basaltic beds. Whether they flowed from the two flanks of the valley, or from far eastward in the region of the Teton group, is uncertain, but the exposure is nevertheless of interest from the great distances that single thin sheets of basalt are seen to have flowed. The well known power of retaining a high temperature and of long continued fluidity on the part of the basalts, is here displayed to remarkable advantage. From a brief inspection it is my belief that single sheets have flowed at very gentle angles for fifty or sixty miles. The region is further interesting as a proof of the intensity and extent of post-basaltic erosion. One is not surprised, in studying the flanks of steep mountain ranges, to find them scored by profound Quaternary cañons; but to see a long, level lava plain gashed by a cañon from 300 to 700 feet in depth shows an energy on the part of the slowly flowing rivers which is positively marvellous.

On the eastern flank of the Aqui Mountains, at the base of Bonneville Peak, near the parallel of 40° 30′, is a small region of trachyte, exposed at the forks of South Willow Creek. The geological characteristics are well shown on the western half of Map III., where it is seen that the range is composed of a body of Lower Coal Measure limestones thrown into a curve which on the eastern edge of the mountains abruptly bends over into a steep, easterly dip. The western half of the range is a great body of Cambrian quartzites faulted up into a position even higher than the geologically superior limestones. Through the sharp flexure of the limestones a fissure has occurred, from which a body of trachytes has outpoured, covering the eastern slope quite to the plain of the Quaternary desert. There are no recent rocks anywhere in the neighborhood to afford a clew to the date of the eruption. North and south of the entrance of Willow Cañon the hills are covered with accumulations of red and gray trachytic ash. The groundmass is fine and porous, varies from reddish-gray to white, and consists of an intimate mixture of crystals of feldspar, both orthoclase and plagioclase, together with a great deal of globulitic glass. Macroscopically the crystalline secretions show an enormous preponderance of distinctly hexagonal biotite laminæ and a few hornblendes, the microscope revealing a little apatite.

An exposure of trachytic rock is seen at White Rock Springs, near the southern end of Cedar Mountains. The ridge already described as a double fold of Lower Coal Measure limestones is marked by the occurrence of a body of andesite at the important angle of flexure of the range. Directly east of the andesites occurs a small body of trachytes occupying an east-and-west region entirely enclosed by limestones, except the very eastern extremity, which passes under the Quaternary of the plain. The greater part of this exposure is of rough, reddish, trachytic breccia, above which rise the white rocks from which the locality takes its name. They are domed masses, about 300 feet high, of grayish-white quartziferous trachyte. These bosses of rock have such smooth, even sides that they are exceedingly difficult of access. The rock is a crystalline aggregation of sanidin (the individuals of which sometimes reach an inch in length), brilliant black prisms of hornblende, flakes of biotite, and cracked, rounded granules of quartz. It shows a close resemblance to the family of quartziferous trachytes of Elk Mountain.

It would seem that all the trachytes of the Salt Lake region naturally group themselves into two main systems of eruption—the great body east of the Wahsatch, with its northern continuation, which marks one of the orographical faults of the Wahsatch; and that of the Traverse and Aqui mountains and Cedar Range, which, though irregular in trend, is practically at right angles to the first-named series.

Over the whole broad desert lying to the north and west there are no trachytes, with the exception of a small body on Peoquop Creek, in the northern part of the eastern half of Map IV. Peoquop Creek drains through Thousand Spring Valley a few miles north of the Pacific Railroad, and traverses a low region of which the geology is quite simple. It consists of island-like spurs and hills of Weber quartzite, surrounded and overlaid by horizontal strata of Pliocene. Through the quartzites has outpoured a small body of trachyte, over and around which the Pliocene strata have been deposited nonconformably. It forms a long north-and-south ridge, with several dome-like points. The rock is more or less decomposed, and is characterized by pores and cavities filled with both calcite and chalcedony. It is made up of sanidin, plagioclase, and hornblende. The two feldspars are present in about equal proportion, and the rock is to be classed with the earlier plagioclase-hornblende-trachyte which is characteristic of the region of Washoe.

Humboldt Range, although the most extensive and lofty in Nevada, is conspicuous for its paucity of volcanic rocks. Minor rhyolitic eruptions have taken place in the northern part of the range, but the only trachytic occurrence is a small body a few miles north of Cave Springs on the eastern base of the range. Here a limited flow of grayish, highly crystalline trachyte has burst out through a fissure in the Lower Coal Measure limestones, its appearance being accompanied by an unusual amount of shattering of the limestone rocks. The exposure is a low, rugged spur, surrounded on all sides by limestone. It is essentially a sanidin-biotite-trachyte, although triclinic feldspars and hornblende are present in small quantities. The plagioclases are noticeable macroscopically for their great size and brilliant surfaces. The microscope reveals prisms and microlites of apatite, besides quite fine particles of hornblende entering into the groundmass after the manner of powdered hornblende in propylite. Rare macroscopic quartzes are present, but the microscope detects none in the groundmass.

In the upper valley of Susan Creek are two small bodies of trachyte, separated from each other by horizontal strata of Pliocene and the Quaternary valley deposit, both of which are later than the trachytic eruption; and it is most probable that the two trachyte bodies have a connection beneath the Pliocene. More recent rhyolites overlap both the trachyte bodies. Of these two exposures, that on Coal Creek, at the base of Seetoya Range, has a colorless feldspathic groundmass in which are enclosed sanidins, plagioclases, and a few biotites, the microscope revealing a little titanite. The more southern of the two outcrops is a pale-reddish, earthy trachyte resembling domite. Its base is decidedly glassy and considerably globulitic, and carries much fine crystalline feldspar. The most remarkable points about this rock are, that it contains, even macroscopically, rose-colored garnets in granular aggregations, and that there are also disseminated through the groundmass bright prussian-blue, hexagonal grains, referred by Zirkel to haüyne. Zirkel remarks (Volume VI., page 151) that the occurrence of such garnets in trachyte is only recorded besides of specimens from the island of Ischia.

One of the most extensive as well as interesting trachyte localities in Nevada is that in the northern part of Piñon Range. The lofty body of mountains here at its northernmost extremity consists of an anticlinal with a trend a little east of north. This broad fold involves strata of the Cambrian, Silurian, Devonian, and Carboniferous ages. The continuity of the great axis is suddenly broken by an east-and-west fault, which has been the theatre of deep dislocation. The group of hills to the north, formed of the united River and Elko ranges, in which the most ancient neighboring rocks are the Uinta quartzites, has retained its natural level, while the Piñon anticlinal has been lifted from a great depth, exposing the lower strata. Besides the east-and-west break described, another powerful fissure passes in a meridional direction along the eastern base of the range. From out of both these cracks an enormous trachytic flood has been ejected, surrounding and burying the edges and ends of the uplifted Piñon strata. In Dixie Pass the sharply eroded edges of the Palæozoic strata plunge suddenly down beneath a series of rolling trachytic hills, which sweep around southward, coming in contact successively with the Devonian and the Silurian of the western half of the Piñon anticlinal, then with the Cambrian nucleus of the fold, and afterward to the south bounding the Silurian and Devonian of the easterly dipping member of the group. There is nowhere a more interesting instance of the direct and obvious connection of

volcanic eruption with mountain dislocation. The trachytes thus exposed extend about twelve miles north-and-south and four to six miles east-and-west, the surface being high, rolling ridges and spurs, those bordering on Dixie Valley forming a chain of characteristic dome shapes. Along their eastern margin for a considerable distance these trachytes overlie the upturned calcareous shales of the Green River Eocene, and to the south are themselves overlaid by a subsequent flood of rhyolite and the horizontal Pliocenes of Huntington Valley. The higher spurs and domes all show a rounded form and an absence of any conspicuous bedding. The general character of the predominating eruption was that of broad, massive accumulations, and even the most isolated and conoidal of the trachyte domes show no evidence of the structure of a true volcano. The main material, and that of all the later eruption, is of brownish and reddish sanidin-trachyte, with a very coarse, rough, friable groundmass, composed of vitreous sanidin and magnesian mica, in which a multitude of the larger crystals of both are included. There is a very close resemblance between certain specimens of this rock and the Sugar Loaf trachytes of Washoe. They exhibit the same method of mingling the biotite and sanidin, and the latter is in the same abundantly fissured condition as the former. At several places near the Cambrian and Silurian foot-hills, and along the northern slopes of Dixie Hills, deeper erosion has exposed a lower family of trachytes These are characterized by the sparing presence of biotite and the decided predominance of hornblende, which occurs, both in brilliant black crystals and in earthy, gray prisms, associated with plagioclase which equals or exceeds the sanidins. Among these hornblendic trachytes the groundmass is far more compact, the rock is evidently bedded and has a habit approximating to that of andesites. The only very similar rock obtained in the Fortieth Parallel area is that which has been described in Volume III., Chapter II., from the cross-spur at Virginia and Washoe, from which this only differs in having rather smaller plagioclase crystals. In fracturing the rock, it is noticeable that it breaks most easily parallel to the planes of bedding, and that all the larger crystals are arranged in such planes that the surface of a fractured specimen usually displays several split hornblende prisms with brilliant black surfaces and large slabs of feldspar. It is interesting to note that this plagioclase-hornblende-trachyte, which verges very near the andesites, is older than the sanidin-biotite-trachyte, the same sequence being observed at Washoe.

At Palisade Cañon the Humboldt has worn a gorge through an area of trachyte about five or six miles from north to south by four from east to west, along the course of the river. The hills to the north rise 1,500 to 1,800 feet high, and to the south reach about 1,000 feet. In the very middle of this trachytic exposure, in a ravine which enters the cañon from the north, erosion has laid bare an underlying massive andesite, which again occurs on Emigrant Road directly north of the northern limit of the trachyte body. It is plain that the fissure which gave vent to the trachyte was a reopening of the weak line of the andesitic break. So many orographical periods had disturbed the whole Cordilleras prior to the Tertiary, that there were innumerable lines of weakness, which the earlier Tertiary eruptions easily found; and although the period of each successive volcanic family enlarged the limits over the previous one, yet in many instances the later volcanic rocks are found to follow the fractured lines of their immediate predecessors, as in this case. Although the whole body is essentially a group of sanidin-trachytes, the hills north and south of the cañon present some different varieties. The cliffs along the southern wall are of normal sanidin-trachyte; the brownish-gray groundmass, composed of sanidin and biotite, containing larger crystals of these two minerals. The microscope reveals the presence of a few hornblendes and apatite. Upon the northern wall of the cañon, in the hills which form the main eruption for several miles, are observed more recent trachytes than those just mentioned. They have a light-gray, porous groundmass composed of biotite and sanidin, in which are remarkably perfect yet earthy prisms of hornblende, together with interesting casts of these crystals where all but the granulated border-material of the hornblende has been removed. The sanidins always obviously outnumber the hornblendes.

The body of quartz-propylite which extends along the ridge of the Cortez Mountains, south of Wagon Cañon, is margined along the west by a narrow exposure of sanidin-trachyte, which to the west is covered by rhyolites. The groundmass resembles that of propylite, from the amount of small hornblende crystals that enter into its composition. Small sanidins, laminæ of partially decomposed biotite, and a few well preserved hornblende crystals make up the list of crystalline secretions. But for the predominance of sanidin over plagioclase, the rock, from the peculiar disposition of the hornblende, would be closely related to the propylites. The microscope shows in the biotites an interesting interposition in the laminæ of colorless muscovite. Zirkel also describes the feldspars as being covered with a glittering dust, the product of alteration, and probably calcite. The instrument also reveals apatite. Between the trachyte and the neighboring volcanic rocks, the question of age is too obscure to allow of any definite conclusions.

The Wahweah Mountains, of which only the northern parts come within the limits of our map, lie, as do most of the Nevada ranges, between two open desert valleys. That upon the west is much the lower. Large parts of the Wahweah group are formed of tabular fields of trachytic rocks which all slope toward the lower or western valley. Above the general plateau-like surface rise rugged hills and points, and the slopes are scored by deep ravines and cañons, which afford excellent exposures. The northern part of the mountains is composed of granite, overlaid by Silurian and Devonian strata, which, in extending southward, pass beneath the great trachytic covering. Examination of the specimens collected here discovers a rich variety, representing nearly all phases of the trachytic family. There are quartziferous trachytes which in the ordinary microcrystalline groundmass carry brilliant sanidins, some fresh plagioclase, and well developed biotite, with large hexagonal crystals of quartz surrounded by a fibrous sphærolitic crust. A second variety is a typical sanidin-trachyte with large sanidins, abundant biotite, plagioclases, and a little hornblende with which decomposition has usually proceeded very far. The microscope reveals apatite and haüyne. The plagioclase-hornblende-trachytes, in which triclinic feldspars rise nearly to the proportions of sanidins and the hornblendes greatly exceed the biotites, also occur, and last of all comes true augite-trachyte with a dark, homogeneous groundmass, enclosing large numbers of plagioclases, macroscopic augites, and microscopic apatite. The relative ages of these varieties were not worked out.

On Jacob's Promontory, a little group of hills in Reese River Valley, north of Jacobsville, intimately associated with some rhyolites which have partially overlaid it, is a small body of gray trachyte, which besides the prevailing sanidin contains some plagioclase and augite, with, however, a predominance of hornblende. The habit of this rock resembles the andesitoid gray trachytes of Virginia.

Not the least remarkable among the isolated outbursts of trachyte is that which occurs on the heights of Havallah Range, near Cumberland, having poured out near the junction of the Triassic quartzites with the Star Peak group. The general inclination of the structural lines of the trachyte is to the east, and its summit is that of a high ridge rising in several rude conical points. The rock itself is a very porous sanidin-trachyte, of a dull gray groundmass, carrying sanidins from an inch to an inch and a half in length, many of the crystals being dislocated and broken. Small flakes of brownish biotite are scattered through the groundmass; and that which above all distinguishes this trachyte is the occurrence of large limpid granules of quartz, a mineral which does not enter into the composition of the groundmass. It is most nearly allied to those trachytes of the Elk Head Mountains, in Colorado, which also carry an abundance of macroscopical quartz, but none entering into the rather basic groundmass; the quartzes in these instances playing a peculiar rôle, since they are enclosed in a groundmass by no means either as acidic or as glassy as in the rhyolites.

In Pine Nut Cañon, of Pah-Ute Range, east of Chataya Peak, is a body of trachyte which has broken out east of the diorite, immediately followed eastward by subsequent eruptions of rhyolite. The habit of the rock is distinctly trachytic. The colors are gray, yellow, and brown. For the most part, the groundmass is a combination of feldspar, opacite, and ferrite, and for a limited portion of the body is decidedly rhyolitic in type, consisting of axially fibrous bands separated by masses of felsitic substances rich in ferrite and opacite. The rock contains no quartz; but the sanidins, reaching a quarter of an inch in diameter, are peculiarly brilliant in lustre and at times are drawn out, showing an almost silky fibre like the threads of pumice. The outcrop is limited, occupying a low position on the flank of the range, and has no orographical importance.

The chain of mountain elevations consisting of the Pah-tson and Kamma groups, really part of the Montezuma system, is continued northward by a range of hills having its rise a little north of Indian Spring and extending beyond the northern limit of Map V. The main body of the southern end of the range is formed of trachytes, which tower above the desert valley of Quinn's River about 3,500 feet. The culminating summit and the ridge extending northward, as well as the abrupt, promontory-like southern front of the range, are made up of sanidin-trachytes, which, in turn, are broken through and overflowed on their western base by rhyolites. At the eastern base of the hills, directly east of the culminating summit, the trachytes are seen to overlie the slates of the Jura, while upon the west they are indistinctly connected with the upturned Miocene beds. The trachyte itself is of a variety of purplish-red colors, having a decidedly conchoidal fracture. It is mostly very fine-grained, consisting of a groundmass of sanidin, opacite, and magnetite, in which are embedded no macroscopic crystals except a few small, brilliant sanidins.

A small and rather unimportant trachytic outcrop occurs in the low foot-hills at the northeast point of the Kawsoh Mountains, directly opposite Carson Lake. Here, rising above the Quaternary desert slopes, are low hills a few hundred feet in height, which above are conspicuously capped with black basalt. The material of the hills is a fine-grained sanidin-trachyte, of a dark, grayish-brown color, with often a dull earthy exterior. Indistinct beds make up the mass of the hills. Lithologically there are no points of interest about the trachyte, except that it is rather compact, and when undecomposed breaks with an unusually lustrous fracture, and contains in the gas-cavities and cavernous spaces considerable amounts of tridymite. Professor Zirkel, who calls attention to this fact, also notices blood-red laminæ of specular iron.

Of the trachytes of Lake Range, which evidently occupy a considerable portion of its body, only those bordering Pyramid Lake and the extension of the same system at Anahó Island have been examined. The western slopes of Lake Range, and the mass of trachyte of the island itself, are rugged piles, showing little or no tendency to lines of flow or bedding. The mountain surfaces are more or less eroded by ravines, which display the rough, dark slopes of trachyte. Under the hammer the rocks of this region break with a rough, hackly fracture. In the hand specimens they are almost always of dark grayish-brown or reddish-brown colors, the groundmass consisting of fine sanidin with magnetite, ferrite, and opacite, in which are frequent large, vitreous sanidins and occasional but rare biotites and hornblendes.

Of the trachytic hills which form the northern part of Virginia Range where it descends to the level of Mud Lake Desert, Mr. Hague says:*

"North of the basaltic body, Virginia Range terminates in a group of low hills, which border Pyramid Lake on the northwest and connect with the southern end of the Madelin Mesa. Astor Pass cuts through these hills, connecting Pyramid Lake with Honey Lake Valley of California, and lies below the level of the ancient Lahontan Lake, the calcareous tufas covering the flanks of the hills, and showing conclusively the flow of those alkaline waters westward beyond the boundary of Nevada.

"On the geological map, these hills are colored as trachytes; it is probable, however, that rhyolites are represented here; indeed, the entire group belongs to that class of rocks which stands on the border line between these two types of acidic rocks. They are characterized by reddish-brown and gray colors, and a decidedly crystalline texture, with the individual minerals usually well developed. One of the most striking rocks of the region, and one characteristic of Astor Pass, is found near the entrance of the pass, about four miles northwest from Pyramid Lake, where it forms broad table-like masses. The prevailing color of its groundmass is brownish gray, in which, forming the greater part of the rock, are porphyritically enclosed crystals of feldspar, mica, hornblende, and quartz. Many of the feldspars have a dull white color, quite unusual in rhyolites, and are frequently three quarters of an inch in length, carrying impurities which may be recognized by the aid of an ordinary magnifying glass. Mica is very abundant and of a brilliant black color, while the hornblende, which is also black, plays quite a subordinate part. The quartz-grains are large, but are by no means frequent, and resemble those usually found in that somewhat limited group of quartz-trachytes; that is to say, they appear more

* United States Geolog cal Exploration of the Fortieth Parallel, Volume II., Chapter V.

like an accessory mineral than a primary constituent of the rock. They are quite clear and colorless, and apparently free from microscopical impurities. Under the microscope, minute crystals of apatite may be recognized. The presence of quartz and the microscopical structure of the groundmass relate this rock to the rhyolites."

The most important body of trachyte upon Map V. is that which is displayed in the cañon of the Truckee, and which forms the body of Virginia Range thence northward to Pyramid Lake. The summit and slopes of this elevated mountain body are for the most part made up of broad, thick beds of dark earthy-brown and reddish-brown trachytes. From Ormsby Peak, an elevation of 9,388 feet, down nearly to the shores of Pyramid Lake, are deeply scored cañons which show lofty, rugged slopes made up of the edges of heavy trachytic beds. With nothing like the evidences of flow that one sees in many rhyolitic regions, there is nevertheless a tendency to form sheets, and a tendency of the sheets to slope both to the east and west and down the flanks of the range, the general impression being that of a body having its source of outflow near the heart of the range, with each paroxysm of ejection superposing a new bed which declined slightly toward the plains on either side. A cross-section of these trachytic tables would show a low, broad arch, resembling the curve of a flat anticlinal. This structure, very common in the basaltic ridges of the region, is certainly indicative of a considerable amount of fluidity retained for some time after the actual delivery of the trachytic matter from the volcanic vent. More commonly the trachytic eruptions are distinctly structureless—that is to say, they betray no lines of flow and no bedding by which the material may be traced to the region of vent. This arched ridge, however, plainly shows the existence of a central fissure following approximately the axis of the range out of which the still plastic trachyte poured, and from which it flowed down to the east and west. This field of trachyte surrounds and overflows the melaphyres, propylites, andesites, and dacites of the Berkshire Cañon region, makes an island of a summit of diorite south of Sheep Corral Cañon, and forms all the low hills bordering the bottom of Truckee Cañon from Clark's Station westward nearly to Wadsworth, except in the lower part of the cañon, where a deeper erosion has laid bare the earlier propylites and diorites. Upon the eastern flank of the range, and in the region of Spanish Peak, rhyolites have broken out upon both sides of the trachyte, and toward the south it is completely overlaid and bounded by deep and extensive accumulations of gray basalt. A considerable variety of trachytes is found in this great field, of which the following are some of the more important and interesting.

The trachyte which appears upon the south side of the lower portion of Truckee Cañon, occupying an intermediate position both as to age and superposition, is a light-colored, friable rock, containing a considerable amount of glassy base, varyingly devitrified, in which are embedded sanidin, hornblende, and biotite. The glassy material and the sanidins are sometimes slightly fibrous, suggesting a tendency toward pumice. Besides these minerals, the microscope discovered to Professor Zirkel augite, apatite, and biotite. The rock, therefore, owes its interest to the concurrence of augite and sanidin. On either side of the river north of Truckee Ferry is also a sanidin-trachyte, rich in magnetite, but containing neither augite nor magnetite.* Directly overlying and immediately subsequent in age to these dark purple sanidin-trachytes are beds of dark, loose, reddish and brown trachytic breccias, containing blocks up to the size of a foot or two in diameter, the whole held together by a friable mass of trachytic rapilli and fragments. It is noticeable that a small proportion of augite is found in all the hand specimens we collected. Directly over this are lofty bluffs with several hundred feet of precipitous front, composed of a pure gray augite-trachyte varying from light ashy-gray to dark, almost basaltic shades. It is distinctly bedded in horizontal tables, and would at once pass for a rather acidic basalt. More than any other trachytes of massive eruption in the Fortieth Parallel area, this occurrence displays the distinct habit of a sheeted flow, a habit ordinarily confined to the true basalts, the augite-andesites, and rare instances of hornblende-andesite which came to the surface in an exceedingly fluid condition. The joinings and superficial cracks of these gray trachytes are perpendicular to the horizontal flows, producing the ordinary bluff edges characteristic of basalts. The rock itself is of an extremely fine-grained groundmass, in which only a few feldspars can be dis-

* For analysis, see Volume II., page 833.

Number of analysis.
143
144
145
146
147
148
149

Trachytes.

Number of analysis.	Locality.	Analyst.	S̈i	Äl	F̈e	Ḟe	Ṁn	Ċa	Ṁg	Ṅa	K	L̇i		Ignition.	Total.	Specific gravity.	Oxygen ratio of— Ṙ	R̈	S̈i	Oxygen quotient.
143	Truckee Ferry, Nevada - - - -	R. W. Woodward	50.36 26.86	17.00 7.92	6.12 1.83	3.84 0.85	0.30 0.06	8.85 2.53	3.02 1.21	3.21 0.83	1.95 0.33	. .	CO^2+HO	5.35	100.00	2.6, 2.7	5.81	9.75	26.86	0.579
	" " - - - -	"	50.03 26.68	16.99 7.92	6.05 1.81	3.86 0.86	0.42 0.09	8.81 2.51	2.98 1.19	3.33 0.86	2.27 0.38	. .	CO^2+HO	5.26	100.00	. .	5.89	9.73	26.68	0.585
144	Ridge of Divide between Slater's and Southwest Fork of Snake River.	"	53.12 28.33	14.54 6.77	tr.	6.01 1.33	tr.	6.01 1.72	5.20 2.08	3.02 0.78	4.54 0.77	. .	. . .	7.58	100.02	2.7, 2.7, 2.7	6.68	6.77	28.33	0.474
	" " "	"	53.25 28.40	14.42 6.72	tr.	6.00 1.33	tr.	6.01 1.72	5.06 2.02	3.13 0.81	4.58 0.78	. .	. . .	7.63	100.08	. .	6.66	6.72	28.40	0.471
145	Leucite Hills, Wyoming - - - -	"	54.42 29.02	13.37 6.23	0.61 0.18	3.52 0.78	. .	4.38 1.25	6.37 2.55	1.60 0.41	10.73 1.82	tr.	CO^2 1.82	2.76	99.58	2.2, 2.2, 2.2	6.81	6.41	29.02	0.455
	" " - - - -	"	54.42	. .	. .	. .	. .	. .	. .	1.57	10.68	. .	. . .	. .	. .	. .	. .	. .	. .	. .
146	Purple Hill, Truckee Cañon, Nevada	"	56.51 30.14	19.61 9.14	5.10 1.53	0.98 0.22	0.11 0.02	7.89 2.25	2.66 1.06	3.12 0.80	3.67 0.62	tr.	. . .	0.40	100.05	2.5, 2.6	4.97	10.67	30.14	0.518
	" " "	"	56.45 30.10	19.85 9.25	4.95 1.48	0.97 0.21	0.11 0.02	7.70 2.20	2.66 1.06	3.15 0.81	3.84 0.65	tr.	. . .	0.38	100.06	. .	4.95	10.73	30.10	0.520
147	Mount Shasta, Red Butte - - -	W. G. Mixter -	60.44 32.23	18.12 8.44	. .	5.16 1.14	. .	6.43 1.83	3.43 1.37	4.09 1.05	1.25 0.21	. .	. . .	0.89	99.79	. .	5.60 4.46	8.44 10.16	32.23 32.23	0.435 0.453
	" " - - -	" -	60.71 32.38	18.32 8.53	. .	5.05 1.12	. .	6.45 1.84	3.42 1.37	4.17 1.07	1.25 0.21	. .	. . .	0.79	100.16	. .	5.61 4.49	8.53 10.21	32.38 32.38	0.436 0.457
148	Mount Rainier, Washington Territory	O. D. Allen - -	61.62 32.86	16.86 7.85	. .	6.61 1.47	. .	6.57 1.87	2.17 0.87	3.93 1.01	1.66 0.28	. .	. . .	. .	99.42	. .	5.50 4.03	7.85 10.05	32.86 32.86	0.406 0.428
	" " "	" - -	61.78 32.95	16.69 7.77	. .	6.62 1.47	. .	6.35 1.81	2.25 0.90	4.01 1.03	1.68 0.28	. .	. . .	. .	99.38	. .	5.49 4.02	7.77 9.98	32.95 32.95	0.402 0.425
149	Divide between North and Middle parks.	R. W. Woodward	61.95 33.04	16.75 7.80	tr.	5.53 1.23	. .	4.24 1.21	2.54 1.01	4.41 1.14	3.48 0.59	tr.	. . .	1.22	100.12	2.6, 2.7	5.18	7.80	33.04	0.392
	" " "	"	61.95 33.04	15.80 7.36	tr.	5.76 1.28	. .	4.24 1.21	2.63 1.05	4.50 1.16	3.51 0.59	tr.	. . .	1.34	99.73	. .	5.29	7.36	33.04	0.382

TAB

Number of analysis.	
150	Cr
151	M
152	M
153	B
154	V
155	M
156	S

TABLE OF CHEMICAL ANALYSES. X.—B.—UNITED STATES GEOLOGICAL EXPLORATION OF THE FORTIETH PARALLEL.

Trachytes—(Continued.)

Number of analysis.	Locality.	Analyst.	S̈i	Äl	F̶e	Ḟe	Ṁn	Ċa	Ṁg	Ṅa	K̇	L̇i		Ignition.	Total.	Specific gravity.	Oxygen ratio of— Ṙ	R̶	S̈i	Oxygen quotient.
150	Cross-spur Quarry, Washoe - - -	R. W. Woodward	63.13 33.67	16.00 7.45	4.34 1.30	1.52 0.33	. . . .	4.45 1.27	2.07 0.83	3.87 1.00	2.65 0.45	. . . .	. . . . . .	2.00 . .	100.03 . .	2.4, 2.5, 2.5 . .	3.88 . .	8.75 . .	33.67 . .	0.375 . .
151	Mount Hood - - - - - - -	"	63.28 33.74	17.96 8.36	1.81 0.54	3.16 0.70	tr. . .	5.34 1.52	2.50 1.00	3.81 0.98	2.06 0.35	. . . .	. . . . . .	0.12 . .	100.04 . .	2.5, 2.6 . .	4.55 . .	8.90 . .	33.74 .	0.398 . .
	" - - - - - -	"	63.18 33.69	18.06 8.41	1.92 0.57	3.15 0.70	tr. . .	5.33 1.52	2.61 1.04	3.80 0.98	2.05 0.35	. . . .	. . . . . .	0.10 . .	100.20 . .	. . . .	4.59 . .	8.98 . .	33.69 . .	0.402 . .
152	Mount Rose, Washoe - - - - -	"	63.30 33.76	17.81 8.30	3.42 1.02	0.83 0.18	. . . .	5.12 1.46	2.07 0.83	4.27 1.10	2.26 0.38	tr. . .	. . . . . .	0.88 . .	99.96 . .	2.4, 2.5, 2.5 . .	3.95 . .	9.32 . .	33.76 . .	0.393 . .
	" " - - - - -	"	63.13 33.67	17.54 8.17	3.22 0.96	0.83 0.18	. . . .	5.15 1.47	2.06 0.82	4.44 1.14	2.22 0.37	tr. . .	. . . . . .	0.95 . .	99.54 . .	. . . .	3.98 . .	9.13 . .	33.67 . .	0.389 . .
153	Between Provo and Silver Cañon, Wahsatch Mountains.	"	64.82 34.57	15.37 7.16	5.11 . .	 1.13	tr. . .	4.90 1.40	2.22 0.88	2.65 0.68	3.03 0.51	tr. . .	. . . . . .	2.18 . .	100.28 . .	2.3, 2.4, 2.4 . .	4.60 3.47	7.16 8.86	34.57 34.57	0.340 0.356
	" " "	"	64.93 34.64	15.38 7.16	5.10 . .	 1.13	tr. . .	4.90 1.40	2.24 0.89	2.55 0.66	3.05 0.52	tr. . .	. . . . . .	2.14 . .	100.29 . .	. . . .	4.60 3.47	7.16 8.86	34.64 34.64	0.339 0.356
154	Volcanic Ridge, Peoquop Range	"	67.81 36.16	15.83 7.37	tr. . .	3.41 0.76	. . . .	3.66 1.04	1.36 0.54	5.10 1.32	0.67 0.11	tr. . .	CO^2 0.49 . . .	1.73 . .	100.06 . .	2.5, 2.6, 2.6 . .	3.77 . .	7.37 . .	36.16 . .	0.308 . .
	" " "	"	67.60 36.05	15.74 7.33	tr. . .	3.47 0.77	. . . .	3.76 1.07	1.39 0.55	5.07 1.31	0.69 0.12	tr. . .	CO^2 0.49 . . .	1.75 . .	99.96 . .	. . . .	3.82 . .	7.33 . .	36.05 . .	0.309 . .
155	Mouth of Sheep Corral Cañon, Virginia Mountains.	Dr. Auger - -	68.81 36.70	13.62 6.34	. . . .	3.91 0.87	. . . .	4.30 1.22	2.74 1.09	2.68 0.69	2.56 0.43	. . . .	. . . . . .	2.30 . .	100.92 . .	. . . .	4.30 3.43	6.34 7.64	36.70 36.70	0.290 0.302
156	Shoshone Falls - - - - - - -	W. G. Mixter -	70.30 37.49	13.65 6.36	. . . .	5.21 1.15	tr. . .	1.92 0.55	0.40 0.16	3.45 0.89	4.50 0.76	. . . .	. . . . . .	0.56 . .	100.05 . .	2.5 . .	3.51 2.36	6.36 8.10	37.49 37.49	0.263 0.279

cerned by the naked eye. Professor Zirkel finds it to be made up of a fine crystalline mixture of feldspar, impregnated with augite dust and minute crystals of pale, brownish-yellow augite. A glass base and olivine are entirely wanting. Here, therefore, are three distinct periods of trachytic eruption, all, however, characterized by the presence of augite. It is interesting that the presence of augite and of triclinic feldspar in these fine-grained gray trachytes should produce the appearance of basalt. But this basaltic habit is even more prominently developed in certain other black trachytes of this region, particularly those which form the low hills between Wadsworth and Sheep Corral Cañon. These occurrences, although not in immediate connection with the foregoing augite-trachytes, doubtless represent the most extremely augitic portions of the same general ejection, and probably its most recent effort. They are black and dark brown, with a highly vitreous lustre, breaking exactly like the half glassy basalts, and were it not for the large sanidin crystals evident even to the naked eye, might readily, in the absence of microscopic examination, pass for an augite-andesite or even for a basalt. The microscope shows them to be made up of predominating sanidin, pale-green augite, a little plagioclase, some brilliant brown hornblende, and an occasional flake of dark brown mica; the groundmass consisting of colorless crystals of sanidin and augite, embedded in an abundant colorless glass base. A similar black trachyte cuts the white acidic rocks just north of Truckee Ferry in sharp dikes.

Petrographically, these rocks are still trachytes, owing to the predominance of orthoclastic over plagioclastic feldspars. In habitus they are actually basaltic, and in a geological sense might, but for their age, as suggested in Volume II., be considered as basalts with the olivine left out, in which a portion of the plagioclase was replaced by sanidin. The heavy exposures of trachyte at the head of Sheep Corral Cañon are of characteristic sanidin varieties, the groundmass consisting of sanidin microlites cemented by black grains and carrying in the interstices a varying amount of glass. The larger secreted minerals are heavy blocks of sanidin, reaching sometimes three fourths of an inch in dimensions, a few brilliantly stratified plagioclases, and large rude brown biotites.

SECTION IV.

RHYOLITES.

The distribution of rhyolite is even more irregular than that of the foregoing family. In the region of the Rocky Mountains it accompanies the two great trachytic localities, but with the exception of the small, insignificant exposure on Bear River, in Wyoming, there are no rhyolites between the Rocky Mountains and the western side of Great Salt Lake Desert. From the meridian of 114° westward to the borders of California, however, rhyolitic rocks cover a greater area than any other of the volcanic family. Taken as a whole, rhyolite is superficially the predominating volcanic rock of the Fortieth Parallel field, and considerably exceeds the basalts, which rank next in territorial area. These two families, at once the most acidic and most basic, cover together ten times as many square miles as all the rest of the volcanic series combined. The rhyolites, as will be seen from certain Nevada localities, are post-Miocene, and the earliest eruptions are contemporaneous with the first Pliocene beds. The line of demarkation between the fresh-water Miocene and Pliocene formations of Nevada and Oregon is exceedingly sharp. The Miocene strata are all disturbed, and frequently thrown into high angle. The extravasation of rhyolites was a feature of the orographical disturbance which followed the dislocation of the Miocene rocks, and the earliest accumulations of Pliocene contain products of the first rhyolitic eruption. In many places, however, notably northeastern Nevada, the outpourings of rhyolite continued well into the Pliocene period; and a vast amount of the Humboldt Pliocene of that region is made of the acidic ejecta of the rhyolitic period laid down in the fresh-water lakes as local tuff-beds. As the trachytic eruptions form the characteristic volcanic feature of the late Miocene, so the rhyolitic were characteristic of the opening of the Pliocene, and extended over perhaps the first third of the Pliocene epoch.

A world-wide observation as to the location of Tertiary eruptions is, the frequency of their appearing at the angles of powerful flexures or dislocations of earlier rock masses. The most eastern exposure of rhyolite is no exception to this rule. Mount Richthofen stands at the point of meeting of two distinct trends of the Rocky Mountain Archæan rocks. The Medicine Bow trend, which for 100 miles has been southeast, suddenly bends at Mount Richthofen into a meridional strike. Within the angle of this sharp flexure occurs an extensive outpouring of rhyolitic rocks. They flank the beds of the Archæan slope for twenty-five miles, rising highest against the base of Mount Richthofen, where the volume of the eruption was greatest. Toward the basin of the Park the rhyolites descend in broad tables, separated by the valleys of the upper branches of the Platte One particular ridge which extends out to the middle of the Park can hardly be considered as a rhyolite stream. It is probably the overflow of a fissure extending out through the Cretaceous rocks. This is rendered probable by the inclination of the beds to the south instead of to the northwest, or in the direction of the rhyolitic body. The greater part of the high ridges and upper slopes of the rhyolite are covered by dense forests, and the outcrops show no very characteristic forms. They overlie the Cretaceous, probably the trachytes, and are in turn overlaid by the Pliocene lacustrine North Park strata. In the region of Mount Richthofen the light granitoid Archæan rocks are deluged by the dark-colored rhyolites. The groundmass is a fine-grained mingling of fragmentary crystals of sanidin and crystalline grains of dark quartz, the color varying through purple, gray, red, and brown, but usually of dark hues. Large single grains of dark, pellucid quartz surrounded by sphærolitic matter, black, shining hornblendes, and large, fractured sanidins are the only crystalline secretions in the main rock.

The rocks at the head of Sioux Creek are somewhat of an exception to this rule, the groundmass being the usual light color, with more of a felsitic homogeneity, the included feldspars and quartzes being larger than the prevailing type of the neighborhood. Besides the sanidin, there are true orthoclase crystals. One of the most curious features about a locality of varied volcanic rocks is the tendency of some one or more peculiar forms to reappear in ejecta of entirely different chemistry and widely separated dates. Here, in the neighborhood of that peculiar rock which shares the characteristics of granite-porphyry and trachyte, and whose remarkable feature is the highly modified orthoclases, occurs a long-subsequent rhyolite also reproducing, though in less perfect crystalline state, the more opaque, ancient form of orthoclase. In these light rhyolites hornblende is very abundant, though never occurring in highly defined or large crystals.

About ten miles north of Evanston, in the neighborhood of some limited Cretaceous exposures, but otherwise altogether surrounded by the nearly horizontal beds of the Vermilion Creek Eocene group, is a small outcrop of rhyolite, far removed from all other volcanic rocks. It is a fine-grained, pumiceous, lavender-colored rock, the groundmass being the ordinary intimate mixture of sanidin and quartz, in which are interspersed laminæ of very dark and of brownish mica. The outcrop is only of importance from its wide separation from other volcanic fields, the nearest eruptions being some miles down Bear River in the neighborhood of its great bend.

West of the Wahsatch the rhyolites first make their appearance along the southern terminations of the spurs of the Raft River Mountains, and in isolated buttes rising to moderate elevations above the desert south of the range. Several are so small as to pass unnoted on the map. The most important are those of Desert Buttes, about four miles north of the railroad, and Owl Butte, about seven miles to the south. The rhyolite of Desert Buttes, near the old wagon road west of the southwest point of the Raft River Mountains, is a dense, compact rock. Macroscopically it is homogeneous, and has a sharp, angular fracture, varying in color from light, warm gray to salmon. It contains rough sphærolites and lithophyses, and is reticulated by fine veinlets of translucent chalcedony. Through the groundmass are brilliant, colorless quartzes and sanidins, the former abounding in inclusions of glass, and also filling the interstices of the groundmass. Certain of the druses carry tridymite. This eruption is doubtless connected with the line of rhyolitic buttes east of the northern termination of Ombe Range, as well as with the sheet of rhyolite which underlies the basalt and forms the northernmost rock of the Ombe.

Along the eastern edge of the northern foot-hills of the range southwest of Lucin, for about four miles, the hills are made up of rounded rhyolitic masses, which to the north give way to Pliocene beds that are themselves almost altogether made up of rhyolitic tuff. A few miles southeast of Tecoma, at the edge of the field of basalt, outcrops a second isolated body of rhyolite. This is doubtless connected underneath the basalt with those on the eastern side of the range, the basic rocks having clearly overflowed the eroded hills of rhyolite. A rhyolitic butte at the extreme northern point near Lucin is a broad, flat-topped hill with steeply sloping sides, the summit 300 or 400 feet above the valley. The rocks of this group are characteristically reddish-brown glass, carrying embedded sanidins and quartzes. A notable feature is the macroscopic inclusions of reddish glass in quartz, which in the hand specimens are very easily visible to the unaided eye. Zirkel* gives an interesting description of the microscopical structure of this rock—alternating layers of different-colored glass, which have been kneaded and squeezed together in confused positions. Some specimens show the glass drawn out into narrow bands and streaks; and although the prevailing shades of all the rocks are salmon, red, and deep, almost sienna colors, yet in places the glass pales out into an almost colorless condition.

North of the railroad and north of this group of rhyolites, the Goose Creek Mountains, formed of the Upper Coal Measure group of limestones, are covered from base to base by a broad flow of rhyolite, which has been eroded off the southern limestone points of the range. The main central flow is a greenish-white, rough, trachytoid rhyolite, having only a few crystals of quartz and tabular feldspars—the latter often twins—scattered through the groundmass. The groundmass itself is one of those peculiar porcelaneous products which reappear at various points in Nevada. Under the microscope it is seen to be a mixture of transparent, polarizing particles, and some dull-yellowish bodies, which are possibly glassy. On the hill slopes are various porphyritic varieties of the characteristic purple and red shales, full of macroscopical quartz and sanidins. In several specimens, representing a considerable area, the quartzes have excellent pyramidal terminations, a feature which is rare in the Nevada rhyolites, but frequently noticed in the dacites. In connection with these terminated quartzes, the groundmass is rich in fibrated sphærolites having a sanidin crystal as the sphærolitic nucleus. Tridymite occurs here in connection with the sphærolites, as it

* United States Geological Exploration of the Fortieth Parallel, Vol. VI, page 198.

does at Ombe Buttes. Along the eastern slopes of the mountains the lithoid varieties of rhyolite give way to half glassy and pearlitic forms. A prominent type of these is a gray, porphyritic mass containing imperfect dihexahedrons of quartz, sanidin, biotite, augite, hornblende, and magnetite, all embedded in a microlitic glass. Another form is a pale yellowish-gray glass, in which are quartzes, sanidins, and microlitic products of devitrification, the latter showing by their arrangement the fluidal lines characteristic of the rhyolite group. The association of porcelaneous rhyolites with rhyolites of a pearlitic groundmass rich in products of devitrification, and including sanidin and quartz which are themselves rich in glass inclusions, again recurs in western Nevada in Montezuma Range.

The westernmost rhyolites of the Goose Creek Hills pass under the Quaternary of Passage Creek. On the western side of this valley, occupying the northern hills of the Toano group, a body of rhyolite defines the western edge of Desert Gap. The hills rise 800 or 900 feet; but we have no means of judging the volume of the rhyolites, since they clearly overlie lofty spurs of Upper Coal Measure limestone. The rock has a purplish-gray color, and is noticeable for rough, drusy cavities lined with minute crystals of quartz. The groundmass, which is composed of stripes and bands of glass of two distinct colors, encloses the druses, and also the grains of quartz and small crystals of feldspar. More than ordinarily large lithophyses are seen.

Unimportant masses of rhyolite occur in the Fountain Head Hills and on the eastern base of the Tucubits Mountains in Holmes Creek Valley, the latter accompanied by dark obsidian. Rhyolites wrap around the southern end of the Tucubits Mountains south of Tulasco Peak, from which flow our specimens show a dark-brownish, rather loosely compacted, highly crystalline rock, with macroscopical quartz, sanidins, and biotites in a groundmass carrying a great deal of glass. Farther up the range, detached from the foot-hills, out of the Pliocene Tertiary rises a hill about 1,000 feet high, called Forellen Butte, in which the rhyolite is a grayish-drab, felsitic mass, carrying large crystals of sanidin and quartz, the whole being intimately brecciated, and the fragments themselves containing bits of an anterior breccia. It is distinctly an eruptive breccia, noticeable for the sharply angular character of the shattered fragments, both of the included hornstone-like rhyolite and of the broken crystals. The relation of the rhyolites, on both sides of the Tucubits, to the geology of the region is very simple. The range itself is a dislocated block of deep-lying Palæozoic rocks which have been brought to the surface by a sharp, powerful, local uplift, and the rhyolites appear along the lines of fracture which define the limits of the dislocated blocks.

A very important region of rhyolites is that lying southwest of the westernmost point of Salt Lake Desert, embracing the Wachoe Mountains, the little chain of buttes in the desert directly west, and the broad field which overflows the northern end of the Schell Creek Mountains and Antelope Hills. East of this, on the elevation which marks the southern prolongation of Gosiute Range, are also isolated tabular hills of rhyolite; and at the lower end of Deep Creek Valley, where the waters flow out upon the desert, is an interesting group of detached rhyolitic hills.

It is a noteworthy fact that in general Salt Lake Desert itself is so free from eruptive rocks, while as soon as the hill country to the west begins to rise toward the high plateau of central Nevada, every range is more or less broken through by volcanic outbursts, and in general the frequency and complexity of volcanic localities increases from Salt Lake Desert westward. In the region of the Wachoe, Schell Creek, and Gosiute mountains the rhyolites all come to the surface in the neighborhood of Lower Coal Measure limestones. In the Wachoe it is true they have flowed around the nucleal mass of Archæan granite; and in Kinsley District they are contiguous to Archæan granites and porphyries. Limited masses of andesite appear on the Gosiute and at the Wachoe; but in general the rhyolites come to the surface over what are the depressed summits of folded Palæozoic limestone ranges, which have been more or less dislocated and thrown down below the level of the neighboring ranges. Antelope Hills and the Schell Creek and Wachoe mountains show the subsided top of a range which to the south rises to quite lofty heights; and Gosiute Range—which from the region of Toano to the south has been a defined, elevated mountain chain—south of Mount Pisgah suddenly drops out of view; its axis, however, is defined by outflows of andesite and rhyolite. It is, therefore, the very reverse of the Tucubits region. There the mountain block of stratified rocks has been lifted above its natural level, and the rhyolites have broken out upon the flanks of the range, following the side fissures. In the case of the southern region, the ranges have gone down and the rhyolites have closed over their summits, covering the whole breadth of the mountain group. The Goose Creek Hills represent a third type of geological occurrence. With no particular depression or elevation of the range itself, the whole block has been riven with fissures, and the rhyolites have poured out, gradually accumulating over the elevated summits and spreading themselves out with a viscous flow down the flanks. The following are some of the varieties of rhyolite of the Wachoe region:

At Spring Cañon, Wachoe Mountains, occurs a hornstone-like, greenish-drab rock, including in the groundmass, granules of quartz and crystals of feldspar, but no mica; also angular porcelaneous fragments entangled in the matrix, which represent probably the débris of some subterraneously solidified rhyolite quite devoid of crystalline secretions. The groundmass, whose devitrification the microscope shows to yield both axial and central fibrations, is not only devitrified, but in some places decomposed, resulting in soft green spots, in the centre of which are sometimes earthy nuclei of carbonate of lime which readily effervesce with acids.

Another variety, also from Spring Cañon, is a brick-red, porphyritic rock containing white crystals of sanidin and prisms of hornblende, but no mica. Near the mouth of the cañon is a granitoid variety approaching nevadite, carrying abundant hornblende and feldspar, but showing no free quartz or mica. The sparing groundmass is of a leaden-gray color, richly microlitic under the microscope. The hornblendes are dark brown. There is also pale-yellowish augite, which the microscope shows to be penetrated with apatite prisms. All the crystalline inclusions except hornblende contain glass inclusions of unusual size.

Along the northern edge of the group, north of Spring Cañon, the rhyolites come directly in contact with the granite, and are also seen to overlie the andesites in immediate contact. This is one of the most admirable localities in our area for observing the contact between these two rocks, and here the rhyolite is unmistakably seen in direct superposition upon the original andesitic slopes. All these northern hills are exceedingly rich in varieties of rhyolite, both in color and texture. The rocks vary from mile to mile through a constant succession of changes. They have a variety of colors, shading through yellow, purple, black, white, and cream-color, and show all degrees of coarseness. For the most part they consist of a micro-felsitic groundmass rich in glass, carrying secreted crystals of varying size composed of sanidin, plagioclase, quartz, and hornblende, with occasional augites. There are also true pumices, besides glassy and half glassy rhyolites of brilliant tint. A characteristic form of the latter has a bright red groundmass in which are blood-red zones of porcelaneous substance which enclose granules of pellucid quartz and water-clear, cracked sanidins. This parallel banding of material gives an almost stratified appearance to the rock. The quartz of this particular variety is noticeable for the liquid inclusions with movable bubbles which were detected in it by Zirkel.

From the broad mass of Antelope Hills an interesting type was collected adjoining the marble hills on the south. It is a porphyritic variety of a bright, brick-red color, with compact, white feldspars, quartz, and hornblende, the groundmass being essentially felsitic. The quartz, which at times is seen grouped in lenticular masses, also lines the interior of druses with brilliant crystals.

On the ridge south of Leach Springs is a rhyolite showing the characteristic fluidal structure of the group, the fine microlitic groundmass containing large hornblendes, tridymite, and apatite.

Properly included in this region are two masses of rhyolite, one to the north of Mahogany Peak, in the northern end of Egan Range. Here, as may be seen from the lower section at the bottom of Map III., the rhyolite bursts through a slightly faulted anticlinal, occupying an axial position extending about six miles north-and-south.

Again, through the limestone of Ruby group, at an interesting locality called by Mr. Emmons "the Beehives," is an eruption of a white, rhyolitic tuff. This, like the Egan Mountain outburst, comes through a fold of the Wahsatch limestone. Although a characteristic tuff, it was probably erupted in a muddy condition, its ejection accompanied by a great deal of water, but there are no signs of the tuff having been rearranged in aqueous strata.

The outcrops are interesting high knolls, whose surface is covered with pits from which the once included blocks of solid white rhyolite have dropped out, leaving a marking like the top of a thimble. The tuff is light-gray and creamy, with fine white spots of kaolinized feldspar, and dotted with hexagonal plates of biotite and small crystalline fragments of quartz. The unaltered fragments contain, in a drab, felsitic groundmass, crystals of sanidin, fine flakes of biotite, hornblende, and large pellucid quartzes.

The northern part of Humboldt Range has suffered severe dislocation and fissuring. A prominent line of dislocation is Sacred Pass, which crosses the range obliquely in a northwest-and-southeast direction. Near the western base of the range, at one end of this depression, is an outburst of peculiar earthy, green rhyolite. The valley of Clover Cañon also has at its head a disturbed region which is walled in eastward by a sort of thumb of Archæan rocks, which projects from the main ridge at Clover Peak. Here, in the angle between the thumb and the hand, as it were, is an outburst of very peculiar rhyolite. It is as black as a basalt, the groundmass being a dark-brown, nearly black glass, rich in feldspathic and augitic microlites, and carrying as macroscopic secretions sanidin, plagioclase, augite, and free quartz. The quartzes are of a brilliant olive-green, and at the first glance resemble the cracked grains of olivine in certain of the basalts that are rich in that mineral. The cracks, which traverse the quartzes in every direction, are filled with and defined by a dark-yellow, earthy ochre, besides which there are no inclusions. Both feldspars, however, are surcharged with half glassy inclusions. This is another interesting instance of the association of augite and quartz, the two minerals of all others characteristic of the two opposing chemical types of volcanic rock.

The rhyolite at the northwest end of Sacred Pass breaks through and overflows the fossiliferous limestone of the Lower Coal Measures, and also abuts against the Archæan foot-hills to the north of the pass, and is overlaid by the horizontal Pliocenes of Humboldt Valley. This rock is a pale-green and pale-olive rhyolitic tuff, inclining to a chalky whiteness in some specimens. It has a little free quartz and sanidin, in a base which has suffered globulitic devitrification. Some of the tuff is fine-grained and compact, showing no macroscopical secretions. Although a large part of the feldspars are kaolinized, there is no indication of stratification-planes or other proof of its having been laid down in water.

Decidedly the most remarkable volcanic feature in the whole field of this Exploration is the great train of rhyolite ranges forming a system having a northeast-and-southwest trend, and occupying Augusta, Fish Creek, Shoshone, Toyabe, Cortez, Seetoya, and parts of Piñon ranges and the Mallard Hills, and extending in the direction of the trend both north and south of our area of exploration. Here is a group of half a dozen ranges, of which the predominating rock is rhyolite, the whole constituting a belt explored by us for over 200 miles in length and from 45 to 80 miles in breadth. The greatest of the orographical features of the far West is Sierra Nevada Range, and at the period of the rhyolitic ejections a series of outflows followed closely the axis of that long line of elevation. In this great middle-Nevada chain of rhyolites the trend is almost exactly perpendicular to that of the Sierra Nevada, a relation which has its origin in the most impressive geological events of which we have any record in the whole West, namely, the great series of mountain folds which occurred at the close of the Jurassic age, defining the strike of the Sierra Nevada and the series of northeast-and-southwest ranges in Nevada, whose trend approaches a perpendicular to that of the Sierras. The great central-Nevada rhyolite belt has another connection which it is interesting to note here. It lies along the western margin of the exposure of Palæozoic rocks. Beyond this chain of rhyolites the Palæozoic series are wanting, and the Triassic and Jurassic rocks rest directly on an Archæan foundation. As was seen in a previous chapter, between the area of Palæozoic and Mesozoic rocks at the close of the Carboniferous a tremendous fault occurred here. The region of that enormous dislocation which had been subsequently thrown into folds at the close of the Jurassic period has given vent to the vast volcanic outflows of the Tertiary. A glance at the analytical map of the Tertiary volcanic rocks at the close of this chapter will suffice to demonstrate the importance of the belt here noticed.

The Mallard Hills, north of Humboldt River, between the meridians of 115° 15′ and 115° 45′, are altogether made up of rhyolitic flows; and with the exception of the andesites of Egyptian Cañon are surrounded by horizontal Pliocene beds. The highest points of the hills rise about 2,000 feet above the surrounding Tertiary valleys, and the general configuration of the surface is that of broad ridges gently sloping from a culminating central region. There is nothing crater-form about the middle elevation. Like many rhyolites, this bears abundant evidence of true fluidity at the period of ejection. Structurally, the Mallard Hills occupy a position analogous to that of the Wachoe and Schell Creek mountains before described.

Elko and River ranges, which have a northeast trend, are suddenly broken off, the continuity of their Palæozoic uplift is lost, and the northern continuation depressed to an unknown depth. Over this gulf (which is clearly proved by the low altitudes from Bone Valley southeastward through Egyptian Cañon in a line to Deeth Station) have flowed the eruptions of rhyolites, the whole depressed region building up to a height even superior to the normal altitude of the Palæozoic uplifts. Several petrographical varieties have been observed among these rhyolites. That from Deer Cañon, on the northeast point of the hills, has the habit of splitting into thin laminæ, from half an inch to an inch in thickness, precisely like some of the Elk Head quartziferous trachytes. The rock consists of a light lavender and gray felsitic groundmass, carrying fairly defined, impure sanidins and large rounded globules of quartz the size of a pea, having the characteristic interior net-work of cracks and an exterior ring which is a granular modification of the groundmass. Neither among the crystalline secretions nor in the finer elements of the groundmass is there any biotite or hornblende. The central summit of the group is composed of a rock of similar type, often showing the same tendency to split into laminæ. The general color of the type varies through shades of brownish red and dull, pure red. The groundmass, which has a somewhat trachytic appearance, under the microscope proves to be highly sphærolitic. Well developed sanidins and large, cracked globules of quartz are present in the groundmass, but there is neither mica nor hornblende. The rock is of varying compactness, sometimes occurring in exceedingly porous, almost scoriaceous forms, the cavities being lined with botryoidal secretions of chalcedony and dark-brown, nearly black glass. The northern end of this group of mountains, on the watershed of Snake River, yields some pure-white porcelaneous rhyolite, with a remarkable conchoidal fracture and a vitreous lustre.

Below the andesite mass of Egyptian Cañon, rhyolitic spurs close in upon either side of the river, showing purplish porphyritic types which do not differ mineralogically from others of the group. So, too, along the eastern slopes of Bone Valley, modifications of the main type were collected. At the very southern end of the group, overlying the quartzites at Peko Peak, is a dull-gray rhyolite, also devoid of hornblende and biotite, but closely resembling some of the older felsites. It contains chips and fragments of chalcedony, but the microscope shows it to contain an enormous amount of ferrite.

The southwestward continuation of this group appears in a little isolated hill west of the North Fork of Humboldt River, completely surrounded by horizontal Pliocenes. It is very compact, almost earthy in texture where decomposed, but where preserving its original characteristics is a white porcelain. It contains very minute but distinct crystals of quartz, which are chiefly smoky, a few feldspars, and hornblendes, the microscope adding biotite.

Normal biotite-rhyolite occurs directly north of the river at Osino Cañon. It is rich in crystalline ingredients, having almost the characteristic habit of nevadite, and contains sanidin, biotite, and quartz.

A singular development of rhyolite is observed directly north of the coal mine near the mouth of Penn Cañon, River Range. The main mountain slopes are here formed of quartzitic beds of middle Coal Measure age. The strata are mainly formed of a peculiar brecciated material, in which the larger part of the fragments are sharply angular, while others are subrounded. The rhyolites which overlie these spurs bear a singular likeness to the brecciated quartzites. They have an earthy, felsitic groundmass, in which are crowded angular fragments of a highly siliceous material, which cannot be distinguished from broken pieces of the neighboring impure quartzites. One may trace almost a continuous passage from these angular rhyolitic breccias to the angular quartzitic conglomerate. It is certainly a very perplexing occurrence, and may possibly be accounted for by the invasion of a region of these shattered, angular quartzitic fragments by an exceedingly fluid, porcelaneous rhyolite, there being just enough of the magma to permit a quasi flow. On the other hand, there is nothing absolutely characteristic in the included fragments of the rhyolitic breccias, and they themselves may be the deep subterraneous fragments of a solidified felsitic rhyolite, free from crystalline secretions, which was shattered in the depths and brought to the surface after the ordinary manner of breccia eruption, in which case the similarity of these fragments to the angular material of the neighboring quartzites would be simply accidental. I incline to the former view—that the fragments are identical; that in one case they are simply held together by the sedimentary cement; and that in the other they have been floated off in a small amount of eruptive matrix.

Among the rhyolites of this locality are very interesting homogeneous felsitic passages, brilliantly striped and banded with an extraordinary array of colors—red, brown, and yellow alternating with gray, white, or pale lavender—the mass closely resembling some of the earlier clay-stones which were the clastic eruptions of felsite-porphyries.

South of Osino Cañon, with the exception of a small amount of quartzites which outcrop on the southern wall of the cut, the heights for eight or ten miles to the south, indeed the whole range from side to side, is occupied by an overflow of rhyolites which possibly represent but a thin sheet of material over the Palæozoic ridge. The most interesting feature of this rhyolite is certain breccias at the southern end of the group, which are composed of innumerable angular fragments of a fine-grained, compact, felsitic matter, carrying brilliantly clear quartz grains, the whole held together by a rhyolitic magma not very different from the fragments in character. Besides this, it is traversed by wandering veins of chalcedony to such an extent that often a quarter of the rock is made up of its milky, translucent material. There are no biotites or hornblendes, but with the white quartzes are well crystallized sanidins.

Seetoya Range, south of the parallel of 41° 15′, is another of those ridges in which the original mountain mass has been depressed and its place filled with rhyolites. The granitic tops of Maggie and Nannie's peaks, and the heavy limestone body around the former, are summits of the earlier range which have remained lifted above the rhyolitic flows.

Connected with a part of this same eruption is the body of rhyolites on the western side of River Range, bordering upon Susan Creek. In the latter group of hills are two distinct types of rhyolite. The first, a light-gray tufaceous rock, not unlike that near Penn Cañon, has a rather porous, earthy groundmass, containing scattered crystals of sanidin and quartz. An unaltered rhyolite of the same neighborhood shows a semi-vitreous, light-gray porcelaneous mass very poor in crystalline secretions, a few isolated grains of quartz being the only ones seen. North of the andesitic body, on the divide between Susan Creek and North Fork, is a dark-gray variety, having a brownish groundmass rich in ferritic needles, which contains a multitude of biotites and hornblendes, the latter of a peculiar rusty-red color. In this rock are contained innumerable balls about an inch in diameter which are made up of distinct feldspar, quartz, hornblende, and occasional biotites in a vitreous base.

The Palæozoic mass about the granite of Nannie's Peak is completely surrounded by rhyolites, and an interesting dike, west of the peak, cuts through the limestones for eight or nine miles, showing a nearly continuous exposure. The weathered surfaces resemble older felsitic porphyries. The rock itself is a yellowish-gray felsitic groundmass, having a ragged, granitoid fracture, inclining sometimes to a greenish color, and passing gradually into a pearlitic, glassy modification, containing highly vitreous sanidins. Under the microscope this groundmass shows rudimentary sphærolites. The macroscopical secretions are large crystals of hornblende and quartz, and a little biotite.

Farther south, in the neighborhood of Maggie Peak, where the rhyolites come in contact with granite-porphyries, they closely resemble them in petrographical habit, their compact, white, felsitic groundmass containing only crystals of quartz and showing interesting botryoidal secretions of hyalite and opaline chalcedony.

In the region of Piñon Pass, latitude 40° 15′, the eastern base of the mountains, as well as the lofty ridge northeast of Piñon Pass, is composed of rhyolite which has come to the surface through a fissure that was a southward prolongation of the line of break characterized by trachytes to the north. It is a light, earthy rhyolite of rather trachytic texture and habit, the groundmass rich in ferrite, containing numerous large, finely formed dihexahedral quartz grains, some more or less earthy, kaolinized sanidin, and a high proportion of flakes of black biotite. With the exception of the latter mineral, the crystalline secretions are not evenly distributed through the groundmass, but are gathered in important accumulations or bunches, ten or fifteen large feldspar grains grouping themselves together. In the whole series of rhyolitic outbursts examined, there is no rock which is at all comparable with this for the proportion of shining black biotite. The groundmass is singularly devoid of glass, and the whole habit of the rock is precisely like that of trachyte, with which species it might be classed but for the abundant presence in the groundmass of microcrystalline quartz.

Twelve miles farther south, also on the eastern base of the range, in contact with Devonian limestone, is a limited rhyolitic outflow without any important petrographical characteristics.

South of Pine Nut Pass, where Piñon Range reaches the southern limit of our map, is a body of rhyolite (not within our area) which is of some petrographical importance. Its peculiarity is the groundmass, which has a highly developed crystalline-granular structure closely resembling the granite-porphyries. In this respect it is only inferior, among American rhyolites thus far studied, to the nevadites of Lassen's Butte, which are altogether made up of individualized crystalline secretions, held together by an exceedingly minute amount of nearly colorless glass base. Here the groundmass consists of pellucid quartz grains, more or less rounded crystals of feldspar, a little brown biotite, and ferrite grains. An interesting accessory mineral is pure, bright garnets measuring two tenths of a millimetre in diameter.

A noteworthy group of rhyolites is that exposed in the middle of Cortez Range, north of Cortez Peak, extending eight or ten miles north of Carlin Peaks, and embracing the broad volcanic outflow north of Palisade Cañon, including also the flows south of Carlin which occupy the heights of a portion of Piñon Range. This is essentially one group. In the region of Carlin Peaks isolated summits of the earlier limestones show that this, like almost all the other rhyolitic bodies, was a predetermined range. The same is true south of Cortez Peak, in Cortez Range, where the high masses of Palæozoic and granitic rocks form conspicuous summits. The northern end of the Piñon also shows an elevated region of Palæozoic rocks. It is in the intermediate depression, where the older ridge had suffered an unusual subsidence, that the great group of volcanic rocks—propylites, andesites, trachytes, rhyolites, and basalts—has burst out.

At Carlin Peaks, in contact with the detached Palæozoic outcrops, the rhyolite forms high, table-topped mountains composed of the ordinary red porphyritic variety, similar rocks extending south to the head of Nannie's Peak and covering the western part of the range in long slopes as far south as the Emigrant Road. These rhyolites, in passing southward, have more and more of a trachytic habit, but may be distinguished from the earlier trachytes by the abundant presence of free quartz. Near the Emigrant Road, the rhyolites are reddish-gray rocks containing no macroscopical inclusions except a few sanidins and plagioclases. A characteristic of the rock here is the occurrence of numerous small cavities lined with a light-gray crust made up of thin, variously colored layers of hyalitic material.

Near the northern end of the Cluro Hills are rhyolites of peculiarly shaly habit, splitting into laminæ only half an inch thick, the whole abundantly stained with iron oxyd. Fresh fractures show a compact, felsitic groundmass containing quartz and sanidin.

The most interesting rhyolites of this group are those occupying the summit of the range a few miles north of Cortez Peak. Here is a lofty ridge of rhyolites which descend very rapidly to the depressed plain on the west Deep cañons scored through this mass show rough, tabular flows piled one upon another in rather trachytoid habit as regards their geognostical characteristics. This eruption skirted the western edge of the ridge in a narrow line, flanking the earlier volcanic rocks almost as far north as Palisade Cañon. The general colors of the rhyolites of this group are buff, green, and purple, and they are largely composed of breccias, of which many of the included fragments are of delicate, apple-green color, having a general felsitic groundmass, including decomposed feldspars and numerous angular and rounded quartz granules, the latter having a peculiar botryoidal surface like hyalite. The fragments vary from the size of a pea to that of a mustard-seed. The general material in which the green breccia fragments are embedded is a yellow and cream-colored rhyolite, the groundmass being in an imperfectly crystalline state, rich in ferrite, containing numerous feldspars which are all more or less kaolinized, and quartz in beautiful dihexahedral crystals and sometimes in simple angular fragments. These quartzes are peculiarly surrounded by a fine siliceous glazing, so that the cavities out of which the quartz has fallen present a smooth varnished surface. There are also in the yellowish or purple groundmass of the including rhyolite, rounded quartz pellets with botryoidal surfaces like those of the included green fragments.

With the exception of certain purely foreign fragments picked up along the walls between which the various volcanic eruptions came to the surface, such as fragments of limestone in trachyte or bits of Archæan granite in rhyolite, it is a common characteristic of all the breccias that the included fragments and the matrix which contains them are of identical material, the two usually showing the minutest petrographical identity.

The dacites of Cortez region are breccias containing dacitic fragments, and the feldspars of both the included fragments and the matrix have suffered precisely the same form of decomposition, resulting, among other products, in a fine crystalline cover of calcite. Here in these rhyolites this very unusual form of distinct botryoidal surfaces of the quartz is common to the fragments and the matrix.

The northern point of the Wahweah Mountains falls within our field of observation, and, like the southern termination of the same group, is characterized by the presence of a small outflow of rhyolite. It has a purplish-gray, crystalline groundmass, consisting of colorless quartz-particles, feldspars, and macroscopical plates of bronze mica. The crystalline inclusions are large, fresh biotites, brown, smoky quartzes, and feldspars, of which a comparatively large number are plagioclases.

The high northern body of Shoshone Range, culminating in Shoshone Peak, slopes to the southeast, throwing out long foot-hill ridges, which are overlaid by a broad zone of rhyolites that reappear east of Carico Lake on the northern slopes of Carico and Railroad peaks, the whole forming a distinct group only separated from each other by the shallow Quaternary valley which carries the drainage of Carico Lake northward through Rocky Pass into Crescent Valley. The rhyolites of what may be called the Carico district are of two distinct types. The earliest outflows are white and creamy tuff-deposits, which are seen immediately west of Carico Lake, and in a cañon about four miles north of the lake, which leads out from the Shoshone Mountains. The groundmass is finely microcrystalline, the only macroscopical secretions being sparing quartz, and feldspars which have undergone kaolinic decomposition. There is no biotite or hornblende. Although the rock shows few planes of stratification, it is probably a subaqueous eruption which poured out into a lake formerly occupying Carico and Crescent valleys. It bears a close resemblance to some of the Miocene trachytic tuffs found north of the Kawsoh Mountains. Here, however, there seems to be no admixture of foreign clastic material, the microscope showing the main mass to consist of fragments of a microcrystalline admixture of quartz and sanidin. It is characteristic of some of the finer-grained rhyolitic tuffs that they show no planes of stratification. The absence of plates of biotite or of tabular hornblendes, which in the act of sedimentation would lie flat, leaves the homogeneous material without any indications of bedding. Probably not over eighty feet of these tuffs are seen. They only appear at wide, irregular intervals, and may possibly be direct ejections of rhyolitic mud. They are, however, on pretty nearly a common level, and that is the sole indication of their having been rearranged by lake waters. Over these the whole border of the range shows a powerful outflow of purple porphyritic rhyolite, with a coarsely crystalline groundmass, carrying but a small proportion of glassy base, the crystalline secretions being very coarse and numerous. The general habit of the groundmass is rather trachytic and crumbling, and the secretions embrace broken crystals of sanidin, small plagioclases, large pellucid quartzes, and some biotite. It is not often that two more distinct types of rhyolite than these white tuffs and the dark purple variety are found thus contiguous.

North of Railroad Peak the rhyolites reach an elevation of 1,500 or 2,000 feet above the valley, presenting the general appearance of rugged granitic hills. Here are numerous high conical and pinnacled forms with precipitous sides, but showing around their bases little disintegrated or earthy débris.

One of the most extensive single groups of rhyolite within our area is that which projects north from the Shoshone Mesa to the northern limits of our map, defining at the north the powerful line of Owyhee Bluffs, together with the broad plateaus which form its eastern and western prolongations. Here is a field of rhyolite, roughly triangular, extending about fifty miles from north to south, by forty miles from east to west. It consists chiefly of three elevated regions, each having a northeast trend: that of the Shoshone Mesa itself, the ridge which separates Rock Creek from Squaw Valley, and the Owyhee Bluffs. The two depressions in this triangle are occupied by horizontal Pliocene beds. The interior drainage of the group passes through these two valleys, delivering the outflow through Rock Creek into the Humboldt. This entire field is surrounded by Quaternary plains, with the exception of a narrow isthmus which unites it with Cortez Range in the locality of Soldier Creek and Tuscarora. In the latter region, lifted above the rhyolites, are the detached outcrops of a quartzite range, the main rhyolitic field occupying a region west of the Cortez and north of the Shoshone. On the geological maps, it will be seen that the powerful Shoshone Ridge and the lofty Palæozoic mass of Battle Mountain drop down abruptly beneath the Humboldt Valley, and do not reappear to the north, the only elevation being the great rhyolitic field. This is but another instance of the frequent mode of occurrence of the rhyolites in regions of deep dislocation and depression.

In the Tuscarora region, where the rhyolites have overflowed propylite and andesite, they are usually white varieties which show a great deal of kaolinic alteration, feldspars being the only crystals macroscopically visible, though the microscope shows minute altered biotite and hornblende, together with more or less quartz. On the foot-hills a few miles north of Tuscarora, the rhyolites are a dark, reddish-brown body, having the field habits of andesite, although composed exclusively of sanidin and remarkably regular hexagons of biotite, together with a few granules of quartz in a dark, compact, felsitic matrix.

South of Tuscarora, where the rhyolites overflow a body of augite-andesite and constitute the foot-hills along the southwestern portion of Independence Valley, is a white porphyritic variety, the felsitic ground-mass having suffered considerable kaolinic decomposition, and the crystalline secretions consisting of biotite, quartz, and sanidin.

A white amorphous rhyolite extends up on the eastern slope of Mount Neva to its very summit, and covers considerable slopes toward Owyhee Valley.

A rock to the west of Mount Neva, which overflows the base of the quartzitic hills, is of quite a different petrographical type. It is a dark-gray mass of pearlite occurring in rude columnar structure. A pale-gray color characterizes the glass base, which is rich in microlites of varied forms. The crystalline secretions, which are exceedingly numerous, are of sanidin, biotite, a little plagioclase, and considerable free quartz.

The broad ridge of Owyhee Bluffs, culminating in Mount Rose, 7,949 feet above sea-level, displays remarkably well the flowing structure from which the name "rhyolite" is derived. The mountain is made up of thin sheets of rhyolitic lava, often no more than one eighth of an inch thick. The mass has a compact felsitic matrix containing only quartz and sanidin. The surface of each of the fine rhyolitic layers is coated with a dull-red earthy substance of ferritic nature, in which are entangled a few flattened crystals of sanidin. Among the flows on the southern slopes of this peak is an interesting rhyolite breccia. The included angular fragments, pink and red, are of rather earthy rhyolite, having sharp, rectangular outlines, with chips varying from half an inch to an inch in diameter. It is characteristic of all the enclosed fragments that they possess the fine parallel fluidal structure which gives them the aspect of woody fibre, so that the rock has much the appearance of inlaid woods, with the grain of different pieces running in different directions.

In the lower foot-hills near Squaw Valley are dark pearlites, containing quartz and sanidin, with microscopic augite. An interesting characteristic of this occurrence is the presence of inclusions formed of grouped granules of dark-green crystalline aggregations very rich in olivine, which is associated with tabular plagioclases and brown augite, the base rich in globulites and titanic iron. East of this, at Sunset Gap, near the western edge of Squaw Valley, is a similar pearlite, interbedded with a rhyolite of purely lithoid type, rich in crystals. The white porphyritic rhyolite, whose groundmass is essentially earthy, contains black hornblende, sanidin, quartz, and biotite, while the intercalated pearlitic beds are predominantly vitreous, but contain also, besides sanidin, a little plagioclase and augite.

On the summit of the ridge which divides Squaw Valley from Rock Creek Valley are banded gray and red rhyolites, alternate bands consisting of the reddish felsitic groundmass and of aggregations of sanidin and quartz crystals, the layers of groundmass showing under the microscope an abundance of ferrite and sphærolites.

A noticeable variety of rhyolite occurs near Warm Springs, where the rhyolites west of Rock Creek Valley pass under the Quaternary of the Plains. It is pearl-gray, rich in small gray, glassy sanidins and large rounded quartz globules intricately cracked, besides which the microscope shows an unusual abundance of tridymite.

Shoshone Mesa itself presents sharp cliffs to the south, east, and west, rising 2,000 to 2,400 feet above the surrounding plain. The lower foot-hills, extending perhaps half-way up the slope, display rhyolites which are overlaid above by a continuous field of basalt. These rhyolites are usually dark-purple and thinly bedded, composed of a groundmass which is rather microcrystalline than microfelsitic, showing little fibration except around the larger crystals It includes plagioclase, considerable apatite, quartz, and large crystals of sanidin. Associated with the last mentioned variety is a peculiar dark pearlite, rich in lithophyses an inch in diameter. In the black glassy matrix are abundant crystals of sanidin and quartz. In the immediate vicinity of the large lithophyses, the glass loses its dark color and is nearly white. The nuclei of some of the lithophyses are noticeable for central groups of quartzes and sanidins. The microscope adds biotite, hornblende, and augite to the list of crystalline secretions. Sphærolites an inch in diameter are richly distributed through the gray groundmass, which upon decomposition develop the well known concentric structure and in the most advanced stages reach the condition of lithophyses.

About a mile back from the edge of the cliff, on the eastern side of the

Mesa, a considerable hill rises above the level of the basalt field, which has a general semicircular shape, and suggests the broken outlines of a crater. The rock is the same pearl-colored rhyolite found at the western base of the hills near Warm Springs. It is less richly crystalline than the rhyolites farther down on the slope, and, like the other pearl-colored rhyolite, contains large amounts of tridymite.

As a whole, therefore, this group displays three types of rhyolite: the pearl-gray variety, poor in crystalline secretions but rich in tridymite; the dark pearlites, which are characterized by more or less sphærolites and their decomposed relics, the lithophyses, and usually more or less augite; and lastly the ordinary typical rhyolite, rich in crystals of sanidin, and cracked quartz granules, together with a little plagioclase and occasional biotite.

Passing southward from Shoshone Peak, the lofty masses of sedimentary rock which have formed the upper portions of the range begin to disappear, and the continuation of the ridge is in great part made up of rhyolites. The deep pass through which Reese River flows, and which severs the range into distinct halves, shows but little of the sedimentary rocks in the cut, which is evidence that they are sunken relatively below the corresponding northern portions of the range. Here again, as we have seen previously, the rhyolites come to the surface where the rocks are comparatively depressed.

The low ridge of the Mount Airy hills and the pass leading from Reese River Valley, near Jacobsville, to Lone Hill Valley, still further show that the main underlying body of Palæozoic rocks has gone down. The ranges of this immediate region have been dislocated into irregular blocks, these blocks or sections have been left at a variety of altitudes, and wherever the bodies have subsided lowest, there the lines of fracture seem to offer the easiest exit to the volcanic materials. As a consequence, the rhyolite has built up enormous piles. Were it not for an occasional deep pass through the range, exposing the full thickness of the rhyolite, we might suppose that the underlying skeleton of Palæozoic rocks was continuous, and at a comparatively high level; and that the rhyolites were mere thin covers which outflowed over them. But in view of the profound passes which cut the ranges sharply through, showing no stratified rocks, and when we further consider the abrupt terminations of the blocks into which the Palæozoic ranges have been broken, such as occur north of the Dome in Toyabe Range and north of Shoshone Peak in Shoshone Range, it is evident that the great rhyolitic regions, with their enormous massive eruptions, do really represent areas where the Palæozoic blocks have gone down. Certain of the valleys of this great rhyolitic region are covered with a thin group of Quaternary and Lower Quaternary formations superposed upon the rhyolitic slopes. Others, as those seen about the margin of the upturned Miocene, are not underlaid by rhyolites, but the volcanic rocks are confined to the actual mountain ranges. The prevailing petrological type in Shoshone Range north of Reese River Cañon, especially in the neighborhood of Hot Springs, is a variegated rock passing from purple and gray into reddish, lilac, and rusty-buff colors. The groundmass is microfelsitic, showing under the microscope a characteristic rhyolitic habit. The macroscopic minerals are sanidins, a few plagioclases, large abundant quartzes, and rare, partially decomposed biotites.

Among the most interesting forms are those which skirt the foot-hills of the Ravenswood mass, where they descend to the cañon through which Reese River traverses the range. Here is exposed a series of rhyolitic breccias mostly purplish-gray and bluish-gray, ordinarily without free quartz, and of a loose, almost tuff-like texture. Among the lower members, and especially those of lighter colors, the orthoclases are decidedly kaolinized, and the material is probably one of those eruptions of mixed volcanic mud and breccia. This is not the sole instance in which the lower exposures, indicating earlier eruptions of rhyolite, are either breccias or tuffs. Not a little of the rhyolites poured into and was ejected under the fresh-water lakes which covered the Nevada lowlands during the Pliocene age. The breccias are altogether made up of rhyolitic material. The fragments which are enclosed in the looser and more friable matrix are uniformly of rhyolite. Some of these included fragments are themselves made up of a rhyolitic breccia, the fine felsitic material of the blocks being cemented by a still finer-grained microfelsitic groundmass. Among the gray, earthy, kaolinized breccias are frequent brilliant, undecomposed biotite crystals.

Interesting rhyolite breccias occur along the eastern base of the Ravenswood mass, resembling the compact rhyolitic tuffs found near Elko and the Penn Cañon coal mines. The included fragments are in general of a finer felsitic paste, containing granules of quartz and occasional crystals of feldspar. They are always sharply angular, and are cemented together by an almost chalcedonic magma. Associated with these are equally fine grayish-purple, hornstone-like varieties, of which the finer included fragments are used for flints by the Indians. The surface is largely covered with chips in which the proportion of silica must run considerably above 80 per cent.

West of the Archæan body that forms the central core of the southern portion of Shoshone Range are red and purple rhyolites which are highly crystalline, containing fine granules of quartz in great abundance, large glassy sanidins, and occasional micas. Along the western skirts of the range are the same ashy-gray volcanic tuffs and cream-colored beds which have been previously described in the region of Carico Lake. This is evidently where the western margin of the rhyolite flows came to the surface under the fresh waters which formerly occupied Lone Hill Valley.

Farther south, the western flanks of a little group of hills known as Jacob's Promontory are formed of dark-gray rhyolites having a marked resemblance to the neighboring andesites. This resemblance also appears in the microscopic examination, since the groundmass is a felt-like aggregation of microlites. They are, however, of monoclinic feldspar, and the larger secretions are also of sanidin. Besides these, free quartz and very perfect dark-green hornblendes occur, the latter having the dark border characteristic of the andesite family. This is another example of a fact frequently noticed by Messrs. Hague and Emmons and myself, namely, that in nearly all cases where several volcanic species occur together, each one possesses some leaning toward the types of the others; as at Washoe certain of the plagioclase-trachytes, andesites, and propylites bear a striking resemblance in the relation of their secreted minerals to the groundmasses, by which the resulting porphyries are puzzlingly similar.

The hills in the neighborhood of Mount Airy illustrate again the succession of gray, earthy tuffs, breccias, and solid crystalline rhyolitic flows. At the bottom are mauve, yellow, and gray tuffs, containing a few particles of feldspar more or less kaolinized, bits of black glass, and occasional but rare crystals of biotite. Above these are hard, brittle, felsitic rhyolite breccias, of which the fragments are always angular, and above is a series of reddish rocks characterized by abundant quartz and sanidin, with very little mica. Much of the quartz is smoky or wine-colored, and is surrounded by a peculiar opaque, white, earthy coating. This succession of rhyolites, having a total thickness of 300 or 400 feet, is arranged in beds with a distinct inclination to the east. It is a rule that nearly all rhyolites observed in ranges of any considerable altitude, and wherever the bedding is at all appreciable, are seen to dip toward the nearest plain. Not unfrequently the edges of these beds appear in a rather sharp escarpment, as if a vertical fault had cut them.

North of Mount Airy a series of hills connects Shoshone Range with the Desatoya group. They are entirely made up of rhyolites, with a distinct bedding which inclines toward the west. They belong therefore to the system of Shoshone outflows, and are made up of alternating beds of dark, pearlitic rhyolite, almost obsidian, and earthy, crumbling varieties poor in large crystals. The glassy beds are from ten to twenty feet thick. Such alternations of distinctly glassy and thoroughly crystalline material are not the least difficult of the problems of volcanic geology. In this case, a few sanidin, quartz, and plagioclase crystals which occur in the glassy mass contain abundant microscopic inclusions of the main glass magma, while the crystals of the less glassy forms are decidedly poorer in glass inclusions. Through the whole range of glassy, half glassy, and distinctly crystallized rocks, the proportion of glass inclusions in the crystals bears a pretty direct relation to the amount of glass base present in the rock.

That portion of the Desatoya Mountains within our field consists of a central elevation of Triassic rocks accompanied by ejections of diorite, this limited body being entirely surrounded by, and all the rest of the range being completely submerged beneath, wide fields of rhyolite. In direct proximity to the diorite, the rhyolites occur as a light-green breccia, containing much half glassy material approaching pumice in texture. With this is associated another type, also a breccia, which has large crystals of biotite and quartz, a yellowish-gray hornstone-like groundmass, containing biotite and apatite, and large, well developed sphærolites, between which are axially fibrous felsitic bands. To the south of these breccias is a red, more compact rhyolite, containing blocks and fragments of the light-greenish rhyolite above mentioned. Here are seen the same large dark-yellow sphærolites. Along the western foot-hills of the groups are dark-red porphyritic varieties, noticeable for the large proportion of apatite they contain. On the other hand, those along the eastern foot-hills are noticeable for their abundance of limpid quartz full of remarkably large glass inclusions.

The most satisfactory display of rhyolites in the Desatoya Mountains may be obtained at New Pass, which opens a walled gorge across the group of hills. Here are displayed not less than 1,000 feet in thickness of rhyolites. In the middle of the pass the type is a breccia, white and green below, with pinkish and reddish colors above. The lower green breccias are quite like those near the diorite body farther north. They are characterized by the presence of pumiceous fragments of a brighter green, and carry quartz, sanidin, and a little plagioclase. The large proportion of glass in these breccias offers a most inviting field for microscopical research. A full account of their interesting details may be found in Volume VI. The green rhyolitic breccia occurs again at the eastern end of the cañon, but is here wonderfully rich in free quartz, which composes fully one third of the mass Along the west of the breccias is a later, solid porphyritic rhyolite containing quartz and sanidin, in a groundmass very rich in glass. The sanidins are noteworthy for their property of labradorizing. The sky-blue color, more brilliant even than the labradorizing orthoclases of Fredericksvärn, is entirely free from those minute bodies interposed between the laminæ of feldspar, which in the case of the labradorite in the Norwegian occurrence have been supposed to account for the remarkable optical properties. In the Fortieth Parallel limit this labradorizing sanidin is confined to an area comprising the rhyolites of the Pah-Ute, Desatoya, and Augusta mountains. Outside of that it has not been noticed, but within this comparatively narrow limit it occurs very frequently, and might be considered one of the characteristics of the rhyolites of the region. This sanidin contains soda in almost equal percentage with potash.

Of the Augusta and Fish Creek mountains, which form one distinct range of elevations, about a twentieth of the exposure is of ante-Tertiary rocks — granites, Triassic limestones, porphyries, and diabases; the granite probably Archæan, and all the rest not later than the close of the Jura. With this very slight exception, the entire range is covered with rhyolites which not only serve to mask the earlier underlying formations, but are themselves piled up to an extraordinary thickness. Viewing the range in profile from the western side, there are four prominent masses: that of the Fish Creek group, of which Mount Moses is the dominant peak; the Boundary Peak mass; the hills to the north of Shoshone Pass; and the high summit which lies between Shoshone Springs and Antimony Cañon. At the last named locality, the edges of rhyolitic beds which are seen gently inclined to the northeast, show an exposure fully 6,000 feet thick, and the Boundary Peak and Mount Moses bodies are not likely to fall much below this amount. It is quite safe to say that the whole of this range is covered with a body of rhyolite from 2,000 to 7,000 feet thick. The exposure is nearly 100 miles long by from 12 to 20 miles wide. The inclination of the rhyolite tables, where any bedding is apparent, sometimes reaches as high as 15°; as, for instance, on the ridge between Antimony Cañon and Shoshone Pass. When we reflect how great must have been the orographical disturbance connected with the Basaltic period altogether subsequent to that of the rhyolites, it would not be strange if the bedded rhyolites which represented the successive flows of that period were thrown into a dip considerably in excess of that of the natural angles of flow. It will not do, therefore, to assume that so high a dip as 15°, which is frequently to be seen in the Augusta Mountains, represents the natural angle at which the sheets of rhyolite flowed out.

Over this great area is exposed an enormous variety of special rhyolitic types. Where successive flows are exposed, it is often evident that the character of the rhyolite changed with each outpouring, making alternations of gray tuff material, black pearlites, a variety of vitreous breccias, and of solid, stony, crystalline rhyolite in which sanidin and quartz form a large portion of the total mass. These minute changes, without considerably varying the ultimate analysis of the rhyolite, produce an enormous number of varieties

If there is any general law which comes out of this tangled mass of ejecta, it is, that the earliest eruptions were of a glassy and brecciated type, and that the later ones were more solid and porphyritic. As a general rule, the higher and central portions of the range lack the bedding which may be seen toward the foot-hills on either side. In the Mount Moses region the enormous thickness of rhyolite is comparatively without bedding. The same is true of the great exposure at the head of Clan Alpine Cañon, while on the other hand Boundary Peak shows on its western base the red edges of a vast series of beds. With such very limited exposures of the older rocks through which the rhyolites must have found their way to the surface, it is impossible to determine the characters of the vents. That they were not volcanic is very evident from the general forms. Like most of the other massive eruptions, they have doubtless come through long fissures riven in the underlying rocks down to the melted source. In other words, they have resulted from the outpouring of a chain of dikes, in this instance more than 100 miles in length. When we consider the long lines of fault which have been brought to light by the labors of Powell and Gilbert, together with those which this Exploration has examined—lines often 100 and sometimes 200 miles in length—it does not seem strange that systems of volcanic outflows should occur for corresponding distances.

As between the more massive bodies of rhyolite and those which are distinctly bedded, there are apt to be characteristic lithological differences. The stratified rocks show either that water was a constant occurrence of the eruption, as in the case of the tuffs and some breccias, or else the presence of a considerable amount of glass, as in the pearlitic varieties and those having a large amount of glass base. The tuffs and some clearly stratified earthy varieties have uniformly a considerable decomposition of feldspars, resulting in kaolinic substances.

Among many interesting types of rhyolites in these mountains, a few may be profitably mentioned. The massive rhyolites around the head of Clan Alpine Cañon are rich in macroscopic crystallized minerals, quartz, sanidin, biotite, and a little plagioclase. A variety from the mouth of Clan Alpine Cañon, equally rich in dark granules of brown quartz and sanidin, contained also finely developed sphærolites. The color at this locality is usually white, and biotite is almost invariably wanting. With these are also associated white breccias, made up of the same mineral combinations, portions of which are distinctly sphærolitic. A later rhyolite, skirting the eastern foot-hills, is of the highly crystalline porphyritic type, red, and rich in sanidin, biotite, and quartz, containing also more or less slender prisms of triclinic feldspar. North of Granite Point are white porphyritic rhyolites with a fine microfelsitic groundmass, containing abundant crystals of quartz, sanidin, and a little black biotite. Here again are associated white breccias, though less decomposed than the ordinary types. On the main mountain crest north of Antimony Cañon are dark-gray, ashy-colored, and drab varieties, consisting of a banded gray felsitic groundmass, often inclining to yellowish and brownish tints, in which are quartz and sanidin. Passing downward in the series, this is underlaid by an unusually black pearlite, which contains in the prevailing dark glass a few cracked and shivered crystals of glassy sanidin and occasional quartz.

Southwest of Shoshone Pass are some porous rhyolites of light-reddish colors, followed to the north by white rhyolites with an exceedingly fine, hornstone-like groundmass bearing a few sanidins and quartzes, with occasional triclinic feldspar. Immediately overlying this is a bright, emerald-green rhyolite of equally fine microfelsitic groundmass, but differing from the white variety by the presence of sphærolites. In passing upward there is a vast series of varied beds, partly pearlitic, partly earthy, partly crystalline, and porphyritic, following one another in rapid succession.

In the region of Shoshone Springs are two distinct types, earthy pink and green varieties, and dark pearlitic sheets containing sanidin and quartz. The rhyolites of the Mount Moses region are of reddish-gray and yellowish-gray colors, and of a crystalline-granular groundmass so coarse as to produce a rough, porous habit and lead to the ready disintegration of the rock. Large black quartz granules, shattered sanidins, and occasional triclinic feldspars are the only crystallized minerals, hornblende and mica rarely or never appearing.

Near Dacy's Cañon is a little different type, with a very compact, dark groundmass, in which are black quartz and vitreous sanidin, besides dark magnesian mica. Beneath these is a series of finely bedded rhyolites, whose escarped edges show bands of red, yellow, chocolate, and gray, generally of an ashy or earthy texture. Here is another instance of the earthy and more bedded rhyolites, which approach the habit and texture of a true tuff, occurring as the earlier ejection, followed by solid rocky varieties.

The northern portion of the Fish Creek Mountains is a promontory of rhyolite, with a gently inclined surface and generally tabular structure. Skirting the western base are a few outliers of rhyolitic hills. They are distinct volcanic cones, and are completely surrounded by the Quaternary deposits of the plains. Those in front of the entrance of Dacy's Cañon are of rhyolitic pumice and ash, of light-gray and cream-gray colors. The mass is chiefly composed of rapilli and tuff, held together by a feldspathic cement. These little hills are exceedingly interesting as being the only true volcanic cones within the field of our research. Their relation to the main rhyolitic mass of the Fish Creek Mountains is doubtless the same as that of the small, parasitic cones to so many of the great volcanic cones of the world. They are also of interest because through their vents, after the completion of the rhyolitic cones, limited ejections of intensely black basalt have taken place. The lower portions of the cones consist of light creamy-gray rhyolites, the summit being capped by black feldspar basalt. The latest eruption was a scoriaceous basaltic lava, which poured down the flanks of the rhyolitic cone and flowed out for a quarter of a mile upon the plain. Its surface is still uncovered by soil or vegetation There is no possibility of mistaking here the younger age of the basalt. The relations of this whole great field of rhyolite to the other volcanic rocks is completely in concord with the law of Richthofen. The rhyolites are later than the trachytes and andesites, and earlier than the basalts.

The mass of Battle Mountain consists of a block of quartzites and limestones, which, relatively to the surrounding country, has been lifted very high. The Palæozoic rocks break off abruptly in every direction, and with the Shoshone Peak mass probably represent a broad anticlinal. They are profoundly faulted, and, like all of the very high masses of Palæozoic rock, are not extensively invaded or covered by volcanic rocks. Rhyolites have burst through the Carboniferous limestones on the western side of the range, and also through the heavy quartzites in Willow Cañon, and have overflowed the eastern base of the group near Battle Mountain Station. But as compared with the Palæozoic exposure, the volcanic rocks occupy a very small part of the mass. At Willow Creek the most interesting exposure is a flat plateau of dark rhyolites showing a precipitous, escarped face toward Willow Cañon. The rock has a compact, microfelsitic groundmass of reddish and pinkish colors, containing abundant quartz in large transparent and brownish granules, a few broken feldspars, but neither biotite nor hornblende.

With the exception of two or three very limited outcrops along the immediate foot-hills of Havallah Range, the rhyolitic rocks are confined to the north and south limits of the range. The elevated and continuous body of Triassic strata approaching Humboldt River is suddenly broken off, and does not reappear for a long distance northward. Where the block has gone down, as usual, a flood of rhyolite has come to the surface and makes the present northern foot-hills of the range. It forms considerable hills, from 1,000 to 1,500 feet high, of rough, irregular contours, margined on the north by heavy Quaternary accumulations, and touched at one point by the overlying horizontal Humboldt Pliocene. The average groundmass of this area varies in coarseness, but is chiefly a microfelsite, in which are a few scattered sanidins, biotites, and hornblendes, and shows a reddish-gray color from the abundance of decomposed ferrite. The extreme northern point of the outcrop varies considerably from this, in that the groundmass is pearl-gray, sanidins are very large, hornblende not infrequent, and the large granules of cracked quartz resemble the quartziferous trachytes of the range, and those of the Cedar Mountains of Utah and the Elk Head region in Colorado. At the southern end of the range, where again the Triassic ridge comes to an abrupt termination, the sunken or ingulfed portion of the range is replaced by a great outburst of rhyolite, rising 2,000 feet from the valley. The most interesting characteristic of this tongue of rhyolite which projects from the Havallah Mountains is its extreme height with so narrow a foundation. All along the eastern base basalts more recent than the rhyolites have burst through and overflowed its foot-hills.

In Pah-Ute Range the rhyolites, as usual, bear an interesting relation to the fractures and dislocations of the older rocks. Granite Mountain, an island of Archæan rocks, flanked both on the north and south by great mountain masses of Triassic strata, descends abruptly to the south. The body of Triassic rocks, which extends in a southerly direction, dips to the east. The western face is a steep mountain front, made up of the edges of easterly dipping beds. The westward continuation of these beds is entirely lost, having been faulted vertically downward out of sight. Directly along the line where this fault must necessarily be, and according to the rule so often mentioned, the rhyolitic rocks have outflowed over the sunken block. Directly south of Granite Mountain is one of the most interesting of these masses, a ridge parallel to the main mass of the Triassic rocks, and rising above the plains in rounded heights of 1,100 or 1,200 feet. The groundmass, of a buff and cream-gray tint, is of ferrite needles and sphærolitic accumulations. This rock is interesting for the high proportion of fresh, brilliant, macroscopic minerals enclosed in the groundmass—remarkably regular dihexahedral quartzes rich in glass inclusions, some black hornblendes, and shining, jetty flakes of biotite.

Upon the opposite side of the range, along the eastern foot-hills, a mass of diorite breaks through the Triassic strata, which, like the diorites of the adjoining ranges, came to the surface in the great post-Jurassic period of dislocation and fold. The same local weakness has given vent again to a powerful outburst of rhyolite, which lies directly to the east of the diorite, having overflowed it. At the northern limits of the rhyolite body, where it comes in contact with the limestone, it is seen to be more or less charged with bowlders of limestone and quartzite, showing that it has come up through the Mesozoic beds. Petrographically this mass of rhyolite differs entirely from those across the valley in Augusta Range, or the last described body on the westward base of Pah-Ute Range. Here the rock is minutely microfelsitic, frequently approaching to porcelain, and having singularly few minerals recognizable by the unaided eye. The subjoined description from the writer's notes in Volume II., page 697, conveys an idea of this interesting locality:

"In the cañon which trends north from the Sou Hot Springs is a remarkable dark Indian-red variety, consisting almost exclusively of a fine lithoidal base, in which are a few sharp, brilliantly defined, and entirely fresh crystals of sanidin and minute particles of quartz. Through this base are waving, ribbon-like bands and strings of minute fibrous material, also more or less distinct aggregations of sphærolites, and narrow lines of devitrified glass. The latest of the flows, capping the others, contain well developed sanidins, a few small biotites, and concentric-radial sphærolites. The flows of middle age appear to be chiefly lithoidal, while the earliest of all are formed of brecciated material. Here, as in many other localities among the rhyolites, the included fragments are composed of the same material as the binding paste; the latter, however, is more finely felsitic, the crystallized minerals being very minute; whereas, in the included fragments, there are large dihexahedral quartz crystals, and sanidins one eighth of an inch in length. A peculiar feature of this breccia is, that the forms of the included fragments are rounded, and show, in the outer eighth of an inch of their section, decided caustic phenomena. In some instances, where the included fragments have been considerably fissured, and earthy decomposition has taken place, the sphærolites are destroyed, leaving spherical cavities; the whole mass being tinged reddish-yellow by the infiltration of iron oxyds, which are probably developed from the ferritic needles of the groundmass. Here, also, it is noticeable, as in many other localities, that the breccia-flows form the earliest of the rhyolitic series. These lithoidal varieties of rhyolite differ so characteristically in their physical aspect from those found on the opposite side of McKinney's Pass (an analysis of which is given in the table following this section), that an analysis of the Indian-red rock just described was made by Mr. R. W. Woodward, to determine, if possible, any marked distinctions of chemical or mineralogical composition. The two analyses, as will be seen in Table XI., agree very closely, showing less variation than may be found in any two highly crystalline rocks of the same species." A considerable portion of this rhyolitic exposure has a rather thin covering of more recent steel-gray basalt.

From the region of Cottonwood Creek nearly down to Sommers' Pass there is a complete gap in the sedimentary series, the middle of which is occupied by huge massive diorites, that make up the centre and summits of the range. Both north and south extensive fields of rhyolite have broken out, and those along the northern summit and western base are covered by a broad field of basalt, which inclines toward the northern valley, the sedimentary rocks having been depressed and their places taken by the volcanic series. The rhyolites are later than the small body of trachyte along the eastern side of the diorite, and earlier than the heavy masses of basalt which at Table Mountain overlie the acidic series in deep and extensive sheets. The rhyolites north and east of the diorite mass along the heights, and down to within 300 or 400 feet of the plains, were a subaerial ejection, and are chiefly of a reddish-gray groundmass, in which quartz, sanidin, and biotite are thickly studded. Among the sanidins here recurs the blue, labradorizing variety, with a more intense play of color than is elsewhere seen. Hand specimens sparkle with a peculiar brilliant opalescent light, flashing out the most exquisitely pure and delicate blue. Microscopic examination shows them to be identical with those already described from the Desatoya Mountains, and to lack the minute foreign particles which are characteristic of labrador and the labradorizing orthoclases of Fredericksvärn. The reader is referred to Volume VI., page 183, for Professor Zirkel's interesting notes on this occurrence. Enough of the blue sanidin was collected for an analysis (see Vol. II., p. 702.), from which it is evident that it is a true sanidin, in which the soda equivalent nearly equals that of potash.

Down the eastern slope from the iridescent rhyolites are earthy-brown varieties crowded with biotite, and these, in turn, are succeeded by a vast series of sub-lacustrine rhyolitic tuffs, which are distinctly bedded and in nearly horizontal position. These soft, earthy strata of cream-colored, gray, and pale-reddish hues are weathered in soft round forms almost approaching some of the Bad-land sculpture. Their peculiar aspect is shown in Plate XX. Some of the strata contain an unusual proportion of glass, and others are reduced almost to clay by the kaolinization of the feldspars.

South of Chataya Peak the summit of the range is made up of soft, easily decomposable rhyolitic beds of purple and gray, showing, within what is evidently a part of the same flow, great variation in texture and even in composition. Biotite and quartz are usually present in about the same proportions, but through the rhyolitic mass are clouded, irregular regions almost destitute of these two minerals, where the light grayish and buff rhyolites are mostly rather coarsely felsitic. The coarser varieties closely resemble trachyte in their field habit, but the presence of quartz in the groundmass and the distinctly fluidal structure revealed by the microscope classes them positively as rhyolites.

Of West Humboldt Range only the southwestern half displays any rhyolitic eruptions. Standing anywhere in the neighborhood of the northern end of Humboldt Lake, and looking toward West Humboldt Range, one sees the dark elevated body of Triassic strata which extends southward from Oreana suddenly break down in a line south of Lovelock's Station. The brilliant red, pink, gray, and white confused hills, which continue the line of mountain elevation, are of rhyolites, and take the place of the section of sedimentary rocks which has gone down.

South of Humboldt Lake itself rises a lofty ridge of highly inclined Triassic beds, which represent the continuation of the sedimentary series. Its northern edge plunges down quite abruptly to the low level of the rhyolite hills. In other words, the rhyolite occupies a depressed region which might be termed a broad, extensive pass between the two blocks of elevated strata. Still to the southwest these inclined stratified rocks suddenly break down again in a depression, which is occupied by the rhyolitic eruptions of the Mopung Hills.

South of the town of Oreana, at the western base of the range, in contact with the Jurassic slates, is a narrow line of rhyolitic eruptions which are of no special importance. The real interest of the volcanic rocks of this range centres about the Mopung Hills. The rhyolites wrap around the southwestern termination of the Tebog Peak Triassic body, rising high on the flanks of the limestones that form the most southern point of the strati-

PLATE XX

RHYOLITE PAH-UTE RANGE NEVADA

fied mass. From the desert plains upon either side the rhyolites rise to a height of 1,000 feet, and are made up of a wonderful variety of colors and forms. Taken as a whole, they are finely microfelsitic; the groundmass, made up of quartz and sanidin, containing singularly few secretions of macroscopic crystals. Small but brilliant sanidins, and quartz both black and colorless, are the only visible minerals. The earliest eruptions were of gray and pink breccias, altogether made up of the fine felsitic materials. These breccias formed a considerable portion of the whole eruption, and are noticeable for the sharp, angular character of the fragments which they enclose. The proportion of angular fragments to the magma is exceedingly large. The ejection was really a rush of finely crushed rock, merely given a sufficient fluidity to insure motion by a scanty magma of finely felsitic material. White and flesh-colored felsitic and porcelaneous rhyolites broke through the breccias, and these again were invaded and capped by gray pearlitic types.

Among these hills were collected some of the most singularly beautiful lithological products that can be imagined—ribanded varieties made up of chocolate-colored, pink, salmon, white, and pale-green. Upon the southern slope of the hills are porous, earthy types in which a kaolinic decomposition of the sanidin has occurred.

The northernmost limit of this flow, directly south of the outlet of Humboldt Lake, shows some interesting rhyolites containing abundant crystals of sanidin and triclinic feldspars. A dark, chocolate-colored variety rich in biotite, and a further reddish-brown variety, with dark, chocolate-colored sphærolites, are among the interesting types. Striped and banded varieties, resembling the ribanded jaspers, are very common here, with a cream-colored and gray groundmass, lined with red and purple. These northern foot-hills are deeply fissured, and at certain places there has been a great deal of local decomposition, the cavities of the rock being filled with carbonate of lime, and many of the fissures being incrusted to the thickness of a quarter of an inch with common salt. Analyses of two types are given in the table of analyses at the close of this section. These analyses are of interest as showing that two specimens of the same outburst, of widely diverse appearance, are really chemically identical, and that the divergence of texture and color may be ranked as accidental results, depending upon phenomena of devitrification and decomposition. The only other eruptive rock associated with the Mopung rhyolites is a small body of basalt near Mirage Lake, which overflows the western terminus of the rhyolites.

Next to the great rhyolitic area made up of Augusta and Shoshone ranges and their northeastern continuation, the most interesting and at the same time the most extensive region in Nevada is that of Montezuma Range and the adjacent Kamma Mountains. The northern and middle parts of the range are made up of granite and the associated Archæan schists overlaid by the unconformable Jurassic slates. Important masses of basalt and rhyolite make up the rest of the ridge. No range shows a more diversified profile, and in none is the geological relation of the volcanic to the older rocks more difficult to ascertain clearly. The rule which I have traced with such apparent uniformity so far, that the rhyolites have come up in a region of depression, seems to hold here.

Where the granite and Archæan schists of the region of the Montezuma Mine, passing northward, are abruptly terminated, there are upon the eastern side of the range bodies of rhyolitic hills, and upon the western, basalts. So to the south of the central mass which culminates in Trinity Peak, the Archæan schists and granites fall off and are immediately overlaid by extensive accumulations of the eruptions of rhyolite and basalt.

The rhyolites northwest of Black Cañon make a group of hills through which rise occasional islands of granite, and which are margined along the north and east by slightly disturbed ashy strata of the Truckee Miocene. The low character of the hills, and the granite islands that penetrate them, give the impression of a rather shallow covering of rhyolite, and the structure of the rock itself is that of a thin flow. The rock is gray, of a rather uniform microfelsitic groundmass with few visible sanidins, but clouded and penetrated by very peculiar, irregular masses of pearlite, hornstone, and obsidian, the latter varying in color from nearly black to almost pearly gray.

An interesting occurrence is that along the southern margin of the rhyolite body. Here is a buff, purple, and isabel-colored body having a fine lithoidal base, with a few small, brilliant, uncrystallized granules of quartz and a little sharply defined sanidin. The aspect of the rock is decidedly porcelaneous, resembling a great many forms of petrified wood. In the prevailing gray and yellow color are stripes and wavy cloudings of purple, lavender, and pale-gray, sometimes with passages of a bright sulphur-yellow. It breaks with a distinctly porcelaneous fracture; and the analysis, given in Table XI., shows a composition strikingly similar to that of the opposite type of rhyolites from Pah-Ute Range. The latter, rich in crystals, has a rather coarsely microfelsitic groundmass made up of sanidin and quartz, while in this the abundant silica, reaching 75 per cent., has gone into solution in the porcelaneous groundmass. The microscope reveals a few quartzes and feldspars, but no biotites, and the groundmass develops a structure decidedly worth noting. (See Volume VI., Plate VII., Figure 3.)

A rhyolite deserving mention occurs at Lovelock's Knob, an isolated hill a few miles south of the mouth of Valley Cañon. Here is a granitic boss rising like an island out of the horizontal Pliocenes, which in this neighborhood are thinly covered with Quaternary. The granite is broken through and overflowed by a mass of rhyolite showing a wonderful variety of texture and color. The prevailing type is a creamy or gray earthy breccia, which passes into dark umber colors and again into red and pink tints. The mass forms a capping upon the surface of the granite 500 or 600 feet thick, the only other associated rock being a small development of basalt on the north side of the knob.

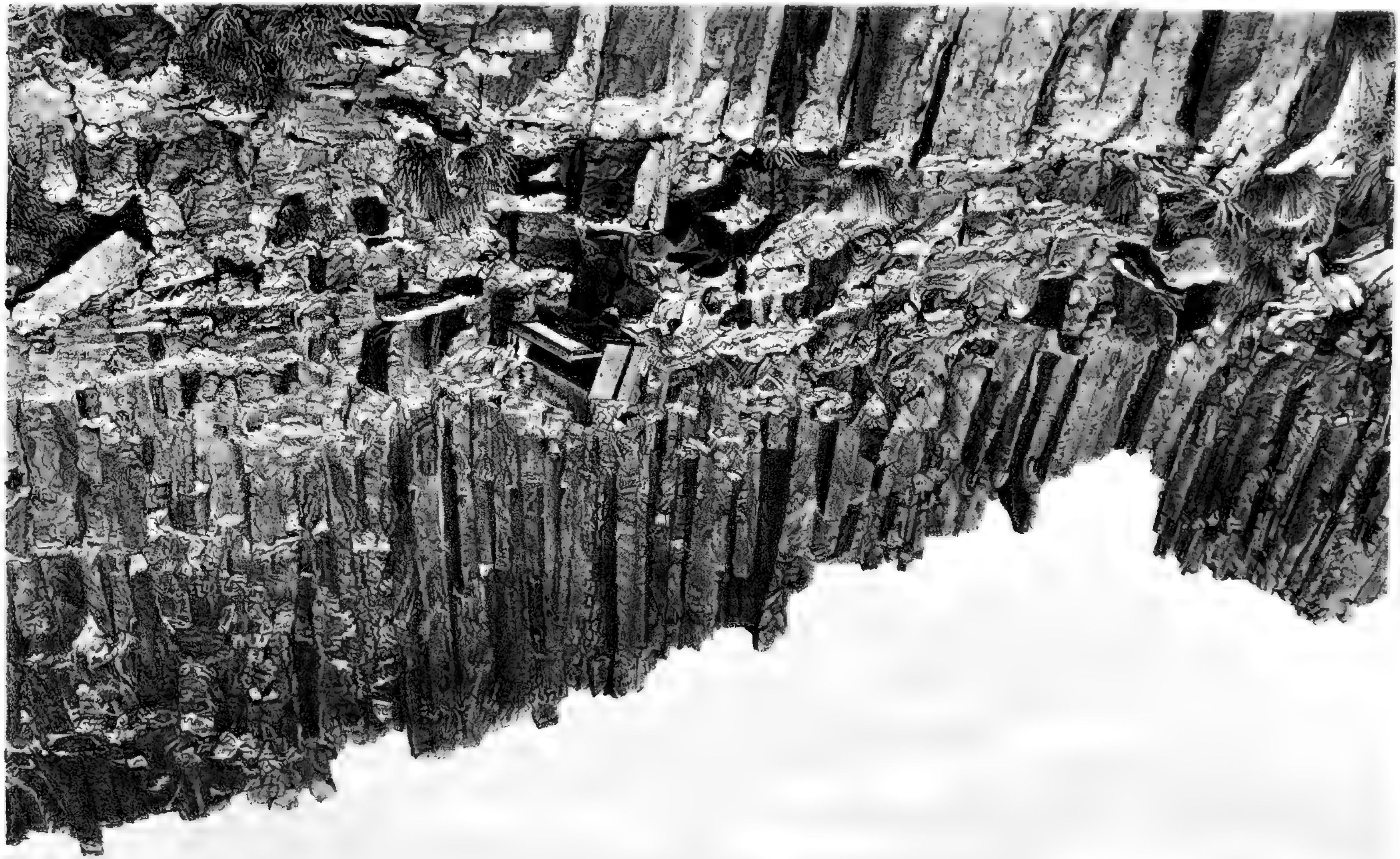
The southern half of Montezuma Range is mostly made up of rhyolites, here and there masked for no great thickness by black and steel-gray basalts. In the region of Valley Cañon are exceedingly interesting pearlitic rhyolites, which have broken through the more crystalline varieties that lie west of them. These glassy and half glassy rocks are rich in large, cracked sanidins half an inch long, considerable shining hexagonal plates of biotite, and a little rather earthy hornblende, all embedded in a gray, yellow, and brownish-yellow base. Their mode of occurrence lends them their main interest. The pearlite ridges which stand out distinctly from the surrounding surface of easily eroded rhyolites show a development of fine, hexagonal columns, whose axis is inclined at an angle of about 80° from the horizontal.

The great body of rhyolites forming the southern end of the range is made up of a wonderful variety of superficial appearances—differences of habit and texture, differences of color, and behavior of groundmass; but all, with few exceptions, belong to two general types, namely, the glassy and half glassy varieties, and the lithoidal microfelsitic.

In Bayless Cañon occurs what is perhaps the most remarkable rhyolitic display of the whole region. It consists of a ridge more than a mile long and rising 300 or 400 feet above its surroundings, altogether made up of well developed prismatic columns, varying in size from two feet in diameter down to an inch. The cross-section along the ridge would show a sharp, roof-like form coming to an exceedingly thin blade, which bristles with fine vertical columns. Upon either side, in descending toward the foot of the slope, the columns are seen to incline from the centre outwardly, while at the middle of the ridge they are tossed into a variety of angles, but approach the vertical. The steep slopes are formed of sharply divided columns, still *in situ*, resembling a pile of architectural ruins and suggesting the name of Karnak. Plate XXI. is a view of the crest of the Karnak rocks. The exterior of the columns, generally of a dark, almost chocolate-brown color, fades in many instances into a reddish-gray. The interior is an exceedingly brilliant, pure gray, formed of a rather coarsely crystalline groundmass in which are embedded brilliant sanidins, well preserved biotites and hornblendes, occasional but rare limpid granules of quartz, and a few triclinic feldspars, the microscope adding to these an abundance of apatite.

The western fork of the same cañon enters a region which is one of the most brilliantly-colored bits of geology in the whole West. The rhyolitic hills show a general tendency to horizontal bedding, and are made up of lithoidal varieties, some of which have passed into an almost earthy condition, and which vary from snowy white, like those of the Mopung Hills, through brilliant vermilion-red to orange, gray, purple, yellow, and green. A more bizarre and extraordinary assemblage of colors is rarely to be met with in nature.

At the southern base of the range, near White Plains, is also an interesting locality. Here the inclined Miocene strata, made up of trachytic tuffs and ashes, and beds of infusorial silica, are broken through by two



successive outpourings of rhyolite. The first is of a rather warm gray, and is distinctly bedded, the layers inclining toward the east about 80°. Across these most prominent structure-planes are jointings that divide the rock into rude approaches to columnar forms. Examined in detail, these rhyolites are seen to be laminated almost as finely as the leaves of a book. The gray material is striped with fine, delicate lilac and brown bands. Through this laminated series has burst a gray and olive glassy rhyolite, rich in flakes of biotite—a rock which has the singular property of forming a brilliant varnish-like glaze upon the surface of all exposed blocks. This glassy rhyolite contains large crystals of sanidin and a few granules of quartz, and is not far removed petrologically from the columnar pearlites at Valley Cañon.

The little group of the Pah-tson Mountains is distinguished by an interesting assemblage of rhyolitic types. The long ridge projecting southward from Aloha Peak is formed of dark-brown tabular masses of rhyolite escarped toward the north and east, developing a rude bedding which is not unlikely to be the original planes of flows, having a dip reaching 30° to the east. It is suggested that this high angle may be the result of a dislocation at the time of the subsequent basaltic eruptions. The main material is of trachytic habit and reddish-gray color, the felsitic groundmass showing alternating stripes of red and gray pores and carrying a little mica and glassy sanidin as macroscopical secretions, the microscope revealing also plagioclase, quartz, and certain undetermined microlites.

Surrounding the basaltic ridge west of Aloha Peak are gray rhyolites of pearlitic type crowded with black biotites and carrying a few sanidins and brown hornblendes. The eastern foot-hills of the range, at the base of Pah-keah Peak, show two varieties of rhyolites, one a compact, fine-grained rock, largely made up of minute glassy sanidins and quartz, the other a mauve breccia, containing opaque kaolinized feldspars.

Directly north of Pah-keah Peak, on the heights of the range, is a compact, greenish-yellow, quartz-bearing rhyolite having a dense microfelsitic groundmass, the average specimens resembling older porphyries. With this was observed a white rhyolitic breccia containing fragments of a lithoidal green variety. The felsitic groundmass and the binding magma being harder than the included fragments, the fracture-planes pass through both alike. Farther north, near the head of Grass Cañon, are more white rhyolitic breccias of scoriaceous habit, the interior of the cavities being colored red, the groundmass bearing sanidin and quartz. The pearlitic varieties displayed along the head of Grass Cañon merit so particular a description that the following paragraphs are quoted from Volume II.:

"Grass Cañon, which is a long, narrow ravine running out at the northern end of the mountains, presents along its slopes the most interesting occurrences of volcanic rocks in these mountains. At its head, and along the upper walls, are gray pearlites of the crystalline type. A characteristic specimen is rich in black biotite, and contains macroscopical crystals of sanidin, plagioclase, and quartz. Under the microscope, the feldspar crystals are seen to contain great numbers of angular bubble-bearing glass-inclusions, sometimes so closely aggregated as to form entire portions of the interior of the crystals. Mica is most abundant in hexagonal laminæ, 0.008^{mm} in diameter, while in the colorless glass base are feldspar-microlites and pale-green needles, together with gas-cavities containing magnetite. This pearlite passes into one in which the crystalline ingredients are still present, but the groundmass is a colorless glass, in which are developed concentrically curved cracks, giving a sphærolitic structure to the mass. Microlites are present as products of devitrification, and, as already stated, crystalline ingredients, feldspar and mica, which are difficult to detect with the unaided eye. Beyond the pearlites, on the west side of the cañon, about opposite North or Basalt Peak (not named on the map), is a peculiar greenish rock, having in general a granular structure, and showing no crystalline ingredients, through which run many bands, alternately quite porous and again compact and lithoidal. The latter pass into chalcedony, which covers the weathered surface, and sometimes forms the mass of the rock in bands a foot or more in thickness.

"At the head of a side-ravine, where, in a low saddle, the underlying rocks have been denuded, is disclosed a most interesting series of rhyolitic pearlites, chalcedonies, and tuffs, which, from the occurrence of rounded obsidian balls within the pearlite layers, have been designated the Ball Rocks The upper layers on either side of this saddle are composed of the green rhyolite already mentioned, and layers of brown chalcedony, on whose weathered surfaces are curious rounded excrescences, of concentric structure, resembling the gnarled growths found on old tree-trunks. This similarity is heightened by the color and interior banded structure of the chalcedony, which resembles woody fibre. Within the chalcedony mass are frequent druses, lined with white banded opaline agate, and containing quartz crystals. Zirkel describes the microscopic structure of the chalcedony as consisting of concentric globules and botryoidal concretions in a seemingly colorless substance, which by polarized light is seen to be an aggregation of siliceous sphærolites. A section is represented in Volume VI., Plate XII., Figure 2.

"On the saddle are exposed layers of pearlite, containing rounded obsidian balls, from half an inch to an inch in diameter, associated with a white pumiceous tuff, enclosing fragments, generally rounded, of the pearlite. The pearlite is blue-gray, devoid of crystalline ingredients, with a tendency to form layers from an inch upward in thickness. It has a wavy appearance, and is entirely made up of sphærolitic concretions. The sphærolites have a concentric structure, and are formed of thin layers. Under the microscope, these layers are seen not to be complete rings, but to be grouped round the centre like the leaves of an onion, and the microlitic products of devitrification to be arranged in parallel wavy bands through the mass, quite independent of the concentric structure, from which Professor Zirkel concludes that this structure is merely a phenomenon of contraction. The pumiceous tuff, which is found abundantly along the slopes of the ridge, is a white porous mass, containing small fragmentary crystals of quartz and sanidin, and enclosing larger fragments of the gray pearlite, in contact with which the white frothy matrix is seen to be compressed and hardened, so that the surface of the cavities left by these fragments is smooth and hard like a plaster mould.

"The obsidian balls, which have an almost perfectly spherical shape and occur imbedded in a layer of pearlite, near the summit of the saddle, are seen by microscopical examination to be remarkably pure, containing only a few trichites in a light-gray glass.

"About a mile from the mouth of Grass Cañon occurs another white rhyolitic tuff or breccia, of much more compact mass than the above, and enclosing fragments of dark porphyritic rhyolite with free quartz, which forms quite high cliffs on the west wall of the cañon.

"In this vicinity, also, is a considerable development of basaltic rocks, which have apparently poured out on the east side of the cañon, and have covered the upper part of the ridge on the west. These basalts develop a columnar structure, particularly on the slopes of the peak on the east side, which has been called Basalt Peak, where they are remarkably perfect and arranged horizontally. They belong to the same general type as those of Aloha Peak. The main mass is a compact, dark, rather vitreous-looking rock, with conchoidal fracture and somewhat coarse texture, in which only small plagioclase crystals can be detected macroscopically. The microscope detects also olivine and augite, and in the groundmass an amorphous globulitic base."

The Kamma Mountains, which are really a northern continuation of the Pah-tson, are divided into two distinct groups. The southern one is composed chiefly of andesites that have broken through Jurassic slates, while the northern body, made up of lofty, rugged hills, is almost entirely of rhyolite and rhyolitic breccias, and, around the lower portions, of a group of tuffs. The predominating breccias display in the angular fragments which they conain a very great variety of microstructure of groundmass. Earthy, rearranged, rhyolitic tuffs occupy the lower foot-hills. Northward from this group the desert slopes are dotted with little rhyolitic and andesitic hills, the former not greatly differing from the Kamma rhyolites. Farther north the western foot-hills of the group which forms the eastern boundary of Quinn's Valley are of porous, earthy-white rhyolites, containing only sanidin and quartz. These rhyolites are of interest, as they are seen to have disturbed and tilted the Miocene strata.

West of the valley of Quinn's River, in the very heart of Mud Lake Desert, is the group of Black Rock Mountains, rising at extreme points about 1,000 feet above the desert level. Within the area of our map it is built of rhyolitic and basaltic eruptions; and the minor ridges which make up the topography are usually capped with a sheet of basalt that inclines to the east, the rhyolites showing along the western base of the hills.

This is repeated several times, giving the impression that the region has been disturbed since the eruption of the basalts. In one instance rhyolites appear to overlie the basalt directly; and since this is the sole exception to the law of Richthofen within our limits, it was examined with some care. It was not clear whether the rhyolite had really come to the surface later than the basalt, or whether the basalt had broken through between beds of rhyolite, as it is often seen to have done between the strata of a sedimentary series. The basalt is a true olivine dolerite, not at all to be mistaken for an augite-andesite. The problem, therefore, is purely one of structure, and requires further study to clear up all obscurities. Standing as a solitary exception in the face of such a multitude of concurrent examples to the contrary, this apparent succession of rhyolite after basalt must be attributed either to an obscurity of structure or to one of those curious alternating eruptions which are described by F. von Hochstetter.*

A supposed exception was brought to light by the late Archibald R. Marvine at Truxton Springs, Arizona, where a light purple and gray rhyolite, rich in crystalline minerals, and having a rather coarsely crystalline groundmass, was observed to overlie a doleritoid rock. The writer examined thin sections of the latter, and found it to contain minute grains of quartz, with specks which had the appearance of very minute fluid inclusions. The olivine had in large part passed over into a serpentinous condition, and the glass base was globulitically devitrified, as is so common in the middle-age diabases. The rock was therefore pronounced, without much hesitation, a diabase, and the law of Richthofen sustained.

Westward from the Black Rock Hills, across an arm of Mud Lake Desert, rise the Forman Mountains, a group of irregular rhyolitic hills reaching about 1,200 feet above the level of the desert. Wherever examined, they prove to be altogether of rhyolite, for the most part a pure felsitic mass, of flinty, conchoidal fracture, containing as macroscopic secretions only a few half kaolinized feldspars. Farther up the range are some reddish, highly crystalline rhyolites, with rough, trachytic fracture, made up of sanidin and free quartz in a compact felsitic groundmass. With this is a breccia similar to the solid rock; and from a little north of our map

* Reise der Oesterreichischen Fregatte Novara um die Erde, in den Jahren 1857, 1858, 1859.

was brought in a very wonderful example of minute rhyolitic columns closely welded together, each prism about one eighth of an inch in diameter. They are quite accurate hexagons, and are composed of a dark, steel-gray rhyolite, the fine, microcrystalline groundmass containing limpid quartz and small, slender crystals of sanidin.

The rhyolites of Truckee Range are confined to the southern portion, directly abreast of the south end of Winnemucca Lake, and a single rhyolitic summit which rises above the broad, basaltic masses directly north of Desert Station, in the most southern ridge. Here a single peak of gray and grayish-brown, half-glassy rhyolite is exposed, rising like an island above the basalts. It is very rich in brilliant biotite, and contains a little greenish-black hornblende, but no quartz; and the abundant glassy base shows the most interesting products of devitrification, as described by Professor Zirkel. Among the rhyolites east of the southern end of Winnemucca Lake are none of special petrographical interest. They directly join the granites, diabases, and metamorphic Triassic strata, and are made up of rugged piles of brilliant pink, red, white, ashy, and lavender-colored rocks, which are quite conspicuous in their contrast with the darker masses of the metamorphic series.

Since all of Virginia Range within the limits of our map is made up of eruptive rocks, and, with few exceptions, of Tertiary volcanic rocks, we have no clew to the relations of the rhyolites to the ancient series. They are quite subordinate, both in amount of exposure and in the position which they hold in the broad topographical features of the range. They are actually confined to the skirts of the group and the low region of Mullen's Gap. Between Black Mountain and the granite ridge which projects southward of State Line Peak, overlying the granites and in turn capped by more recent basalts at the extreme head of Louis' Valley, is a small development of reddish-gray rhyolites with a finely felsitic groundmass and the most characteristic banded structure. Biotite, sanidin, and occasional quartz are the only visible secretions.

At Mullen's Gap, both north and south of the pass, are limited exposures of rhyolites which have broken through and overlaid the foot-hills of quartz-propylite, and northward they are themselves overlaid by broad basaltic sheets which come down from Black Mountain. How far the rhyolites may continue under the heavy, overlying masses of basalt is, of course, an open question. In these few foot-hills are to be seen a very great variety of rhyolitic types; some with felsitic groundmass crowded with secreted minerals—sanidins, plagioclases, quartzes, and biotites. With these are associated light, cream-colored tuffs, dark pearlites, and a wide range of glassy and half glassy varieties. The prevailing color of all the Mullen's Gap rhyolite is a very brilliant Indian-red, not unlike those from Sou Springs. The most porous pearlites and the pumices, which here occur in great profusion, are of pearl-gray and lavender colors. Here, too, are found stratified pumiceous tuffs in which the material has been evidently rearranged in lacustrine waters. They are remarkably friable, crumbling at the touch like beds of volcanic ashes. An ash-gray breccia from the north side of the gap is made up of a loose, rather incoherent binding material and fragments of several varieties of more or less decomposed rhyolites. Sanidins are the only secreted crystals. That which lends the rock its interest is the occurrence of liquid inclusions in glass, and of an apatite included in glass, itself carrying a minute fluid inclusion.

The most extensive rhyolite body in this part of Virginia Range occurs directly north of Truckee Cañon, having its culminating-point at Spanish Peak. Here is a lofty, rugged hill, from which a rude bedding declines in every direction. These rocks have overflowed the sanidin-trachyte that forms the main summit of the range to the west, and in turn are nearly surrounded by basaltic outbursts, as seen upon the geological map. It is a pinkish-gray and lilac rock, of a fine-grained felsitic groundmass, containing only a few macroscopic individuals of sanidin. Under the microscope it is seen to be very rich in tridymite and well rounded sphærolites. The most interesting petrographical feature is the extremely fine lamination visible at various points of its body. Hand specimens show laminations of not over a fortieth of an inch in thickness, and these are not merely parallel, straight lines, but are often contorted into regularly defined scollops, sharp points, and complicated, compressed waves. For the most part, these laminations are present in perfectly parallel, smooth planes, upon which the rock has a slight tendency to break. Approaching the river, the gray and pink rhyolites overlie a dense white felsitic variety which is very rich in large, brilliant granules of quartz—a rock closely resembling the white felsite porphyries of middle age. Over this extremely white, pure variety of rhyolite, are the ends of a flow of excessively black, fine-grained basalt, affording the most extreme contrast in color and texture.

In the region of Berkshire Cañon, the eastern foot-hills of Virginia Range are composed of an important belt of rhyolites which have burst through and overflowed the trachytes and dacites. Seen from the valley of the Truckee, these rhyolitic foot-hills rise from 1,200 to 1,800 feet above the level of the Pliocene mesa, and in their rough exterior and suddenly variegated colors make a thoroughly characteristic rhyolite display. They are white, pale pea-green, salmon-colored, pale lilac, Indian-red, olive-brown, and deep purple. Directly north of Berkshire Cañon they are broken through and overlaid by a small mass of basalt. Taken as a whole, this field of rhyolites, about twelve miles in length, shows almost no bedding whatever. It is a fine type of structureless, massive eruption. It embraces several petrographical varieties, shading through a dense white felsitic rock without a single macroscopic crystalline secretion, and through mica-bearing, quartz-bearing, and sanidin varieties, up to a highly crystalline rock with a scanty felsitic groundmass and a crowd of brilliant crystals of quartz, plagioclase, sanidin, and biotite. The quartz is invariably in rounded, cracked granules, the sanidins often dislocated and varying in dimensions from a fine point up to the size of a pea. One salmon-colored variety was characterized by an enormous amount of large, open cavities lined with a thick coating of siliceous sinter. The more solid parts of this rock were salmon-colored felsitic masses, so fine as to resemble the most close-grained jasper. Decomposed sphærolites are seen by the microscope to be very common. A few of the more brilliant sanidins possess the labradorizing quality to a slight extent.

TAB

Number of analysis.	
157	Lasse
	"
158	Lasse
	"
159	Harle
	"
160	West s Ran
161	Huml Ran
	"
162	Back zun
	"
163	Pine M
	"
164	Fish (
	"
165	Hot S
	"
166	Mopun Ran
	"

Rhyolites.

Locality.	Analyst.	Si	Al	Fe (ferric)	Fe	Mn	Ca	Mg	Na	K	Li		Ignition.	Total.	Specific gravity.	Oxygen ratio of— Ṙ	R̈	S̈i	Oxygen quotient.
[illegible] Peak, California	R. W. Woodward	68.84 36.71	15.73 7.33	. .	3.11 0.69	. .	3.58 1.02	0.90 0.36	2.89 0.74	3.59 0.61	tr.	. . .	1.50	100.14	2.4	3.42 2.73	7.[illegible]3 8.37	36.71 36.71	0.292 0.302
“	“	68.98 36.78	15.57 7.25	. .	3.22 0.71	. .	3.65 1.04	0.93 0.37	2.89 0.74	3.61 0.61	tr.	. . .	1.52	100.37	. .	3.47 2.76	7.25 8.32	36.78 36.78	0.291 0.301
[illegible] Peak, California	“	69.66 37.15	15.71 7.32	1.02 0.31	1.48 0.33	. .	3.25 0.93	1.27 0.51	4.10 1.06	3.02 0.51	tr.	. . .	0.48	99.99	2.3, 2.3, 2.3	3.34	7.62	37.15	0.295
“	“	69.36 36.99	16.23 [illegible]	0.88 0.26	1.55 [illegible]	. .	3.17 0.91	1.34 0.53	4.06 1.05	3.02 0.51	tr.	. . .	0.45	100.06	. .	3.33	7.82	36.99	0.301
[illegible] Range	“	70.29 37.48	14.85 6.81	1.20 0.36	1.20 0.26	0.16 0.03	1.09 [illegible]	0.26 0.10	3.66 0.94	5.66 0.96	tr.	. . .	1.36	99.73	2.1, 2.2, 2.2	2.60	7.17	37.48	0.260
“ “ “	“	70.15 37.41	14.51 6.76	1.24 0.37	1.20 0.26	0.11 0.02	1.12 0.32	0.27 0.11	3.79 0.98	5.60 0.95	tr.	. . .	1.38	99.37	. .	2.64	7.13	37.41	0.261
[illegible] McKinney's Pass, Pah-Ute Range.	“	74.00 39.46	11.93 5.56	2.08 0.62	0.61 0.13	. .	1.56 0.44	. .	2.64 0.68	5.65 0.96	tr.	. . .	1.24	100.24	2.3, 2.3	2.21	6.18	39.46	0.213
[illegible] Group, Montezuma Range.	“	74.62 39.79	11.96 5.57	1.20 0.36	0.10 0.02	. .	0.36 0.10	. .	2.26 0.58	7.76 1.32	tr.	. . .	1.02	99.18	2.2, 2.2, 2.3	2.02	5.93	39.79	0.199
“ “ “	“	75.34 40.18	11.68 5.44	1.35 0.40	0.10 0.02	. .	0.49 0.14	. .	2.20 0.57	7.35 1.24	tr.	. . .	0.97	99.50	. .	1.97	5.84	40.18	0.194
[illegible] of Montezuma Mines, Monte-[illegible] Mountains.	“	74.95 39.97	13.61 6.34	. .	0.54 0.12	. .	2.02 0.57	. .	3.72 0.96	4.85 0.82	. .	. . .	0.64	100.33	2.4, 2.5	2.47	6.34	39.97	0.220
“ “ “	“	74.87 39.93	. .	. .	. .	. .	2.18 0.62	. .	3.83 0.99	4.90 0.83	. .	. . .	0.66	. .	. .	. .	. .	. .	. .
[illegible] Pah-Ute Range	“	75.07 40.04	11.40 [illegible]	0.53 [illegible]	1.28 [illegible]	tr.	0.61 0.17	0.11 0.04	1.15 0.29	8.33 1.41	tr.	CO² trace.	1.74	100.22	2.3, 2.4	2.19	5.47	40.04	0.191
“ “	“	75.15 40.08	11.27 [illegible]	0.54 [illegible]	1.38 [illegible]	tr.	0.78 0.22	0.11 0.04	1.26 0.32	8.28 1.40	tr.	CO² trace.	1.67	100.74	. .	2.28	5.50	40.08	0.194
[illegible] Mountains	“	75.44 40.23	13.98 [illegible]	0.38 0.11	0.20 0.04	. .	0.50 0.14	tr.	3.48 0.90	5.36 0.91	. .	. . .	0.77	100.07	2.4, 2.5	1.99	6.62	40.23	0.214
“ “	“	75.55 40.29	13.67 [illegible]	0.40 0.12	0.20 0.04	. .	0.57 0.14	tr.	3.50 0.90	5.29 0.90	. .	. . .	0.85	99.97	. .	1.98	6.49	40.29	0.209
165 Hot-spring Hills, Pah-Ute Range	“	75.65 40.34	11.52 5.37	1.82 0.54	0.73 0.16	. .	0.76 0.22	tr.	2.91 0.75	5.93 1.01	tr.	. . .	1.03	100.39	2.4, 2.5	2.14	5.91	40.34	0.199
“ “ “	“	75.70 40.37	11.48 5.35	1.87 0.56	0.73 0.16	. .	0.77 0.22	tr.	3.00 0.77	6.09 1.03	tr.	. . .	1.02	100.66	. .	2.18	5.91	40.37	0.200
166 [illegible] Hills, West Humboldt Range.	“	76.80 40.96	11.64 5.42	0.66 0.20	0.50 0.11	. .	0.43 0.12	tr.	2.53 0.65	6.69 1.13	tr.	. . .	0.77	100.02	2.5, 2.7	2.01	5.62	40.96	0.186
“ “ “	“	77.00 41.06	11.54 5.37	0.69 0.20	0.42 0.09	. .	0.43 0.12	tr.	2.45 0.63	6.72 1.14	tr.	. . .	0.77	100.02	. .	1.98	5.57	41.06	0.183

SECTION V.

BASALTS.

Like the rhyolites, the basalts show their most prominent development in middle and western Nevada. There are a few limited bodies around the northern edge of Salt Lake; and north of the limits of Map III., in the valley of Bear River, there are important but restricted basaltic areas. The great and repeated dislocations and orographical disturbances which have marked the region of the Wahsatch have been accompanied only in modern times by trachytic eruptions. No basalts are seen along the grander part of that range. North of the Fortieth Parallel limits, however, are basaltic areas which seem rather to be the outliers of the wide basalt country that borders the Snake Plains.

On the eastern base of the Rocky Mountains, south of our work, are basaltic localities; but within the Fortieth Parallel limits the most easterly bodies are those exposed along the divide between North and Middle parks. As has been seen, the middle of that ridge is formed of a trachytic eruption, the eastern wall of North Park being lined with rhyolites. The basalts, which cover less area than either of these two, occur west of the trachytic masses along the eastern base of the Archæan slopes of Park Range. From a little north of the parallel of 40° 30′ they extend south beyond the limits of our map, a most important point being Rabbit Ears Peak. They extend eastward across the valley of the West Fork of the Platte, having an irregular, rugged surface which rises here and there in rude domes. Near the Indian trail which crosses the divide from the head of West Fork, they distinctly overlie the rhyolites, and west and south of Ada Springs appear as powerful dikes cutting through the Cretaceous sandstones which have been weathered away from their sides, leaving the basaltic walls projecting strongly above the surface. These dikes were observed to have a trend about northwest. Over the lower levels of the basaltic area, which is only about 15 miles from east to west, the horizontal strata of the North Park

Pliocene have been deposited, abutting nonconformably against the basaltic slopes. These lacustrine sandstones occupy a deep bay south of the Rabbit Ears and west of the Ada Springs Cretaceous body, and cover all the basalts, with the exception of isolated points which rise abruptly above the Tertiary plain. The most important of these is Buffalo Peak, a point about 700 feet above the Park level, which measures only 300 or 400 feet across the flat summit. The specimens collected from all these basaltic exposures are rather uniform in petrographical habit. They are fine-grained, and, with the exception of macroscopical olivine and occasional augites, possess no crystals recognizable by the naked eye. The microscope shows the usual combination of augite, plagioclase, and olivine, besides specular iron.

Deep-seated fissures within the angle formed by the flexure of Park Range, a little south of the 41st parallel, have given vent, as before described, to an extensive outpouring of trachyte. Subsequently the same region was the theatre of volcanic activity in the period of the basalts. It has suffered severe erosion since the latest eruptions, and a great many of the attenuated ends and edges of the longer flows have been cut through, leaving only fragmentary outliers. The main basaltic mass is the high east-and-west ridge of the Elk Head Mountains, culminating in Anita Peak and Mount Weltha, and at the northern extremity in Navesink Peak. Outliers of the group stretch north of Little Snake River to Watch Hill and Bastion Mountain; and even south of the Yampa detached remnants of the southern flows have been observed.

The most eastern exposure is a small outcrop directly in contact with the Archæan rocks north of Hantz Peak. The main body is about 20 miles from east to west and 24 miles along the longest axis through Navesink Peak and Mount Weltha. The basaltic country is for the most part very elevated, being from 8,000 to 10,000 feet above sea-level, and is well covered with soil and dense woods, so that the exact age and character of the underlying sedimentary rocks cannot always be made out with certainty. Along the main exposure to the north and south it is clear that the basalts have broken through the sandstones of the Laramie or closing group of the Cretaceous. At the west end of the group, the long, interesting dike of the "Rampart" has broken through the Vermilion Creek Eocene; and from that region up to Navesink Peak the edges of the basaltic field are seen to rest on coarsely bedded, friable sandstones, which continue westward and define themselves as the Vermilion Creek group. At one or two places are obscure bodies of sandstones in the heart of the group, which may possibly be later members of the Eocene; but their nature and extent are too obscure to warrant any opinion.

The basalts themselves have an exceedingly rugged surface, piling up in horizontal beds one above another, with plateau-like summits and broad, rugged spurs. They are interesting from a petrographical point of view, since two distinct types of the rock are here outpoured, namely, feldspar-basalt and nepheline-basalt. With the exception of the Elk Head region and the little group of the Kawsoh Mountains in western Nevada, all other Fortieth Parallel basalts belong to the feldspar group. Throughout the very great number of localities studied by us, not a trace of nepheline was found, except within the narrow areas of these two distant fields, and there the two types occur together, the nepheline group forming by far the larger flows at Elk Head. The ordinary feldspar-basalt, composed of plagioclase, augites, and olivine, occurs on the benches of Upper Little Snake River south of the valley, at Watch Hill on the north wall of the valley, also at Anita Peak, the elevated summit on the meridian of 107° 15′, and again south of Yampa River near the forks. The rock on the benches of the Upper Snake is very peculiar, consisting of quartz, plagioclase, augite, and magnetite, olivine being wanting. It has a dark, grayish-black groundmass of a rough habit, and bears a distinct likeness to the quartziferous trachytes of the neighborhood, which also have abundant augites. It rather expresses a transition between the augite-bearing, quartziferous trachytes and basalt, though from its habit and connection with the other basalts it has been here referred to the latter family. Considered as a basalt, it is interesting as an instance of the manner in which certain petrographical characteristics run through the different species of rocks of one locality. The trachytes of this region stand out with peculiar distinctness, on account of containing the large, cracked granules of quartz, while the groundmass is free from microscopical grains of that mineral, thus differing from the family of rhyolites. The quartz grains of the basalt play a similar rôle. They are not constituent in the groundmass, but appear as distinct macroscopical secretions. Perhaps this occurrence throws light on the similar occurrence of quartz in the older diabases. Primary quartz, when present in our diabases, behaves as an irregular accessory mineral, bearing the same relations to the other constituents as in this quartziferous basalt.

Across the valley of the Snake at Watch Hill is a coarse-grained dolerite, noticeable for the amount of dark globulitic base imbuing the groundmass.

The plagioclase-basalt south of Yampa River, near the forks, belongs to the ordinary type of basalts, without distinguishing characteristics except the occurrence of haüyne as an inclusion in the colorless plagioclases.

The rock at Anita Peak consists of plagioclase, dark brown augite, olivine containing picotite, and an abundance of amorphous brown glass.

The family of nepheline-basalts are broadly distributed over a large part of the Elk Mountain basaltic field, the following furnishing important examples: Fortification Peak, Navesink, Bastion Mountain, Mount Weltha, the ridge northeast of Hantz Peak, and the singular dike projecting westward from the main field, called the "Rampart." Bastion Mountain, a detached outlier rising above the Laramie sandstones north of Little Snake River, is a flat-topped mass, about 1,200 feet of basalts being displayed upon its flanks. The rock is light-gray and very porous, the spherical cavities having a parallel arrangement which gives an almost schistose fracture. The interiors of the cavities are incrusted with yellowish calcite. In the rather fine groundmass, augite and olivine are distinctly seen with the unaided eye, and the microscope adds biotite, magnetite, nepheline, plagioclase, and a yellowish mineral referred by Zirkel to göthite. Toward the western edge of the body are beds having very coarse pores underlaid by a greenish tuff somewhat resembling the palagonitic tuffs of western Nevada. The tuff encloses broken, angular fragments of scoriaceous basalt.

Below the junction of Slater's Fork with Little Snake River, upon the Cretaceous benches south of the stream, are two detached knobs of basalt which are doubtless outlying relics from the flows of Navesink Peak Navesink Peak itself has a distinctly conical shape. Its rock is a very dark, fine-grained body, of anamesitic texture. In this fine, uniform groundmass, dark, almost black augites and translucent olivines alone appear macroscopically, the microscope detecting magnetite, biotite, nepheline, and a little plagioclase.

Mount Weltha and the broad region around it, the highest elevation reached by the basalts in these mountains, yielded a rock extremely rich in olivine, associated with which the microscope shows magnetite, augite, nepheline, and sanidin in Carlsbad twins.

One of the most interesting volcanic features in the neighborhood is the "Rampart," a high, narrow wall of basalt extending four or five miles to the northwest from the western end of the basaltic flows of Mount Weltha. It is perfectly straight, and varies in height from thirty to sixty feet, having an average width of six feet. The sides are absolutely perpendicular and very smooth, and its summit is broken into crenelations, like the walls of a fortification. It is simply a dike which has resisted weathering, while the soft Eocene sandstones have been eroded away upon either side, and is altogether composed of basaltic columns arranged horizontally. In hand specimens the rock is light gray, entirely free from triclinic feldspars, rich in biotite, and shows fine augites, nepheline, and sanidins.

Fortification Peak, which is a detached outlier, the relic of a former flow from Mount Weltha, is also of nepheline-basalt. It is rather coarse-grained, like some of the specimens from the slopes of Mount Weltha, and contains a little triclinic feldspar, augite, olivine, magnetite, and nepheline. A similar rock is observed on a ridge running northeast from Hantz Peak. It bears plagioclase individuals, nepheline, augite, olivine, and biotite. For a minute microscopical description of these rocks, the reader is especially referred to Volume VI., where Professor Zirkel has fully detailed their characteristics.

As to the question which of the two types of basalt in the Elk Head Mountains is the older, we have not the data to determine; but the commanding position and wide expanse of the nepheline-basalt make it probable that this was the later and more important eruption.

Passing westward from the Elk Head Mountains, the broad area of the Green River Basin, the high Tertiary plateaus east of the Wahsatch, the great range itself, and the eastern margin of the basin of Salt Lake are totally without basalts within the limits of our Exploration. Directly north of our map, on the prolongation of the trend of elevation of the Wahsatch, are basaltic bodies, which in passing northward increase in frequency until they connect with the great basaltic plains of the Snake.

Here and there in Curlew Valley a few isolated knobs of basalt appear above the Quaternary, but the first basalt masses of any elevation are those in the region of Red Dome and Matlin. Red Dome itself is a noticeable mound of basalt, rising about 600 feet above the surrounding Quaternary slopes. The rock here has a dense, fine-grained groundmass of chocolate and reddish hues, usually quite compact, but at times highly porous. There are no macroscopical secretions other than plagioclase, augite, and occasional olivines. The extension of the rocks north of Red Dome shows sheeted tabular flows, with an inclination toward the south.

West of this body the Quaternary of Duff Creek Valley covers the basalts; but on the western side of the valley they rise again, forming hills 1,500 or 1,600 feet high north of Matlin Station. The distinct beds here incline 2° or 3° to the south and east, a bold ridge capped by domes and points defining the middle of the outflow. It is a black, brilliant, crypto-crystalline rock, without secretions visible to the unaided eye.

The Ombe Mountains form one of those narrow, lofty ridges which rise out of the desert with no visible connection with any other range, continue a few miles upon a defined trend, and suddenly sink again beneath the Quaternary plains. This peculiar orographical structure is due most unquestionably to great dislocations. Each one of these ranges may be considered as a block, more or less separated in altitude from its belongings. The sharp break at the northern end of the Ombe is accompanied by eruptions of rhyolite and basalt, the basalt having broken out in immediate contact with the ends of the Palæozoic strata and flowed northward, overwhelming the greater part of the rhyolites. The inclination of the beds is to the north, and the general surface of the country rough and rugged, with a very slight accumulation of soil. The basalt has an extremely fresh look, the surface having not infrequently the ropy structure of lava-streams. The fracture of this rock under the hammer is characteristic of those basalts of very coarse groundmass and little or no glass base. It is a very dark gray, almost black, middle-grained rock, uncommonly rich in augite and unusually poor in olivine. The presence of a large amount of olivine or of glass base produces an easy fracture, with more or less vitreous lustre; and the field habit of these rocks approximates to glassy andesites. Basalts poor in olivine and glass, on the contrary, present always very rough surfaces and a dead, lustreless appearance. Indeed, an experienced eye detects the proportion of glass in a basalt almost as well by the fractures of the natural surfaces of the rock as by examining a thin section under the microscope. The more porous parts of the Ombe basalt show the ordinary scoriaceous, spongy condition, the pores being frequently filled with carbonate of lime. An analysis of this occurrence is given in the table following this section. While of exceedingly low specific gravity, it is correspondingly high in the equivalent of silica. In fact, it is the most acidic basalt of all the specimens analyzed by us, approaching some of the most basic of the augite-andesites. Aside from this locality, the eastern half of Map IV. has but two basaltic regions, both small and unimportant.

One is the chain of basaltic outflows in the Ruby group, of which the most important exposure is upon the rhyolite field of the Beehives. Overlying the rhyolitic tuff of the Beehives is a small field of fine-grained, dark-gray and black basalt which has flowed in a remarkable liquid condition, the entire formation being only 50 to 100 feet thick, and conserved on spurs, where its position has sheltered it from erosion. The beds are nearly horizontal, and along their eastern edge show some traces of underlying limestones, dipping slightly to the west. This basalt breaks with great freedom under the hammer, giving a curved, often conchoidal fracture, the surface having a peculiar greasy lustre. The fragments ring under the hammer like bits of bottle-glass. A few fragments of feldspars and grains of olivine are the only crystalline secretions visible, and these are but rare, the greater number of specimens showing no secretions at all. It is chiefly a dark-brown, acid glass, the true obsidian of basalt, and is the same noted by Zirkel as occurring at Ostheim, in the Wetterau, and at Sababurg, in the Reinhardswald. The most remarkable occurrences of this rock, however, are not the German but the great glass flows of the island of Hawaii.

South of Eagle Lake, from the detached outlying limestone west of Spruce Mountain, rises a basaltic dike forming a low connection between the limestone body and the Archæan rocks of Humboldt Range. It is a fine black compact rock of andesitic habit.

On the western side of the South Fork of Humboldt River two small basaltic knobs rise above the more recent Pliocene beds. This is an ordinary kind of porous basalt, rich in dark globulitic base, poor in olivine; the augites almost wholly in the form of microlites, and plagioclases in slender pellucid tables.

In the midst of the great trachyte mass on the eastern side of Piñon Range, east of Pinto Peak, one or two outflows of basalt through the trachytes have occurred. They are black, highly vesicular basalt, having a somewhat vitreous lustre, owing to the large amount of acidic glass which forms the abundant base of the rock. It is noticeable for the great size of the triclinic feldspars and its paucity in olivine. Farther south along the range, in the neighborhood of Fossil Pass, and south of Piñon Pass, are small outflows of basalt immediately contiguous to Devonian limestones.

More important basaltic outbursts occur along the line of the eastern base of Piñon Range, in the field which has outflowed along the southern foot-hills of the rhyolite mass east of Piñon Pass, and, extending southward to Railroad Cañon, has formed a broad volcanic connection between Piñon and Diamond ranges. Topographically, the form of this mass is that of a broad, low ridge having a few dominating dome-like summits. Lithologically, the basalts of the group are very uniform, unusually rich in dark glass, poor in olivine, and rich in fine grains of augite. West of Piñon Range, lining the western foot-hills for twelve or fourteen miles, south of Cave Cañon, is a series of tabular flows of basalt which slope toward Garden Valley. This table abuts directly against the Devonian quartzite of the Ogden group, presenting toward the range an escarped wall, while the main sheets dip toward the west at 3° or 4°. It is a hard, porous basalt, poor in glass and olivine.

Piñon, Cortez, and Shoshone ranges and the Shoshone Mesa form a basaltic neighborhood which is of great importance. It will be seen that the outcrops, although locally determined by the strike of the ranges in which they occur, nevertheless extend themselves in a general line having a northwest trend. From Chimney Station, which may be taken as one point of the chain of outflows, the masses of Cortez Range, Whirlwind Valley, and the Shoshone Mesa form a suggestive chain of basaltic eruptions parallel to the axial basalts of the Sierra Nevada.

The body which margins the eastern side of Cortez Range from the neighborhood of Wagon Cañon southward to the slopes of Mount Tenabo forms a continuous inclined plane of basaltic beds dipping from the range at gentle angles of 2° or 3° for about 30 miles. The line of fissure from which they outpoured cuts through the earlier volcanic rocks, and invades the Palæozoic and granitic formations to the south. Flowing by gentle inclination down the eastern slope, it has been subsequently overlaid by the horizontal Pliocenes of Pine Valley and the later Quaternary of Garden Gate and Garden Valley. One of the most interesting centres of this great outflow is where the rocks break through Carboniferous quartzites at Agate Pass. Here the lateral cañons eroded in the basalts make excellent exposures of the surfaces and edges of the thin black sheets. Lithologically it is a fine-grained basalt, rich in brown glass base, poor in olivine, but with abundant colorless plagioclase, augite, and magnetite. Although the fine-grained varieties are most common, there is a good deal of local change between the different layers as to the amount of crystals, the lower beds usually showing a greater abundance of microscopical secretions. Some of the very uppermost flows are as fine-grained as hornstone, breaking with a sharp, flinty, conchoidal fracture, and showing no macroscopical secretions. In occasional localities the rock is highly porous, the cavities being extended into long ellipsoidal pores. North and south of the summit of Agate Pass the size of these pores sometimes reaches a foot on the longer axis, and they are most frequently filled with masses of chalcedony or agate, from which the pass derives its name. These inclusions vary widely in character. Some of the large cavities are simply lined with a complete coating of flesh-colored and white chalcedony, presenting a smooth botryoidal surface to the hollow interior, the entire lining being only about half an inch thick. Again, they are only partially filled with chalcedony or sharply terminated quartz crystals. On the lower sides of the cavities and in the hollows of the chalcedony there are frequently considerable deposits of delessite, which also plays an important part in the layers of agate inclusions.

One of the most noticeable geological features of Shoshone Range is the reëntrant angle north of the Shoshone Peak mass. The high mountain body suddenly drops to a comparatively low level, and a deep bay of Quaternary enters the range, nearly cutting it into two separate parts. The northern part, which displays the characteristic Palæozoic rocks around the western and northern margin of the body, is depressed far below the level of the Shoshone Peak mass. Basaltic rocks have broken out of a meridional fissure, flowing off eastward in gentle, inclined tables. An area of basalt is thus formed, measuring sixteeen to eighteen miles from north to south, and nearly as much from east to west. The lofty region is a plateau-ridge extending north and south, which from both extremities sends out to the northeast secondary ridges, that slope gradually down to Humboldt Valley. Between these two ridges is the Quaternary depression of Whirlwind Valley. The main and earlier flow is a fine-grained gray dolerite, with a moderate amount of grayish, globulitic base, and for crystalline secretions, plagioclase, augite, olivine, and magnetite. Near the western escarpment of the main basaltic table a rude columnar tendency is noticeable in these gray dolerites, and in sections of the columns a tendency to develop globular forms by the flaking off of thin, concentric shales. Numbers of these doleritic balls roll down the slopes to the west, and might easily be mistaken for volcanic bombs, if not traced to their source. Through these crystalline dolerites break out several vertical dikes of a brilliant black basalt rich in acidic glass. These more recent basalts are very fine-grained, never showing any macroscopical crystalline secretions. The microscope discovers them to be made up of minute crystals of colorless plagioclase, fine globules of olivine, and yellowish-brown augite, the whole interspersed through a largely prevailing base of dark-brown acidic glass. Both the gray dolerite and the glassy basalt are more or less covered by a thin varnish of hyalite, which in some cases thickens, with a botryoidal surface, to a fourth of an inch.

The broad field of basalt which covers the surface of Shoshone

Mesa shows on the escarped edge of the table lands about 1,000 feet of basalts, in nearly horizontal layers of varying thickness. At Stony Point, the highest summit of the plateau, the basalts are rather light brown, with a mottling of green material. The rock is often vesicular, and is exceedingly fine-grained, no crystalline ingredients being visible to the unaided eye, with the exception of some sparingly distributed pale plagioclases and grains of dark, pellucid quartz. The olivine is very dark, and approaches magnetic iron in appearance Even under the microscope augite is rare. The occurrence of quartz in a true dolerite entirely free from sanidin and possessing a normal percentage of silica, is certainly very remarkable; but the crystals must be considered as purely accidental accessory ingredients. The predominating rock of the whole Mesa is a normal dolerite, which is rather porous, the vesicles being filled with carbonate of lime. Coarse-grained varieties are most common, in which plagioclase, augite, and olivine appear as plainly visible macroscopical secretions, the microscope adding apatite and magnetite and an amorphous base. For the chemical analysis of this rock, see Table XII.

At Jacob's Promontory, associated with Carboniferous quartzites, augite-andesites, trachytes, and rhyolites, occurs a small field of basalt, forming the latest extrusion and the middle of the group of hills. It is often quite vesicular, the cavities being more or less filled with carbonate of lime. The rock is made up of augite and plagioclase, with very little olivine.

The few basaltic occurrences in the Augusta Mountains are of little importance. They are simply limited outflows of dikes that in each case have broken through rhyolite and are completely surrounded by that rock. They belong without exception to the type with globulitic base, contain more or less olivine, and are of no geological interest except as emphasizing the earlier occurrences of augite-andesite in their neighborhood.

In connection with the rhyolite which forms the great outburst of the Fish Creek Mountains, there is surprisingly little basalt. Only a few restricted outcrops occur along the northwestern foot-hills, where they have broken through the rhyolites and flowed toward the west in low, unimportant tables. The chief geological interest of the basalts here, as already alluded to under the head of rhyolites, centres in the flows of basalt which have come to the surface through true craters in the little rhyolite volcanic cones. Lithologically these rocks consist almost exclusively of feldspars. a fine, partially globulitic base, and large included crystals of sanidin. Neither in the hand specimens nor under the microscope is the base resolvable into its constituent minerals. It is a fine, grayish-black, compact, uniform rock, in which only the large sanidins are visible. The occurrence of orthoclastic feldspars in the basalt, always rare, is of interest here since the basalts have come to the surface through highly acidic rocks, whose chief constituent is also sanidin.

The small patches of basalt connected with the granite region between Ragan's Creek and Rocky Creek, in the Havallah Mountains, have little petrological or geological significance. On the other hand, the body which lies along the eastern base of the range, in the region of Golconda Pass, is interesting as coming to the surface over rhyolites and as finding its exit near the abrupt termination of the great body of Triassic strata which make up the main mass of the range.

A glance at the geology of Pah-Ute Range shows that its basalts are confined to the middle third, and consist of three independent masses: the Table Mountain body; the thin, interesting outflows from dikes which have cut the various rhyolites of the Sou Springs group; and the large, little studied body which lies north of Granite Mountain, along the eastern base of the range. The Table Mountain and Sou Springs bodies are both easily related to the lines of weakness due to prior disturbance of the range. The former comes to the surface through rhyolites and in the immediate vicinity of the great diorite body of Chataya Peak, where a block of the Triassic strata has been ingulfed. The Table Mountain basalt body is one of the most interesting specimens of massive eruption in this whole region. It consists of nearly horizontal tabular sheets imposed one upon another, culminating in the long, level plateau ridge of Table Mountain, which has a height of fully 4,000 feet above the valley to the west. To the east it is escarped down for a thousand feet, where its lowest exposed beds are seen to rest upon rhyolite. Westward the declivity of the hills shows the edges of the heavy basaltic tables nearly down to the plain, where the bedding grows less distinct, and the body projecting northwestwardly toward Buffalo Peak seems to be a relic of true flow. It is not unfrequently the case in the Great Basin that basaltic tables cap a high ridge, showing in their descent in every direction the escarped edges of horizontal beds. It is a little difficult in such cases to determine the loci of outflow. In the present instance it appears that the fissure which gave vent to the material was in the neighborhood of Table Mountain, that the viscous ejections flowed off in every direction, leaving nearly horizontal surfaces, and that subsequent erosion cut away the flanks of the body, exposing the edges of successive sheets. On examining the contact-planes of the different beds of basalt, they are sometimes seen to merge together with a continuity of material; and in others again there is a little volcanic dust or basaltic rapilli separating successive flows; and it is not uncommon where heavy beds are superposed one upon another for the vertical or highly inclined jointings through a given sheet to cease at the plane of contact with the next bed, which in turn may develop an entirely different set of joints.

At the hills north of Sou Springs, basalts appear only as the limited outflow from a system of dikes. It is as interesting an instance as may be seen anywhere within our field of the direct superposition of basalt over rhyolite. While the underlying acidic rocks are notable for their glassy and porcelaneous groundmass and the almost total absence of crystallized material, these basalts represent the other petrographical extreme and are unusually free from the glass base so common in Nevada basalts, and inversely rich in crystallized materials, of which well preserved augites, brilliantly striated plagioclases, and a little olivine form the bulk. The rock is sometimes slightly porous, but often very compact, with a bright, steel-gray color. In its geological habit there is a noticeable absence of the well defined horizontal bedding shown at Table Mountain, although the petrological characteristics of the two rocks are essentially identical. A large basaltic field which occupies the eastern flank of the range north of Granite Mountain, like the Table Mountain group, is made up of distinct beds, which likewise dip toward the valley, having an easterly inclination of from 3° to 8°, with an average of 5°; a position which may not improbably be referred to the original inclination of the outflow. The basalt here reaches 3,600 feet above the plain, and is deeply scored by cañons which show a great thickness of material. It bears very close resemblance to the other basalts of the range, and, like them, is characterized by a large amount of crystalline minerals and little glassy material. The northern half of West Humboldt Range may be considered as an isolated block displaced upwardly from its direct geological connections. Its margin is more or less marked by narrow exposures of basalt, which are always at the junction of the foot-hills with the neighboring desert valleys. They are comparatively unimportant, and are only noticeable for the fact that as a group they repeat the characteristics of the Pah-Ute basalts as to the absence of glassy or globulitic material and the prevalence of defined crystals. As a rule, the West Humboldt basalts are of an exceedingly fine grain, olivine alone being visible to the naked eye. The basalt of Eldorado Cañon is noted by Zirkel as a rather rare rock, being entirely crystalline, with olivine as the sole macroscopic constituent. The microscope reveals plagioclases and augites, the latter remarkably well crystallized and showing a zonal structure; the olivines contain picotite.

Of the basalts of the southern half of the range, those which lie southeast of Oreana are the outflowing of northwest-southeast dikes, which are seen in the form of bedded masses inclining to the east. They are chiefly a very vesicular rock, whose pores are for the most part filled with a soft, crumbling calcite not improbably derived from the adjacent limestones, the basaltic material being quite undecomposed.

Directly east of Lovelock Station, the foot-hills of Humboldt Range are again overflowed by basalts which here have broken through about on the line of junction of the steeply inclined Triassic series and the gently disturbed Miocene beds. The basalts, which are dark, vesicular rocks, rather finely crystalline, have steel-gray and reddish-gray colors, and show to the unaided eye only olivines. They are specially interesting geologically, since they occupy a shallow, saucer-like depression eroded on the edges of the Miocene beds. It is noteworthy that these Miocene beds were upheaved prior to the rhyolite eruptions, that the stratified series themselves are largely composed of trachytic material rearranged in a fresh-water lake, and that between their uptilting in connection with the rhyolitic disturbances and the appearance of the basalts, there has been a very considerable erosion. This would indicate for this region quite an interval between the rhyolitic and basaltic periods. Such a period of volcanic quiet is further indicated by the fact of the basalts frequently occupying valleys and depressions in the rhyolite, which were evidently not accidents of original structure, but decidedly the effects of erosion. No special study has been given to the scattered masses of basalt which have come to the surface through the Triassic beds to the south, and these minor basaltic masses are of no special interest, unlike the one at the western end of the Mopung Hills, which is an excellent sample of the superposition of basalts over rhyolites.

Montezuma Range, one of the most heterogeneous pieces of geology in the whole region, has three prominent basaltic areas. The ancient Archæan mass which culminates in Trinity Peak is cut off northward and southward by sharp depressions. That at the north is occupied by low, gently rolling hills of soft Miocene beds, through which a heavy dike of basalt has burst up, forming a well defined ridge having a northwest-and-southeast direction and rising above the level of the desert and of the Miocene formations from 1,000 to 1,200 feet. At the southern end of the Archæan body is another topographical depression in which is an enormous flood of heavy bedded black basalt cutting diagonally across the range, having a northwest trend parallel with the Indian Pass body.

The minor occurrences of basalt margin the ends of the granite spurs which border on Humboldt Valley in the region of Antelope Peak. The southern termination of the range shows a large number of small basaltic eruptions. Coming to the surface through the rhyolites, and where the two rocks are exposed by modern degradation, there is ample evidence of considerable erosion of the rhyolites prior to the outpouring of basalts. Physically, the two northwest-southeast basaltic bodies bordering upon the older rocks in the middle portion of the range are essentially a bedded series. They are exposed in deep cañons and show not less than 1,200 or 1,500 feet of superposed beds. On the contrary, the basalts of the southern end of the range are irregular masses, covering ridges or extended as in lava streams. When closely examined, these latter deposits, especially those in the mouth of Bayless' Cañon, are indeed bedded, but on a smaller scale and with less conspicuous planes of division than the broad masses to the north.

The Montezuma basalts show a very considerable variety of texture and color, passing from dark chocolate-brown into steel-gray and certain greenish shades, due to the prevalence of olivine. As a whole, they have a common likeness, due to the abundant presence of glassy and globulitic base, giving them in general a strongly vitreous lustre upon the newly broken surfaces, and producing in extremely glassy varieties an almost flinty fracture. In this respect they offer a complete contrast to the neighboring basalts of Humboldt and Pah-Ute ranges. The microscope shows this family of basalts to be extremely poor in large, well defined augite crystals, that mineral almost always occurring as minute microlites or as small shattered prisms, always inferior in size to olivine and in crystalline finish to plagioclase. The olivines in the basalts near White Plains are characterized by an abundance of picotite. In the same rock are associated remarkable structures of magnetite crystals.

The northwesterly trend of the two large basaltic bodies of Montezuma Range is noteworthy as belonging to a series of northwest fissures, which become evident in approaching the Sierra Nevada.

The granites of Granite Point are largely overflowed by powerful outbursts of gray and black, more or less vesicular basalt, which is seen to overlie the rhyolites and to slope toward the desert to the east, with a defined bedding. At Lovelock's Knob, also, the granite and overlying rhyolite are broken through on the north base of the hills by a small overflow of basalt, which is a close-grained, half glassy rock, containing no macroscopical individuals except olivine, breaking with a distinctly conchoidal fracture and displaying upon fresh surfaces the characteristic vitreous lustre of a basalt rich in glass base. Similar but somewhat less glassy basalts are found in small, detached outcrops north of Brown Station. This little group partly breaks through and overlies the rhyolites of the main range and partly rises as low, detached outliers, lifted above the Quaternary of the desert. These latter are extensively incrusted by thinolite, the remarkable pseudomorphic tufa of Lake Lahontan.

The little group of Kamma Mountains geologically repeats many of the leading conditions of Montezuma Range. The basalts, however, of which there are two separate groups, come to the surface at the highest parts of the range and are in contact with the older Archæan formations, and at the same time break through and overlie the rhyolites. The group in the region of Aloha Peak is surrounded on all sides by rhyolites, except to the west, where the Archæan mass forming the east wall of Crusoe Cañon rises into contact with the capping basalt. Generally the rocks here are dark and vesicular, their only crystalline secretions being white specks, which the microscope shows to be plagioclases that have suffered more or less decomposition. The groundmass is finely crystalline, and there is a high proportion of amorphous, glassy base. They are also deficient in augites. At the northern point of the range, in Grass Cañon, the high summits are again of basalt, and have come to the surface and piled themselves up upon lofty, rugged masses of rhyolite. Not far from the mouth of Grass Cañon the basalts are of well defined columnar structure, the prisms lying horizontally. The material is vitreous, with sharp, conchoidal fracture, the eye discerning abundant plagioclases and the microscope adding augite and olivine in an amorphous, globulitic base. The rocks to the south of Basalt Peak, near the head of Grass Cañon, are heavy bedded, dark, richly augitic types, underlaid by basaltic tuff, which is of a dark-olive color and an earthy, crumbling texture, composed of dark-brown augite and shattered crystals of plagioclase, associated with abundant, very acidic brown glass. The latter fails to gelatinize when treated with acids, and has received the designation from Professor Zirkel of hyalomelane tuff. There is a much higher proportion of acidic glass than in any of the solid basalts of the region. It was doubtless an accumulation of volcanic sands blown from some neighboring orifice; the angular character of the minute glassy fragments closely resembling that of the glassy basaltic sands observed by the writer upon the Hawaiian Islands.

The remarkable level plains of Mud Lake Desert, in the northern portion of Map V., are surrounded on every side by more or less abrupt mountain masses rising like islands above the Quaternary sea. One of the most interesting of these is a low, rugged group of hills known as the Black Rock Mountains, which invades the desert from the north and lies directly west of the sink of Quinn River. Here is a mass of hills made up within the limits of our map entirely of rhyolites and basalts, the latter occurring in a series of ridges, presenting rather sharp, abrupt escarpments to the west and a gentle declivity to the east. It is not certain whether this position is due to flow or to tilting. The anomalous position of the rhyolites overlapping the base of the basaltic slopes gives rise to the idea that the whole region has suffered sharp dislocation since the basaltic period. At the extreme southern point of the range is a conspicuous basalt mountain rising 500 or 600 feet above the white desert. Examining the hand specimen, the rock is seen to have a very fine-grained, greenish-gray groundmass, in which plagioclase and amber-brown augites are conspicuous. Just north of this rock was collected a coarse dolerite in which the plagioclase crystals are an inch long. The augites also are a quarter of an inch in diameter, and stand out very roundly above the slightly vitreous groundmass. The true dolerites, always rare in the Fortieth Parallel area, occur here in considerable variety. The feldspars are always better crystallized than the augites, the hand specimen indicating little or no glass base, and the microscope revealing only a small proportion of globulitic material. The prevailing colors of the dolerite are dark, greenish-gray, weathering to dark-brown and black.

Near Hardin City, overlying the white rhyolitic breccias, is a series of basalts, the uppermost beds on the top of the cliffs being fresh, black, and lustrous, having an exceedingly resinous surface. The augites are shown by the microscope to be pale colored and few, often occurring only as microlites. Unlike the neighboring dolerites, they are entirely wanting in olivine, and the magnetite is highly altered, resulting in yellowish-brown, hydrated matter. Beneath these less altered basalts is a series of highly porous and very decomposed beds; the extreme results of decomposition being an earthy, green, spongy seladonite, and a waxy material consisting of alumina and silica, with a small percentage of alkalies and iron. Besides these earthy, green inclusions, many of the cavities are lined with botryoidal chalcedony, and others again have a botryoidal surface within their cavities, which is varnished over with a brilliant glaze of iron oxyd. The neighboring hills abound in geodes and ellipsoidal pebbles of chalcedony, which are the sole relic of decomposition, all the basaltic mass having passed through the seladonite phase, ending in disintegration and erosion.

This little group of hills is still further noticeable for the occurrence of two forms of basaltic tuff—one an earthy-looking mass which under the microscope is seen to consist altogether of partially decomposed augites and plagioclases associated with an enormous amount of acidic glass, which remains almost totally undecomposed, in sharp angular, wedge-like chips. There is little or no cement to hold these together, and like the similar tuffs of Pah-tson Range they are doubtless a simple accumulation of rather acidic basaltic sand. The other is a true palagonite-tuff, which receives special mention from Professor Zirkel in Volume VI., page 275. Unlike the palagonite of other Nevada localities, it is directly connected with basaltic eruptions, never having been rearranged and enclosed in the Tertiary strata; all the rest being distinctly stratified members of a conformable Miocene series. As has been seen, when treating of the Truckee Miocene, the other palagonitic beds altogether antedate the period of basaltic eruptions, and we have been led by their higher acidity to refer them to the augite-andesites with whose date of eruption the stratified palagonites sufficiently well agree.

Both the Black Rock palagonites, which are so intimately associated with the main basaltic eruptions as to be considered their dependent, and the Miocene stratified palagonites, must have undergone their characteristic metamorphism entirely without the presence of marine waters. If we are right in dating the Black Rock palagonites with the basaltic eruptions, there have been clearly two palagonite-making periods in Nevada.

West of the great Mud Lake Desert, and occupying the northwestern corner of our map, is the escarped edge and the broad, undulating surface of a great basaltic plateau The desert lowlands are walled in in that direction by a rampart of basalt from 1,200 to 1,500 feet in height, which either rises in steep slopes, as along its southern portion, or recedes in broad plateau steps, as at the north. Reaching the summit of this ascent, the country stretches west and north for a great distance in a gently undulating plateau, altogether of basalt, known as the Madelin Mesa. It is the beginning of that great series of basaltic fields which covers so large a portion of northern California, eastern Oregon, and Idaho. South of the Fortieth Parallel, basaltic areas are never very wide. No great province of the Cordillera is wholly free from occasional exposures of basalt, but there are elsewhere none of those enormous sheets which characterize the region to the north. In riding over hundreds of miles of this northern country, whose surface is made up of apparently continuous sheets of basalt, one has constantly forced on him the question, whether these broad fields are sheets which have come to the surface and flowed out, covering wide areas, or whether the whole country beneath them is riven with basaltic dikes, whose overflows have mingled or piled one upon another, forming a general plain. An examination of a considerable part of Shoshone or Snake River, which flows for over a hundred miles through a sheet of basalt, has inclined me to the belief that, in some cases at least, the basalts have flowed for a very long distance.

For many miles the great section of the volcanic Snake plain, as shown by the cañon, consists of a trachytic underlying body, whose surface indicates hills of several hundred feet in height, capped by a series of thin, superposed sheets of basalt, which for very many miles received no addition by new eruptions; long distances of the trachytic wall showing no volcanic dike whatever. So, too, in Cascade Range, the long basaltic streams which flow down the western slope have frequently received no reinforcement by new dikes throughout the whole length of their flow, which often exceeds fifty miles. The power of basic lavas to retain their heat, and consequent fluidity, making exceedingly long flows, is well known, and there seems to be no strong reason to doubt that these great mesas, like that of the Madelin and of the Snake plain, may be simple sheets spread out over a country which itself contains few or no basaltic dikes.

A considerable stretch of granite ranges, noticeable for their Tertiary eruptive rocks, separates the northern and southern basaltic regions of Truckee Range. Along the western foot-hills of the northern terminus of the range, the elevated granite mass is edged by low hills of basalt, which are of no considerable orographical importance, but the southern region and the angle between the railroad and Truckee River from Natche's Pass to Desert

Station, offer a most interesting exhibition of basaltic rocks. The mountain ridge, at an elevation of 4,500 feet above the adjacent valleys, is for the most part covered with heavy accumulations of basalt. That the entire body of this elevation is not made up of basalts, is clearly seen by the points of diabase and rhyolite which rise above its surface, and the broad mass of metamorphic Triassic strata and diabases which interrupt the basalts in the region of Miner's Cañon. Along the southern margin of the basaltic foot-hills are innumerable highly scoriaceous, rudely globular fragments of basalt, which lie disposed about on the desert far from any line of drainage, suggesting by their appearance and isolation the idea that they are volcanic bombs. The extremely diversified volcanic topography is chiefly made up of irregular ridges and spurs, which when studied in detail are found to be composed of rather thinly bedded, dark basalts, each ridge having its bed inclined down both flanks, after the manner of an anticlinal. In fact, a section of each separate ridge or prominent spur would show a clear arched structure of volcanic flows. Between successive beds there is a little débris or dividing matter. Occasionally large steam-cavities, evidently made by molten basalt rapidly overflowing a pool of water, are seen. Some of these steam-cavities are eight or ten feet in diameter, and the interior walls are remarkably even and smooth. It is interesting to observe the basalts in immediate contact with the earlier diabases, the two augitic rocks are so entirely different in geological habitus. The older rocks uniformly occur as a structureless, massive body showing none of the bedding or evidences of flow which the basalt everywhere indicates. The arched structure of all these basaltic ridges is unquestionably to be accounted for as the direct overflow of dikes. The continued eruption through long, vertical dikes has effected the piling up of the centres of the ridges, while the sheets of molten material poured down either side. As the operation continued, the centre grew faster than the flanks; and for the uppermost beds the result was quite a steep arch. In the immediate neighborhood of the diabase hills, the lower basalts, representing the earliest flows which are exposed, are of a highly crystalline type. They are rich in olivine and poor in augite. The olivines change into a reddish-brown material, not unlike the brown serpentine of the diabase olivine. This type of rock is extremely rare here, and nowhere appears among the more important and later eruptions. The character of these is somewhat peculiar. Crystalline minerals are reduced to a minimum, the microscope showing a considerable number of twin plagioclases and a small amount of sanidin, which, however, is large for basalts. The augite is rather pale and never over-plentiful, and the olivine shows at times a slight alteration into serpentinous material. Picotite is not infrequent in the larger olivines. But the most remarkable characteristic of the basalt is the very large amount of acid glass which fails to gelatinize under long digestions in acids. Nearly all the basalts of this neighborhood, certainly all the later eruptions, have a peculiar flinty fracture, and although the steel-gray or brown surface may in extreme sunlight show a brilliant steely lustre, due to minute crystalline ingredients, yet the resinous lustre of the highly glassy rocks predominates. It is interesting to note that in the presence of this highly acidic glass the more acidic feldspars also occur. The average proportion of silica, fully 55 per cent., as determined by tests, would indicate a relation with the augite-andesites were it not for the normal proportion of olivine, which at once removes the rock from the andesite family. The basalts of this particular region have been fully treated in Volume VI., page 233 *et seq.*

The importance of the basalts of the Kawsoh Mountains is due rather to their geological connections than to any special petrographical interest. They have come to the surface through cracks and fissures in upturned Miocene beds, and have poured over a surface which was much modified by erosion after the uplift of the beds and before the outpouring of the basalts.

In the Miocene section of Chapter V. of this volume is discussed the evidence as to the age of these lacustrine Tertiary beds, evidence which has led quite conclusively to their Miocene date. Across the little valley which separates the Kawsoh from Montezuma Range, at the foot of the latter hills, near White Plains, these Tertiary beds are seen to be invaded and disturbed by rhyolitic eruptions. The beds themselves are largely made up of andesitic and trachytic tuffs, yet the trachytic rocks which occupy the northeast corner of Kawsoh Range would seem, from their relative position to the Tertiaries, to be more recent. It is probable, therefore, that the upheaval took place near the close of the age of trachytic outflows, an enormous amount of ejecta being represented in the rearranged Tertiary beds.

In the superposition of basalts at White Plains above the rhyolites, and in the Kawsoh Mountains above the well defined Miocene series, we have a very direct piece of evidence as to the real geological age of the basalts. The basalts of the Kawsoh group have a rugged surface rising to 1,200 feet on the southwestern elevations. The ridges and hills show a very great variety of rough, lava-like surfaces, and at the northeastern limit of the hills, near Mirage Station, are seen some evidences of considerable dislocation since the basaltic flow. There are masses of Tertiary with a tilted cap of basaltic beds at an angle evidently higher than that of natural flow in position, which cannot readily be accounted for otherwise than by their direct uplift. Near the northwest base of the hills are hot springs, interesting from their proximity to the basalts and from their considerable tenure in boracic acid. Petrographically, these basalts belong to the family just described in Truckee Range. They have always a low proportion of defined augite crystals, whose colors are usually delicate and pale, with considerable olivine. But rather the most characteristic feature is the abundance of globulitic, half glassy, or purely glassy base, which occurs either as inter-wedged, cuneiform inclusions, or as a true ground-paste. Scoriaceous and finely porous rocks are not uncommon. Among the volcanic bombs found on the desert along the western margin of the range are many dark, almost brick-red globes of basaltic scoria, the innumerable pores lined either with a pale-lilac or a brick-red varnish-like coating. Some of these large blocks, one or two feet in diameter, are found almost as light as a sponge.

Near the south point of the group a rather compact, fine-grained basalt was found, in whose pores Professor Zirkel discovered microscopical tridymite in hexagonal laminæ precisely as they occur in rhyolites and trachytes. The occurrence of infusorial silica in such enormous masses in the very beds through which these basalts have come would seem to furnish a near source for foreign silica, and to indicate that the basalt during its passage up a fissure through the soft, infusorial silica might easily have taken up portions of the earthy material, and by the influence of heat and pressure, together with some moisture, have produced the hexagonal tridymite.

The limited triangular group of hills south of Deep Wells repeats the geological conditions of the Kawsoh. It is a body of basalt superposed upon the upturned edges and inclined backs of dislocated Miocene strata. The basalts themselves are almost uniformly of the variety which is poor in developed crystals of augite and rich in amorphous globulitic glass.

From far to the south of the limit of Map V., Virginia Range, up to its northern extremity, is at various points covered by local sheets of basalt which, as usual, constituted the latest of the great series of Tertiary eruptions. In their physical mode of occurrence the basalts of Truckee Cañon are of interest, since their relation to the underlying trachytes and rhyolites shows that the line of depression where the river traverses the Virginia mountain-range was a pre-basaltic gorge. In the river bottom near Clark's Station the basalts overlying rhyolite and trachyte descend to the water-level. The high hills which rise to the south of the cañon are entirely covered with great sheets of heavy bedded basalts inclined toward the river, showing that the flow of the repeated eruptions was down the slopes of preëxisting trachyte mountains toward the bottom of the cañon. Post-basaltic erosion has certainly cut away the base of the basalt slopes which no doubt formerly filled the entire cañon bottom. The vents from which these basaltic flows must have come are far up on the southern hills. South of Clark's Station an important cañon opens into the range, displaying basaltic beds for a thickness of perhaps 2,000 or 3,000 feet.

North of the river the west portion of the range is made of rhyolites and trachytes, with a long meridional basaltic flow which covers all but the higher portion of the range. The petrological characteristics of these basalts are considerably varied. The rocks upon the south base of the upper portion of the cañon are composed of a rather coarse-grained anamesite rendered peculiar by the absence of olivine and the presence of a brownish-gray globulitic amorphous mass. The flows which reach nearest to Truckee River a few miles above Clark's Station are extremely fine-grained passages of the same anamesitic type. North of the cañon all the basalts

Number of analysis.
167
168
169
170
171

Basalts.

Number of analysis.	Locality.	Analyst.	S̈i	Al	F̈e	Ḟe	Ṁn	Ċa	Ṁg	Ṅa	K̇	L̇i		Ignition.	Total.	Specific gravity.	Oxygen ratio of— Ṙ	R̈	S̈i	Oxygen quotient.
167	Summit of Elkhead, Geodetic Point	R. W. Woodward	48.60 25.92	15.78 7.35	3.22 0.96	7.21 1.60	. .	[illegible].34 [illegible]	10.13 4.05	3.77 0.97	1.65 0.28	tr.	PO^5 0.11	1.30	100.11	2.7, 3, 2.8	9.28	8.31	25.92	0.678
	" " "	"	48.46 25.84	15.61 7.27	3.44 1.03	7.21 1.60	. .	8.33 2.38	9.89 3.95	3.84 0.99	1.68 0.28	tr.	PO^5 0.11	1.30	99.87	. .	9.20	8.30	25.84	0.677
168	Edge of cliff, Stony Point Range -	"	48.40 25.81	17.95 8.36	2.28 0.68	8.85 1.96	tr.	10.05 2.87	6.99 2.79	2.86 0.74	1.03 0.17	tr.	TiO^2 0.24 (0.09) CO^2 0.84	0.34	99.83	2.8, 2.8, 2.8	8.53	9.04	25.90	0.678
	" " "	"	48.38 25.80	18.45 8.59	2.12 0.64	8.90 1.97	tr.	10.32 2.94	7.02 2.81	2.73 0.70	1.03 0.17	tr.	TiO_2 0.24 (0.09) CO_2 0.84	0.25	100.28	. .	8.59	9.23	25.89	0.688
169	Buffalo Peak, North Park - - -	"	49.04 26.15	18.11 8.44	2.71 0.81	7.70 1.71	tr.	7.11 2.03	4.72 1.89	4.22 1.09	2.11 0.35	. .	TiO^2 2.46 0.96	1.29	99.47	2.7, 2.7, 2.8	7.07	9.25	27.11	0.602
	" " "	"	49.01 26.14	18.32 8.53	2.63 0.79	7.74 1.72	tr.	7.14 2.04	4.72 1.89	4.21 1.08	2.18 0.37	. .	TiO^2 2.55 0.99	1.35	99.55	. .	7.10	9.32	27.13	0.605
170	Three miles Northeast of Wadsworth, Nevada.	"	53.94 28.76	17.05 7.94	2.93 0.88	7.15 1.59	tr.	7.41 2.11	4.67 1.87	3.45 0.89	2.19 0.37	. .	. . .	1.10	99.89	2.6, 2.7	6.83	8.82	28.76	0.544
	" " "	"	53.98 28.78	17.05 7.94	3.00 0.90	7.09 1.57	tr.	. .	. .	3.41 0.83	2.23 0.38	. .	. . .	1.10	. .	. .	. .	. .	. .	. .
171	Ombe Range, Nevada - - - -	"	54.80 29.22	17.58 8.19	0.97 0.29	8.84 1.96	tr.	8.22 2.35	4.47 1.79	3.14 0.81	1.16 0.19	. .	. . .	CO^2+HO 0.94	100.12	2.5, 2.6	7.10	8.48	29.22	0.533
	" " - - - -	"	54.79 29.22	17.59 8.19	0.94 0.28	8.85 1.96	tr.	8.13 2.32	4.54 1.81	2.97 0.76	1.16 0.19	. .	. . .	CO^2+HO 0.98	99.95	. .	7.04	8.47	29.22	0.531

TA

Number of analysis.	
172	D
173	E
174	A
175	T

DIABASES AND DIORITES.

Diabases.

Number of analysis.	Locality.	Analyst.	S̈i	Äl	F̈e	Ḟe	Ṁn	Ċa	Ṁg	Ṅa	K̇	L̇i		Ignition.	Total.	Specific gravity.	Oxygen ratio of— Ṙ	R̈	S̈i	Oxygen quotient.
172	Diabase Hills, Northeast from Wadsworth, Nevada	R. W. Woodward	54.52 29.07	19.10 [illegible]	2.83 [illegible]	5.89 1.31	tr. . .	7.25 2.07	3.92 1.57	3.73 0.96	2.30 [illegible]	. .	TiO² trace.	0.59	100.13	2.6, 2.7	6.30	9.85	29.67	[illegible]
	" " "	"	54.80 [illegible]	19.10 [illegible]	2.67 [illegible]	5.90 [illegible]	tr. . .	7.26 [illegible]	3.78 1.51	3.74 0.66	[illegible]	. .	TiO² trace	0.62	100.17	. .	6.24	9.80	29.22	0.54[illegible]

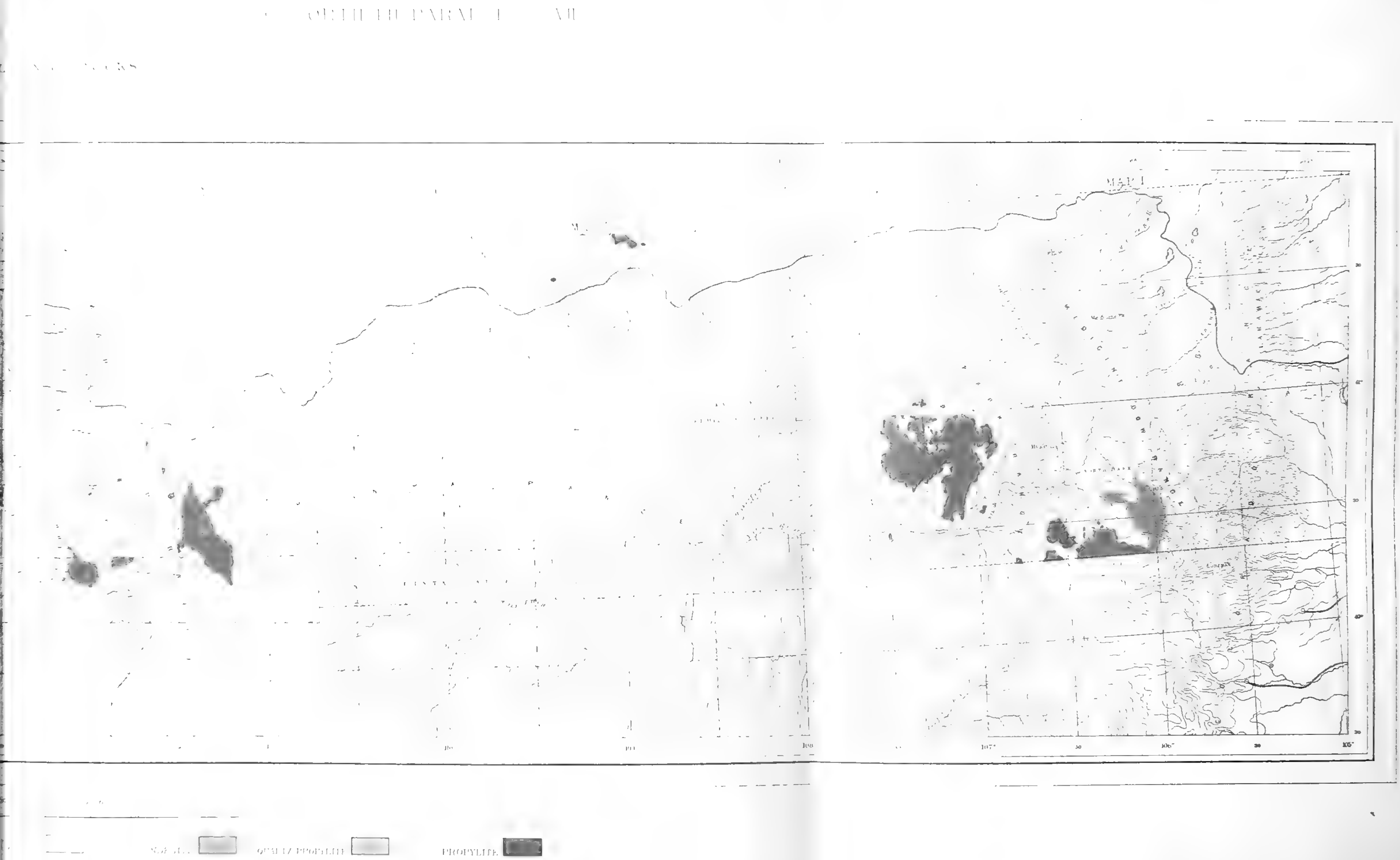
Diorites.

Number of analysis.	Locality.	Analyst.	S̈i	Äl	F̈e	Ḟe	Ṁn	Ċa	Ṁg	Ṅa	K̇	L̇i		Ignition.	Total.	Specific gravity.	Oxygen ratio of— Ṙ	R̈	S̈i	Oxygen quotient.
173	Eldorado Outcrop, Mount Davidson.	R. W. Woodward	56.71 [illegible]	18.36 [illegible]	. .	6.45 1.43	. .	6.11 1.71	3.92 [illegible]	3.52 [illegible]	2.38 [illegible]	. .	. . . .	1.94	99.39	2.86, 2.88	6.05	8.55	30.24	0.482
	" " "	"	56.58 30.17	18.20 8.43	. .	6.30 1.40	. .	5.99 1.71	3.83 [illegible]	3.58 [illegible]	2.41 [illegible]	. .	. . . .	1.96	98.85	. .	5.97	8.48	30.17	0.479
174	Agate Pass, Shoshone Range - -	"	58.14 31.00	16.68 7.77	None.	5.62 1.25	tr. . .	6.00 1.71	5.22 2.09	2.76 0.71	2.5[illegible]	. .	. . . .	2.15	99.47	2.8, 2.7	6.18	7.77	31.00	0.450
	" " - -	"	58.24 31.06	16.85 7.85	None . .	5.59 1.24	tr. . .	5.92 [illegible]	5.33 2.13	2.78 0.71	2.50 0.42	. .	. . . .	2.23	99.44	. .	6.19	7.85	31.06	0.452
175	Three Peak Mountain, Shoshone Range.	"	60.20 32.10	18.55 8.64	. .	4.37 0.97	tr. . .	4.41 1.26	2.20 0.88	3.20 0.83	3.87 [illegible]	tr. . .	. . . .	2.97	99.77	2.6, 2.7	4.59	8.64	32.10	0.412


113°

GEOLOGICAL MAP OF THE

TERTIARY


MAP I
QUARTZ PROPYLITE
PROPYLITE

are of the ordinary feldspar variety, and poor in the globulitic or glassy base. The triclinic feldspars are correspondingly large, and the olivines small.

At the entrance of the cañon, opposite the andesite flows which form the southern hills, is a body of sanidin-trachyte overflowed by black vesicular basalt which is for the most part a compact, fine-grained rock with few macroscopic crystals and little globulitic base. The microscope shows it to be made up of abundant triclinic feldspars, extremely minute olivines, a high percentage of magnetic iron, and occasional apatites.

SECTION VI.

CORRELATION AND SUCCESSION OF TERTIARY VOLCANIC ROCKS.

Quantitative Chemical Relations.—Regarded from a chemical point of view, the Tertiary volcanic rocks of the Fortieth Parallel conform in general to the law of Bunsen. A reference to the tables of chemical analyses given with the section devoted to each rock will disclose the fact that there are no wide deviations from the numerical relations of constituents as laid down in that law. Further, a comparison with the published analyses of Roth shows a close parallelism with the type-rocks of the Old World.

Classing the various species by their silica equivalents, we have: 1. A series of acidic products—quartz-propylite, dacite, quartziferous trachyte, and rhyolite. 2. A group of chemically mean products—hornblende-propylite, hornblende-andesite, and the peculiar group of hornblende-plagioclase-trachyte. 3. A basic family composed of augite-propylite, augite-andesite, augite-trachyte, and basalt.

When we come to examine into the quantitative relations of these three chemical groups, it will be seen from the foregoing description of localities or from analytical Map VII. accompanying this chapter, that the acidic products as a whole are enormously in excess of the basic products, and that they are almost equally in excess of the rocks of mean constitution. Certainly eight tenths of the basic ejections are of basalts, the latest of the whole series. Recalling that the basalts have in a great majority of cases outpoured from the vents of former acidic eruptions, and generally partially, sometimes wholly, covered the early siliceous rocks, and that, in spite of this considerable burial, the actually exposed area of the highly silicated rocks is still far in excess of the basic ejecta, we see at once that the rocks of Bunsen's normal trachytic magma are quantitatively very far in excess of the normal pyroxenic magma Furthermore, they far exceed the sum of the basic and mean rocks.

Having seen a very considerable portion of the volcanic field of the West from the Mexican line to Washington Territory, I am convinced that this quantitative law holds good for the whole Cordilleras of the United States. A geological map alone, without a correct knowledge of the underlying rocks, conveys but a crude idea of the actual and relative amounts of extravasation of the various species. For instance, the great basaltic plain of the upper Shoshone Valley on a map of ordinary geographical scale could only be laid down as a continuous field of basalt, but an examination of the cañon walls of Snake River, and the mountain flanks bordering the basin, shows even there a probable quantitative predominance of acidic trachytes.

So, too, all we know of the great chain of massive eruptions and volcanic cones which have built up their prodigious floods of ejecta along the axial region of the Sierra Nevada and Cascade ranges, in like manner shows that the acid rocks enormously predominate. An erroneous impression may also be derived from geological maps, from the well known property of pyroxenic species to retain their fluidity far longer than the trachytic type, and in consequence to flow out in thin sheets, covering more area than an equivalent amount of acidic rock. This property of retaining fluidity is obviously in direct accord with the actual temperature of fusibility of the pyroxenic magma, which can retain fluidity at a considerably lower temperature than the acidic magma. Yet it is doubtful whether this property alone is enough to account for the great difference of habit of flow between the two opposing types, and it will be argued in the sequel that the pyroxenic rocks in general have reached the surface in an actually hotter state than the acidic ones.

In spite of the enormous basaltic fields of Oregon and Washington Territory, all the great cones thus far examined are trachytic, with the exception of two which are of andesite. And a very great number of exposures in the region of the broad basaltic areas show heavy underlying acidic bodies like that of Shoshone Plain. To all these must be added the vast series of acidic tuffs bedded in the Miocene and Pliocene lakes of

Nevada, Utah, Idaho, Oregon, and Washington, besides the Miocene volcanic acid mud-beds exposed in the coast series of rocks through Oregon, California, and Mexico. Taken as a whole, there is without doubt a very great predominance of acidic rocks.

In the Fortieth Parallel area the various species, beginning with the most abundant, stand in the following quantitative order:

1. RHYOLITE.
2. BASALT.
3. TRACHYTE.
4. ANDESITE.
5. PROPYLITE.

A comparison of the quantitative relations of the augitic, quartzose, and mean products of the last three groups shows in general terms a similar result.

Quartz-propylite exceeds normal hornblende-propylite, and that has a far greater volume than augitic propylite.

Dacite and normal hornblende-andesite far outweigh augite-andesite.

So, too, true augite-trachyte is much rarer than sanidin-trachyte and comparatively of unimportant mass.

Whether, therefore, we view the whole series of volcanic products together, or whether we study only separate groups, the pyroxenic magma is quantitatively inferior.

A detailed quantitative scale would therefore be:

1. RHYOLITE.
2. BASALT.
3. TRACHYTE.—*a.* Sanidinic and Quartziferous.
   b. Hornblendic with much Plagioclase.
   c. Augitic.
4. ANDESITE.—*a.* Dacite.
   b. Hornblendic.
   c. Augitic.
5. PROPYLITE.—*a.* Quartziferous.
   b. Hornblendic.
   c. Augitic.

In this expression the augite member always fails to equal the mean or highly acidic type member of the group, with the single exception of basalt, which has no heretofore recognized acidic correlative. In the succeeding section I shall attempt a somewhat new feature of classification, in which basalt and rhyolite will be thrown into a generic relation, and it will be argued that rhyolite is the acidic member to be coupled with basalt.

THE LAW OF RICHTHOFEN.—While Bunsen's remarkable law offered a thoroughly satisfactory chemical scheme, a sort of projection on which the chemical latitude and longitude of volcanic products might be laid down, as in any way affording a key to the natural succession of volcanic rock it was soon seen to be totally valueless. The frequent sequence of certain pyroxenic species after trachytic seemed at first to warrant the prevalent belief that the liquid interior, as deep as it was the source of ejected rocks, was arranged by its relative acidity in two zones of the normal magmas of Bunsen, and that the lighter acidic magma, since from its lower specific gravity it must lie nearest the surface and hence be erupted first, would of necessity be followed by the deeper, heavier, pyroxenic material. But when the minute results of petrographers came to be carried into the field, it was found that the actual succession of volcanic products was excessively complicated, and that the simple and beautiful law of Bunsen gave no clew whatever to the causes or relations of the observed natural sequence.

Petrographers most often contented themselves with a laboratory study of the mineral constitution of species, and while the science gained in complexity under their hands, it likewise equally fell into confusion from the geognostical point of view.

In 1860 Richthofen* first announced his law of the Natural Succession of Volcanic Rocks, a statement more fully expressed and illustrated in his classic memoir on the "Principles of the Natural System of Volcanic Rocks."†

Richthofen's scheme of "the succession of *massive* eruptions during

* Jahrbuch der K. K. geologischen Reichsanstalt in Wien, Vol. XI.
† Memoirs of the California Academy of Sciences. Vol. I. 1867.

the Tertiary and Post-Tertiary ages" is as follows, beginning with the most ancient group:

1. PROPYLITE
2. ANDESITE.
3. TRACHYTE.
4. RHYOLITE.
5. BASALT.

As already announced in the opening of this chapter, the great number of widely spread volcanic occurrences discovered and studied by this Exploration offers but one obscure, questionable exception to this chemically singular sequence. I have also taken into this comparison the results of many thousands of miles of geological travel in other parts of the Cordilleras, and in no case have I to report a valid exception to the law.

Certainly it may be said with all safety that our ten years' labor has resulted in the complete establishment of what can only be called the Law of Richthofen.

This author, in his Classification of Volcanic Rocks, in the remarkable memoir already cited, divides the order andesite into, 1, hornblende-andesite, and 2, augite-andesite—separating the order propylite into, 1, quartziferous propylite or dacite; 2, hornblende-propylite; 3, augitic propylite.

Since the date of his production it has been found that quartziferous eruptions were common to both the orders propylite and andesite, and that the two products, besides their time-separation, were microscopically distinguishable by a variety of permanent characteristics, being the same points which clearly separated propylite from andesite, with the added difference that the quartzes of quartz-propylite carry fluid, while those of dacite or quartziferous andesite bear only glass inclusions; the main essential difference being that the irregularly cleavable green hornblende made of staff-like microlites is common in and confined to the hornblendic and quartzose propylites, while the brown-black bordered hornblende is similarly confined to the andesites and dacites. For the other concurrent diagnostic points of difference, the reader is referred to Zirkel's memoir.*

This separation has had the result of fixing dacite as the quartzifer

* Geological Exploration of the Fortieth Parallel, Vol. VI., pages 133 and 141.

ous member of andesite, with which its time-relation also concurs, and places the proper quartziferous propylite as an acid member of the propylitic order.

The list of volcanic rocks has been further amplified through the labors of our corps by the addition to the order of trachytes of a characteristic augite member. This rock, composed of sanidin and augite with inferior amounts of plagioclase and brown hornblende, is one of the family of Tertiary eruptions, and succeeds the main if not all sanidin-trachyte ejections.

The law of Richthofen, as set forth by him, goes no farther than to assert the succession of the five orders as integers, not attempting to establish within the limits of single orders what the sequence of their subdivisions may be.

Since no one could claim that rocks so different as sanidin-trachyte and augite-trachyte, or dacite and augite-andesite, could be the superficial and post-eruptive differentiation by crystallization from the same magma, in order to complete the detailed law of natural succession it is necessary not only to prove the place in the series of each of Richthofen's orders as a whole, but to discover within each order the time-place of all the subdivisions.

Some progress toward this essential rounding out of the law has been made by this Exploration.

As regards the rhyolites and basalts, they are at present considered by petrographers as separate and independent rocks, the former having no augitic representation, and the latter no acidic variety, the few quartziferous basalts containing the mineral as an accessory ingredient which never enters into the composition of the groundmass.

The other three orders, however—propylite, andesite, and trachyte—all embrace quartziferous and augitiferous members besides the mean member, in which hornblende or biotite is rather abundantly present.

In the case of the propylite order we have but one obscure, much decomposed occurrence of the augitic member, that of the Lower Truckee Cañon, in which its relations to diorite, trachyte, rhyolite, and basalt are seen, but not to other propylitic forms. At Washoe quartzose and hornblendic propylite are seen in conjunction, and there quartz-propylite was considered to be later, but as since the period of these observations quartz-propylite and dacite have been separated, a doubt is thrown over the reading of that locality.

Otherwise the only contact between the two types was seen in Cortez Range, near Wagon Cañon, where the relations again are obscure, but where the quartz-propylite seems to have been the later eruption.

Within the order propylite, therefore, there is nothing fixed by our observations.

Among the andesites our results are both positive and are multiplied by numerous contacts.

First, as between andesites and propylites. At Washoe propylite is invaded and overlaid by both hornblende-andesite and dacite. The Wagon Cañon quartz-propylites are followed by both dacites and andesites. Berkshire Cañon propylites are earlier than andesites and dacites. There is no semblance of an exception to the law as between these two orders.

Secondly, within the andesite order we have at Wagon Cañon dacite cutting hornblende-andesite, and the same is true at Berkshire Cañon.

Wherever augite-andesite and hornblende-andesite are in contact, as at Jacob's Promontory, Augusta Range, and Wagon Cañon, the augitic rock is manifestly the later, and hence the latest of the three rocks. The sequence for the andesite order is therefore —

1. Hornblende-andesite.
2. Dacite.
3. Augite-andesite.

The general relations of priority established by Richthofen between trachytes and andesites hold uniformly good for the Fortieth Parallel area.

At Washoe both types of trachyte are later than hornblende-andesite. On the Traverse Mountains, near the west base of the Wahsatch, are little outcrops of andesite overspread by sanidin-trachyte. So in Palisade Cañon, at Crescent Peak in the Augusta Mountains, and in Virginia Range north of Truckee Cañon, trachytes are seen distinctly overlying andesite, both hornblendic and augitic. The dacites of Mullen's Gap and Berkshire are also capped by the heavy flow of sanidin-trachyte.

Within the trachyte order we have seen that there are three distinct types:

1. A hornblende-plagioclase-trachyte, in which triclinic feldspar nearly and sometimes quite equals sanidin, and in which the union of plagioclase and hornblende produces a habitus approaching andesite. From that rock, however, the plagioclastic trachyte may be readily distinguished by the character of the groundmass, which is unmistakable.

2. The regular sanidin-trachyte.

3. Augite-trachyte.

At Washoe and in Piñon Range, where the first two varieties are observed in contact, they are in the order mentioned, the plagioclase rock having a bedded and columnar structure. In volume it is evidently the least.

A fourth variety of trachyte, characterized by the abundant presence of granules of free quartz, constitutes a member parallel to the dacites and quartz-propylites, with the exception that the quartz of the trachytes in no case enters the constitution of the groundmass, but is present in purely segregated granules, rarely or never dihexahedral, and never appearing of microscopic size.

Besides the true augite-trachyte, very many exposures of the sanidin species contain accessory augite, either in the presence of biotite or associated with hornblende. This occurrence resembles the case of accessory augite in the true hornblende-andesites. There is never enough augite to produce the true pyroxenic habit.

The quartziferous trachytes only occur in presence of the other varieties in Wah-Weah Range, where their relations of succession were not made out.

The andesitoid-trachytes, characterized by the presence of plagioclase in proportion nearly equalling the orthoclase and sanidin, are invariably earlier than the true sanidin types. All the trachytic outbursts of the two eastern districts in the region of the Wahsatch and the Rocky Mountains are varieties with more or less free quartz and a large amount of accessory augite. They are comparatively uniform, and all the rocks of both of these large exposures represent the same general type.

True augite-trachytes occur only within Virginia Range, and there they are unmistakably later than the great outflows of sanidin-trachyte which crown the range north of Truckee Cañon. Here, as in the case of the andesite order, the augite member is the latest.

Between the trachyte and rhyolite orders the relations of succession are more difficult to make out. As a general rule, trachytic bodies are not seen in direct contact with the rhyolites. On the divide between North and Middle parks, in the Rocky Mountains, from the situation of the two outbursts it is evident that they do come in contact, but the region is obscured by an enormous amount of glacial débris and covered by a dense forest. In the region of Piñon and Cortez ranges, however, the two rocks are seen directly in contact, and in these cases the rhyolite is clearly superposed on the trachyte, having surrounded and nearly overflowed it The trachytic body at the northern end of Montezuma Range, near the northern margin of Map V., is another locality of contact in which the unmistakable signs are of the rhyolite having broken out later than the trachytes; but the most characteristic locality of all is that of Virginia Range, directly north of Truckee Cañon. There the broad field of sanidin-trachyte, which forms the mass of the range for fifteen or sixteen miles, is broken through by a powerful outburst of rhyolite, which has built a lofty series of conical and domed hills, culminating in Spanish Peak.

Outside of the Fortieth Parallel area, on the great chain of axial volcanos which rise at intervals along the crest of the Sierra Nevada and Cascade ranges, there are cases of the direct superposition of rhyolites over trachytes. An interesting instance is the most recent cone of Lassen's Peak, which, as described in the Geological Survey of California, is built of late rhyolitic flows which have broken through a foundation-region of gray trachytes, they having come to the surface within the ancient crater-line of a former and far grander andesite volcano. In the interesting volcanic region of Mono Lake, where there is a superb display of volcanic glasses, pearlites, and acidic pumices, the entire rhyolite field has succeeded normal sanidin-trachyte. Considering, however, the frequency of trachytes and rhyolites, it is not a little noticeable that they usually occupy quite independent regions, and the instances of contact or superposition are more rare than between any two of the other volcano orders. We have seen that through the three earlier orders each one was characterized by an augite member. The present definition of rhyolite admits no pyroxenic form; but, for reasons to be adduced in the succeeding section, I have come to consider basalt as the augite-correlative of rhyolite; and in the multitude of instances where these two rocks are found in contact, basalt is invariably the more recent, with the single exception, already noted, at Black Rock, where there are structural difficulties, and where there appears to be one of those interpolations of successive flows of basalt and rhyolite such as are described by Hochstetter in the volcanic field of New Zealand. Richthofen, in his memoir on the Natural System of Volcanic Rocks, calls attention to the infrequency of contact-relations between rhyolite and basalt. This rule, which he has drawn from his wide personal examination of volcanic fields, does not hold good in the Fortieth Parallel area. As will be seen by a glance at the Map accompanying this chapter, the contact of the two is not uncommon, and there can be no mistaking the fact that their relations are as stated. In the Rocky Mountain field, basalts directly overlie the trachytes, but the single rhyolitic region lying along the west base of Medicine Pole Range has within our field no basaltic connections. The prominent rhyolitic region of the Fortieth Parallel is west of Salt Lake Desert. From the 114th meridian to the 120th no single range is free from rhyolitic outflows, and in a majority of cases more or less basalt is found in contact with it. The northern end of Ombe Range is an interesting example of the overlie of basalts. Here, as already described, a thick sheet-flow of black basalt directly caps the round rhyolitic hills. The curious group of white rhyolitic breccias of the Beehives in the Ruby group furnishes an interesting example of the relation of these two rocks. There the thin black basalts are seen in irregular masses, the relics of erosion, lying upon the summit of the white breccias. Piñon Range furnishes two examples of the overlie of basalt, one on the east base of the range near the gateway of Piñon Pass, and the other in the angle of junction between Palisade Cañon and the Eureka Railroad. In Cortez Range the lofty mass of rhyolite which overflows the quartz-propylites between Cortez and Papoose peaks is overlaid on the eastern foothills by a general sheet of basalt which overwhelms and margins all the earlier volcanic species. One of the most extensive and interesting cases of overflow by basalt is that of the Shoshone Mesa. This singular plateau rises from the level Quaternary plains of Humboldt Valley and Rye Meadows, showing an abrupt escarpment of about 2,000 feet. The lower half of this great, sharp wall of volcanic rock is composed of rhyolite, and the upper half of remarkably bedded black basalts. The Augusta Mountains—the greatest single body of rhyolites in the whole Fortieth Parallel area—are broken through at various points south of Shoshone Cañon, and near the northern extremity of the group, by dikes of basalt which have piled up their limited outflows on the tops of the great rhyolitic mountains. White rhyolitic cones near the northern end of the range—the only true volcanos within our field of exploration—not only are succeeded by black basalts, but the latter rocks have distinctly come to the surface through the old rhyolitic craters, and overpouring the rim, or breaking through breaches in the crater walls, have flowed out in distinct lava streams down the exterior slopes of the rhyolitic cones. No more evident and unmistakable exhibitions of basaltic sequence may be seen than in the Sou Spring Hills, where a rugged group of rhyolitic mountains has been broken through by a series of black basaltic dikes, whose overflow spread out in thin sheets over the more level portions of the rhyolitic summits. Table Mountain, in Pah-Ute Range, is a similar case where a thickness of two or three thousand feet of basalt has been superposed on an already extensive accumulation of rhyolites. Equally unmistakable is the relation in Montezuma Range, the southern half of that complicated structure being for the most part formed of four or five successive outflows of rhyolites. Through these extensive rhyolitic bodies have broken a great number of basaltic dikes, which have poured out in important fields covering fully a quarter of the underlying rhyolite. Spanish Peak, north of Truckee Cañon, is three quarters surrounded by more recent flows of basalt, which have piled themselves up unconformably against the rhyolitic slopes, leaving only the central mass lifted above the basalt. Near the mouth of Antone's Cañon the pure white felsitic rhyolite—a dependent flow of the Spanish Peak mass—is capped by an extremely fine-grained, jet-black, lustrous basalt, whose liquid flow occupied all the hollows and ravines of the rhyolitic topography.

Professor Whitney has shown, in the Geology of California, the sequence of basalts after rhyolites at Lassen's Peak; and in studying the structure of the great cone of Shasta, it was there seen that north of the mountain is a series of true rhyolitic cones subsequent to the great trachytic peak itself. In the surrounding foot-hills of Mount Shasta is a series of interesting basaltic eruptions, which have come to the surface through the lower portions of the trachyte slopes. These fissures have given vent to important streams of basalt, which have flowed down prior valleys of erosion, and in their northward extension have surrounded and overwhelmed the base of the rhyolitic cones.

In western Arizona, and in the Great Colorado Desert of southern California, I have observed at several localities the same superposition of basalt over rhyolite. There can be no manner of doubt that both the enormous numbers of massive eruptions of these rocks and the actual volcanic cones of the Sierra Nevada and Cascade ranges fall distinctly and uniformly within the law of Richthofen.

On grounds which will be explained in the following section, I have concluded to consider basalt as the augite-correlative of rhyolite, and, since the combination of those two orders of Richthofen into one new order is upon my own responsibility, I have concluded to bestow upon the united order a name, and in view of the relative newness of its ejecta propose for it "Neolite," in which rhyolite and basalt represent the acidic and basic members, exactly as within the orders trachytes, andesites, and propylites Richthofen has assembled the different chemical expressions in one natural group. While, therefore, considering the volcanic products simply in the light of natural groups, or, as Richthofen has called them, orders, his law of succession has seemed to hold uniformly good, it is the attempt of the present section to carry that law of succession into greater detail and to make out a full scheme for the periodic succession not only of the orders but of the subdivisions within the orders. It has already been said that the succession of three subdivisions of propylite is not clearly made out by us, but within the orders andesite, trachyte, and neolite it has been clearly seen that the acidic members are in each order invariably followed by the pyroxenic members. The quartziferous members are also, for andesite and trachyte, held to be intermediate in time between the hornblende-mica member and the augite member. Since this holds good in the groups where we have been able to establish the relation, the probability is, that propylites also fall into the same sequence, and that augite-propylite closes the eruptions of that natural group. Provided they do—which yet remains to be proved—there will be the following sequence:

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. Sanidin-trachyte (quartziferous).
	c. Augite-trachyte.
4. NEOLITE.....	*a.* Rhyolite.
	b. Basalt.

If I am able later to show good reason for uniting such chemically opposing types as rhyolite and basalt under one natural order, I trust that the eminent founder of the law of natural periodic succession of volcanic rocks will accept neolite and the slight modification of his statement, and still permit his name to be connected with the law which I have done nothing to invalidate, having sought only to amplify it and apply it to the minuter subdivisions.

Comparing the law of sequence with the quantitative products of eruption, it will be seen that, when compared as orders, the quantities are inversely as the antiquity, the earliest orders having produced the smallest amount of ejecta. Within each separate order the quantitative relations reverse this law, and the acidic member of each order has produced far greater outflow than the latest augite member. I do not attempt to carry this comparison between age and volume beyond the limits of the western United States, where, in spite of the enormous superficial development of basalt, I believe that the relation will hold firm.

It is unnecessary to repeat here the diagnostic points upon which either the orders or the submembers of the orders are to be distinguished from one another. I only wish to emphasize the fact, first, that each order, being a time group, has impressed upon it certain petrographical features which are uniform through all the subdivisions; secondly, that within any single order the subdivisions bear to each other a relation harmonious with the law of Bunsen, each order containing an expression of a mean chemical product and of the normal trachytic and pyroxenic magmas; although in the case of the earlier orders the extreme members of the pyroxenic type are less basic than those of the neolite order, and consequently do not reach the last and most basic term of Bunsen's series.

In the more general relations of the volcanic group, decidedly the most interesting question concerns the relations of its members to the continuous geological history of the period in which they have made their appearance. Unfortunately, as in the purely petrographical domain, the paucity of exposures of the propylite group defeats an exact fixing of their geological date. The internal evidence of supposed Tertiary leaves, which are found in abundance in the propylitic tuffs, weighs but little. The sole indication of their time-relations is to be found in the obscure mass lying between Montezuma and Truckee ranges, and where the stratified Miocene deposits surround an early propylite eruption, with every appearance of being later and unconformable. Propylites are, therefore, probably pre-Miocene, and are likely eventually to be dated somewhere within the lapse of Eocene time. The latest stratified rocks anterior to them in age in the country of their exposure are the upper Jurassic slates, and the total area in which they have been erupted did not again become a region of sedimentation until the dawn of the Miocene. There are, therefore, no data for conclusively fixing the exact age of propylites.

Of the hornblende-andesites little more may be said. They, too, are distinctively earlier than the Miocene strata, as may be seen in the low lands between the Kamma, Pah-tson, and Montezuma mountains, where the inclined Miocenes abut directly against eroded slopes of andesitic mountains. But it should be repeated here that these andesites are of the hornblendic variety, and that in the lowest of the Miocene series are found palagonitic tuffs whose chemical nature has led me to correlate them with the andesites and to consider them as simply the sedimented tuffs of the augite-andesite period. If this correlation is correct—and it coincides with all the facts we now have—the beginning of Miocene time would have come between the main period of hornblende-andesites and that of augite-andesites, which would have the effect of placing dacites, hornblende-andesites, and all the propylites in Eocene time. In the case of the trachytes the evidence is far clearer. A very large portion of the enormous bulk of fresh-water beds of the Pah-Ute Miocene lake are really trachytic tuffs, which in Oregon show a thickness of 4,000 feet, and in Nevada certainly 2,500 feet.

In the former locality these trachytic tuffs are literally crowded with a typical Miocene fauna already catalogued in the Cenozoic chapter. No characteristic fossils have been found in the lowest beds of the tuff series in the horizon of the palagonite tuffs, and it is not impossible that when found they may carry back even the augite-andesite period within the Eocene; but the whole thickness of trachytic tuffs from bottom to top is unmistakably of Miocene age. This great series of volcanic lake deposits subsequent to the Eocene has its beginning at the close of a period of enormous erosion.

The Eocene, as a whole, was remarkable over the Fortieth Parallel area for the intensity, rapidity, and grandeur of its processes of disintegration and removal. Like the deposits of the Alps and the enormous Eocene fields of Asia, it stands out in the Tertiary as a great interval of degradation and sedimentation. The four periods of orographical activity already demonstrated by the change of boundary and sediments of the four Eocene lakes, would afford ample disturbance for the ejection of the various members of propylite and andesite families which came to the surface before the Miocene trachytic age.

The more important Fortieth Parallel trachytic eruptions are those which lie at the east and west boundaries of the basin of the Colorado upon lines of weakness which were developed at the close of the Cretaceous, and which were again regions of disturbance during and at the close of the

Eocene period. The next most important trachytic outflows are those within the limits and along the borders of the old Pah-Ute Miocene lake. During the Eocene we have no evidence that the latter area was occupied by water; on the contrary, all the known facts tend to the belief that it was a land region, and that at the dawn of the Miocene or in the latest of the Eocene time it was suddenly depressed to form a great lacustrine basin. It was the fissures incident to this great subsidence that gave vent to the trachytes whose eruptions along the lake-borders built themselves up as mountain masses and cones, while the enormous subaqueous ejections were rearranged as the Miocene tuffs.

The close of the Miocene and the close of the trachyte period coincided, and at this epoch a very severe dynamic disturbance took place; all the beds of the Miocene lake were thrown into folds, and erosion at once began upon the highest exposures of the Miocene folds.

The lines of trachytic eruption as developed on the Fortieth Parallel are in general northwest-southeast lines. The northern part of Virginia Range shows an extension of trachytes parallel to the trend of the Sierra Nevada. The Wahsatch group has its chief line in the northwest-southeast strike, with a subordinate series of contemporaneous eruptions trained at right angles to this line. The Rocky Mountain group consists of two masses, of which one is northwest of the other. The Wahsatch and Rocky Mountain trachytes have broken out along the flanks of the previous lofty ranges, not in either case invading the summit region. In the case of Virginia Range the trachytes are north of the high ancient group of mountains which had its culmination in the region of Washoe. The trachytes here were high mountain eruptions, and piled up their ejecta over the depressed summit of the range.

The great and elevated region of the Sierra Nevada from the latitude of the 40th parallel south is comparatively free from trachytes. They make their great development in the northern or depressed part of the range and the low ridge of the Cascade, upon which they have built lofty isolated cones.

Either accompanying the folding of the Miocene beds or not long subsequent, through a new series of fissures, the rhyolites broke out.

The greatest rhyolitic line is that of the broad group of ranges in middle Nevada, which is a northeast-southwest line, or approximately at right angles to the Sierra.

The region over which the great rhyolitic eruptions have taken place within the Fortieth Parallel area was a country of great mountain folds that had existed since the close of Jurassic time. In the series of disturbances which closed the Miocene and compressed the trachytic tuffs and their accompanying sediments into waves, the folds of the Jurassic ranges were dislocated by a series of approximately vertical faults, accompanied by a remarkably varied displacement. Single ranges were divided into three or four blocks, of which some sank thousands of feet below the level of others. The greatest rhyolitic eruptions accompanied these loci of subsidence. 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 foot-hills of the mountain mass. There are a 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. Quantitatively, these rhyolitic ejections were of enormous volume, building up mountain groups 3,000 to 6,000 feet in thickness, in blocks seventy or eighty miles in length. Where seen in contact with the Miocene it has broken through the disturbed and faulted strata and overflowed a topography which was the result of erosion of the Miocene beds. In eastern Nevada, in the plateau region between the basin of Utah and that of Nevada, a considerable development of rhyolitic tuffs is found in an approximately undisturbed position. Eight hundred or a thousand feet of these are seen, consisting of fine glassy rapilli and sands, in which is entombed the characteristic fauna of the Niobrara Pliocene. It is interesting to observe that in the abundant rhyolite field of western Nevada the rhyolitic tuffs are rare, never appearing in distinct lacustrine strata; on the contrary, all the rhyolitic eruptions which are seen in contact with the disturbed Miocene beds are subaerial ejections of stony and glassy rocks, which is evidence that the first Pliocene lake in which the rhyolitic tuffs were deposited was an eastern Nevada lake, and that in early Pliocene times the area of the Miocene lake was dry land. The main great rhyolitic eruptions were all subaerial and to the west of the earliest Pliocene lake. In the section devoted to Tertiary lakes, I have shown that after the final deposition of the rhyolitic tuffs came an orographical disturbance, the nature and extent of which are unknown, which gave vent to basaltic eruptions. In the basin of Idaho sheets of the basaltic flows overlie horizontal undisturbed Pliocene beds of purely detrital origin. The sub-basaltic beds, from their fossils and their position, are held to be the equivalents in age of the undisturbed rhyolitic Pliocene tuffs, and to be the representative of the Niobrara portion of the whole Pliocene age. Subsequent to the first basaltic appearance there were no rhyolites; they were, therefore, wholly post-Miocene, and confined to the lower division of the Pliocene, equivalent to the Niobrara beds of the Great Plains. The geological relations of the basaltic outflows are highly varied. They appear as the trivial outpourings of dikes in the hearts of many of the mountain ranges, but their great rôle throughout the West is that of broad sheets occupying comparatively level areas, having overflowed the surfaces of plateaus or spread themselves in repeated conformable sheets over wide valleys. In the Fortieth Parallel region, subsequent to the last basaltic activity, a second series of Pliocene deposits has been laid down, covering a large amount of the basaltic field Fossils in this post-basaltic Miocene are extremely rare, and their facies very recent. It is highly probable that since the entire cessation of the great basaltic eruptions a lingering activity has been maintained at a few widely separated localities, particularly in the Sierra Nevada.

SECTION VII.

FUSION, GENESIS, AND CLASSIFICATION OF VOLCANIC ROCKS.

FUSION.—Starting from the one central fact of the enormous extravasation of molten rock material which has been recognized by geologists both in the act of ejection and as the superficial product of eruptions in past time, all questions concerning the general subject of vulcanicity resolve themselves into the one preceding problem of the origin of fusion. Three distinct theories have been thus far advanced to account for hypogeal heat:

First, the chemical doctrine of Davy, that deep within the material of the globe there exist chemically active elements which are and have been in the act of energetic combination, disengaging heat. This idea, finally abandoned by Davy himself, was so totally opposed to all known facts relating to the materials of the earth as to have completely failed to gain any respectable following.

Secondly, the old Plutonic idea, of a molten globe enveloped by a thin congealed crust, since its early advocacy, has always found an abundant company of geological believers. Even to-day, in spite of physical and astronomical arguments to the contrary, a respectable body of geologists finds no solution of the facts of volcanic geology save in the assumption of a general liquid interior, owing its mobility to igneous fusion. According to their belief, the earth is still in its early stages of cooling, and the great globe of molten matter is but little advanced from its first concentration into a revolving sphere under the conditions of the nebular hypothesis. Insuperable objections have been advanced against this doctrine by William Hopkins, in his "Researches in Physical Geography," 1839.* The conclusion of Hopkins that the earth has the rigidity of a solid globe, and therefore cannot be in the main liquid, was later substantiated by the researches of Sir William Thomson on the Rigidity of the Earth,† in

* Philosophical Transactions for 1842. Part II.
† Philosophical Transactions for May, 1862.

which he concludes that the earth must have the rigidity of steel or glass. A reëxamination of these views, in which he abandons the Hopkins argument from precession, but holds to the argument from the tides, and rests in the conclusion of the great rigidity of the earth, is to be found in his address, as president of the Section of Mathematics and Physics, before the British Association for the Advancement of Science, at Glasgow, in the Report for 1876. Admitting, as we cannot fail to do, the validity of the physical arguments against a fluid interior, geologists are driven from that long cherished source, not only for the molten material of volcanic eruptions, but for a general theatre of the "reactions of the interior against the exterior" crust upon which have been based all the theories of upheaval and subsidence that have gained even temporary credence.

Hopkins, in his considerations of the mode of cooling of the once molten globe, gives his belief to a theory of refrigeration, of which the following are the leading outlines: Owing to the enormous pressure at the centre and throughout the deeper portions of the molten globe, solidification took place, first, by the raising of the temperature of fusion above the temperature of the mass; secondly, the formation, by congealment, of a superficial cold crust, leaving between this rigid envelope and the solid middle a shell of unknown thickness of residual molten matter, which, in the accident of cooling, separated itself into detached lakes. It has been admitted that these residual lakes, if small enough, would not affect the physical conclusion of the general rigidity of the earth; but among geologists the phenomena of the igneous rocks, their chemical and mineralogical differences, and the secular petrological change which has been noted between the earliest and latest products of eruption have been held to render entirely improbable the existence of such permanent residual lakes. Hopkins's argument in favor of these lakes rests, first, on his ideas of the sequence of events in cooling, and their continuous existence in a state of fluidity is only explained by him under the notion that they are composed of matter more fusible than the surrounding and bounding regions of the solid earth. Robert Mallett, in his paper on "Volcanic Energy,"* very justly remarks, as an objection to this notion,

* Philosophical Transactions. Volume 163. Part I. 1873.

that there is absolutely nothing in our knowledge of the earth's crust to warrant a supposition of isolated masses of greater relative fusibility. The most important geological objection to permanent residual lakes is the varying character of volcanic products erupted in the same region. Another geological objection to supposing the residual lakes to be connected in a continuous shell of molten matter, is the total want of sympathy in volcanic action between closely contiguous vents, and the well known fact that adjacent volcanos simultaneously pour out materials of widely different chemical and mineralogical character. Similar objections might be made from the geological point of view to a generally fused interior.

The third conception by which to account for fusion is Mallett's own. His theory is the production by mechanical means of local lakes of fusion within the solid matter of the globe by the crushing of the earth's solid crust from the terrestrial contraction due to secular refrigeration. Assuming the earth to be still a very hot body, from the observed increment of temperature in depth, and that the materials of the earth are such as contract by the loss of heat, he reasons that the exterior remains at a temperature rendered stable by radiation into space, while the nucleus, constantly losing volume by the outward conduction of its heat, tends to shrink away from the crust, leaving the latter partially unsupported; that by the continual shrinking away of the contracting nucleus a shell of weak support is formed, and the unsupported crust eventually falls by its own gravity; that the work expended in the process of crushing the rock at the surfaces of impact is transformed into heat; that this heat raises the crushed material to the point of fusion. Physical objections have been raised to this by the Rev. O. Fisher, by C. E. Dutton,* and by Pfaff.†

The conception of Mallett seems to be based upon an assumption of sufficient rigidity of crust to sustain itself on the principle of the arch while the contracting nucleus shrinks away, leaving either vacuity or a shell of relatively slight density. This idea, which might easily be true of a very small sphere either of homogeneous material or of matter arranged in shells which increase in density toward the centre, seems totally inappli-

* Penn Monthly, May, 1876.
† Allgemeine Geologie als exacte Wissenschaft.

cable when applied to a globe of the size of the earth. One of the most noticeable features in the rocky material of the crust, as observed by geologists, is the extraordinary plasticity of the most apparently rigid materials. The flexing and crowding together of rigid quartzitic strata, the remarkable plasticity of granite rocks as shown in the torsion of mountain ranges, the plasticity of a rock so highly crystalline as marble, tend together to show that the earth's materials, as we know them, must in a large way be considered as distinctly plastic. If the materials of the superficial crust are so plastic as to be folded, flexed, and deformed by tangential pressure, it is impossible to suppose them sufficiently rigid to sustain themselves on a large scale on the principle of an arch, while actual vacuity was developed beneath them by the shrinking of the nucleus. It is vital to Mallett's theory that this vacuity should be formed, and its formation is entirely at variance with the observed plasticity of the rocky material. If granite and marble are able to yield without fracture to a shearing stress, it is inconceivable that materials at all resembling them should sustain themselves in a thin spherical shell.

That the operation, according to Mallett's theory, must be extremely superficial, is evident from the character of the products of fusion, since all the extravasated rock falls within a range between a specific gravity of 2.5 and 3.1. It obviously could not have been formed where the average density of the crust was greater than the higher figure. The very nature of volcanic rocks necessitates their having been formed within superficial shells of low specific gravities. Mallett's self-sustaining shell must, therefore, be so thin as to lie wholly above a depth represented by a shell of the maximum specific gravity of ejected material. When we realize that the mean density of the earth is attained at less than 1,000 miles in depth, and that the heaviest known lavas do not exceed 3.1, it is clear that the self-sustaining shell of Mallett must be excessively thin. A further evidence of this necessity is in the probable shallowness of the theatre of volcanic activity as demonstrated by the focal point of earthquake waves accompanying eruption. To suppose a self-sustainingly rigid shell of only fifty or sixty miles in depth, made of the yielding materials of the known crust, is to suppose a physical impossibility. Everything we know of the physical properties of the superficial rocks leads us to believe that the formation of vacuity by the settling away of the nucleus would be utterly impossible; every property of rocks indicates that the crust would follow down the shrinking nucleus, change its molecular arrangement, and yield to the necessary tangential strain by the readjustment of its chemical combinations.

The series of experiments upon which Mallett bases his results was the crushing of cubes of rocky material under conditions in which the amount of work expended could be accurately estimated. His cubes were placed upon a bed and crushed by a descending plunger, but they were totally unsupported upon the four sides. The first effect of the increased pressure was an appreciable diminution of the height of the cube, the second effect a series of vertical cracks, which may be otherwise expressed as a lateral increase of dimensions of the cube. Now, unless the supposed vacuity is really formed within the solid shells of the crust, the crushing conditions do not fairly represent the operations of nature. If there is absolute continuity of material without vacuity throughout the whole radius of the earth, then the effect of downward pressure involves not the simple behavior of the cube of rock able to spread in all directions laterally, but the relations of a particle under far more complicated dynamical conditions. It is obviously incorrect to compare the evidences of the superficial applications of geological pressure with those at the depths of the loci of volcanic fusion, but all we know of the crushing effect of tangential strain or vertical pressure developed or shown on the surface of the globe is not at all in the direction of crushing. When thousands of feet of the rocky superficial matter of the globe are thrown into waves and folds and enormously compressed, the effect is to obliterate the form of the original particles out of which the rock was built up, and to produce new molecular combinations. When from the depth of 50,000 or 60,000 feet a break in the crust brings to the surface underlying sedimentary beds, as in the case of the Cambrian or Archæan strata, the effect upon the original sedimentary particles has not been to crush them, but rather to weld them. Between the deep and the shallow strata there is a constant perceptible change in the direction of consolidation, not of crushing. It is true that the tangential work which has been employed on the surface of the globe in the formation of mountain ranges may be quantitatively far less than the work used up in rock-crushing in depth under the supposition of Mallett; but without vacuity it is difficult to conceive of any separation of particles, which is the essential feature of crushing. In general, Mallett's theory may be said to rest upon the formation of vacuity, which could only be formed under a superficial shell of far greater rigidity than that of the earth, and hence to be inadequate to explain those fused regions whose existence is definitely proven by the phenomena of molten lava.

The greatest single difficulty which the whole theory of fusion has to contend with, is the extremely localized character of its phenomena, the fact of the non-sympathy of adjacent volcanic regions, and the chemical diversities of successive and contemporaneous products.

If the generally molten interior is banished from consideration by the unanswerable objections of physical astronomers, and if the secular phenomena of volcanic geology seem to disprove the theory of the numerous residual lakes of Hopkins, and if the non-rigidity of the crust and its probable inability to sustain itself upon the principle of the arch are, as I believe, fatal to the theory of Mallett, what possible cause can there be to account for those extremely localized and only temporarily existing pools of fusion within the earth's superficial shell which the facts of volcanic geology demand? The considerations which are about to be put forth here are little more than an hypothesis, which, at the present stage of his studies, is all the writer has to offer.

It is first assumed that the earth is still, as Sir William Thomson holds, a very hot body in a comparatively early stage of refrigeration. Whether we arrive at the heat gradient of the earth's interior by the process of reasoning employed by Thomson, in his paper on the secular refrigeration of the earth, or from an empirical formula derived from an accommodation of the conflicting observations of the actual augmentation of temperature in depth, the nature of that gradient in the superficial part of the globe is due in the main obviously to the law that conductivity is in the inverse ratio of temperature; and whether the interior is solid or liquid, from the nature of the rapid conduction through the congealed exterior shell of the earth, the gradient must show a rapid increase of ordinates from the surface downward for a certain distance, and then a very slight increase of ordinates to the centre. In other words, the curve showing the rate of augmentation of the temperature downward will after a comparatively short distance show but slight change in its ordinates. A rapid change of temperature between different contiguous shells is confined to the superficial part of the globe.

On the other hand, the pressure gradient, owing to the curve of density, will show its least rate of augmentation near the surface, where the densities are the least, and its greatest rate of augmentation in depth. From the relation of these gradients of heat and pressure it is evident that after the maximum curvature of the heat-gradient is passed, as it inevitably must be in the upper regions of the crust, since the pressure-gradient continues to show a constant increment of ordinates, the effect of pressure in raising the fusing-point must constantly increase below the maximum point of curvature of the heat-gradient; and from the slight increment of heat from that point down to the centre there will be a constantly greater effect of pressure in raising the fusing-point. Whence it follows that the region where pressure has the least effect in raising the temperature of fusion will be at or above the region of sharp curvature of the heat-gradient. In other words, in passing down from the surface of the earth, the temperature rapidly increasing, a point will be reached in the superficial crust of the earth where the effect of pressure in preventing fusion will be at its minimum; and below that point the increasing rate of augmentation of pressure will render fusion more and more impossible down to the centre of the earth.

Provided, as there seems no valid reason to doubt, the mean augmentation of temperature were to continue approximately according to the rate shown by the empirical formula derived from observation, a shell would be reached at a depth of not over fifty miles in which the temperature of fusion would exist, but where fusion might be restrained by the downward pressure cf superincumbent material. If by any means a portion of the superincumbent weight should be suddenly removed, it is clear that a certain liquid shell would form. Hopkins in his investigations actually supposes the existence of regions retained in fusion by the removal of superincumbent pressure by the formation of rigid arches. Another method of the reduction of pressure has occurred to the writer.

Babbage and Herschel sought to account for several of the more difficult problems of dynamic geology by the transportation of material on the surface of the earth by erosion and sedimentation, but their application was totally different from that which I am about to suggest.

Starting with the well known fact that in general the isothermal *couches* must, from the law of conductivity, follow the superficial contours of the globe, and that the isobaric *couches* must also follow this configuration, it is evident that not far beneath the surface—probably within forty miles—there is a *couche* above the temperature of fusion, but restrained from fusion by pressure. Under continents that *couche* must rise, and under the deep basins of the ocean it must be depressed nearer the centre, following the superficial contours. According to that view, under each continent, and especially under each lofty mountain region, this shell of the temperature of fusion must rise to its maximum radial distance from the centre of the earth. This thermal topography will, therefore, have its peaks under the centres of high mountain systems. As is obvious from all geological study, high mountain ranges are the centres of the most active and intense erosion. Maximum removal, therefore, will actually take place over the immediate top of the peaks of the thermal topography, and there the column of superincumbent matter, or, as otherwise expressible, the actual superincumbent pressure, will be most suddenly and most remarkably varied during the history of erosion.

Starting with a high mountain range, with its corresponding peak of thermal topography beneath it, and a surface-depression upon either side into the basins of the oceans, with a corresponding depression of the *couche* of fusion-temperature, what would be the effect when erosion begins? Suppose the material to be rapidly removed from the high mountain peak and transported to and laid down in the ocean valleys. The effect is to remove the pressure from the mountain peak and add to it in the ocean bed. It is demonstrable, according to the views of Herschel and Babbage, that in the region from which material is taken, and whose downward pressure is thus lightened, the *couches* of temperature will sink correspondingly, and that over the ocean region where the radii are loaded with more material the *couches* of temperature will rise. The immediate effect upon the *couche* of fusion-temperature will therefore depend on a question of rate. Let us examine the case of the mountain peak. Suppose above the temperature of fusion is a column of thirty miles of rock, and suppose three miles are rapidly removed by erosion. The position of the *couche* of the temperature of fusion will constantly tend to retire toward the centre of the earth. If it retires at the same rate as erosion, the effect of pressure on the *couche* of the temperature of fusion will remain the same; but if the rate of erosion and consequent removal of pressure is greater than that of the recession of the *couche* of temperature, plus that of general secular recession, the effect, it would seem, must be to create a local fusion. Professor James Thomson's formula for determining the amount to which the freezing-point of water is lowered by known pressure might be quantitatively applicable to determining the effect that the diminution of pressure by erosion would have in lowering the fusion-point of rock, if we knew the latent heat of fusion of the volcanic rocks, which, so far as I know, has not been determined, and the difference of specific gravity between the liquid and the solid state, of which existing data are quantitatively conflicting. Of course, obviously, for the production of fusion by erosion it is essential that the rate of removal shall be greater than the recession of isothermal *couches* due to removal.

From the point of view of the Uniformitarian school, erosion sufficiently rapid to produce such results is inconceivable; but when we come to compare in western America the periodic eruptions of volcanic matters through the Tertiary age, it is seen that each new order of eruptions succeeds a period of rapid erosion. It is clear, both physically and geologically, that the peaks in the *couches* of temperature will underlie the erosion centres of the globe, and it seems not improbable that the rate of removal exceeds the immensely slow rate of real thermal conductivity, and that the isolated lakes of fused matter which seem to be necessary to fulfil the known geological conditions may be the direct result of erosion.

In this view, all continents which are the areas of erosion would, whenever the removal of material exceeds the rate of recession of temperature, be underlaid by a bed of molten material, which would in general follow the contour of the surface, but which would be thickest under places of most rapid and excessive erosion.

The anomalies of the earth's gravity, as shown by pendulum experiments, has led to a general law that the gravity upon continents is less than that upon islands, or, as expressible geologically, that the regions from which material is being removed have less gravity than the regions over which material is now being loaded. Airy, in discussing the anomalies of the pendulum results, has suggested that the inferior gravity of continental areas might be accounted for by *the solid crust floating on a liquid lake.* Stokes, however, as quoted in Pratt's "Figure of the Earth," accounts for the anomalies in another way, viz., that the mass of continents above sea-level attracts the water upward along the shores of continents, and that the insular stations in which greater gravity is observed are really nearer the centre; in other words, that the sea-line is higher on continent shores than on island shores. Airy's idea is quite in harmony with the subterraneous conditions which I have been supposing.

The conception of what may be called the topographical form of the thermal *couches* has certainly not received the weight it deserves in geological considerations. It is not at all impossible that the observed non-sympathy of contiguous volcanos might be because their vents communicate with the tops of domes or peaks of fusion, and that the activity might be of such a nature as not to communicate an impulse sufficient for ejection from one dome of fusion to another.

In the above remarks, by fusion I have meant true igneous fusion, not the igne-aqueous liquidity held by Scrope—a theory interestingly stated by Stoppani.* It is my belief that the rôle of water in determining the volcanic eruptions, and in the fluidity of lavas, has been greatly overestimated.

Genesis of Volcanic Species.—Whatever may be the prevalence of opinion as to the genesis of volcanic rocks, modern microscopical research ought to have made it forever clear that a sharp line is to be drawn between the so-called Plutonic rocks and the true igneous ones. The inclusions of glass within the secreted minerals of volcanic species, the frequent presence

* Bulletin de la Société Géologique de France. 1869-'70, page 137.

of isotropic substance wedged between the crystalline ingredients in greater or less amount in every one of the volcanic species, the frequent eruptions of molten glass, the relative ages of the glass magma and secreted minerals of innumerable volcanic masses, ought to have rendered it entirely clear that the original condition of each volcanic species prior to the formation of the ingredient minerals and to ejection was that of a melted substance in the nature of a glass. Arguments by Scrope, Lyell, and Stoppani,* in support of the theory that most, if not all, the secreted minerals of volcanic rocks are formed subterraneously, lend a high degree of probability to the statement that few or none of the constituent minerals receive their crystalline form in the process of cooling after eruption. The microscopic demonstration of the inclusion by various minerals in volcanic rocks of portions of the glass magma, both before and after it has suffered the process of devitrification, confirms the view of subterraneous crystallization. Most ideas of the genesis of eruptive species start either with a melted magma or the igne-aqueous development of crystals. The adherents of hydrothermal fusion form a class of theorists who, in my belief, fail to appreciate sufficiently the gulf of difference which separates the true igneous rocks from the group embracing granite, syenite, and diorite. Led away by brilliant modern synthetic results, they have come to believe that the subterraneous genesis of all crystalline rocks is paralleled by the artificial processes of Delesse, Deville, and others. They ought, at this stage of microscopic research, to be fully aware that all the volcanic rocks show abundant evidence of fusion in the presence of glass base and glass inclusions, while the group which is typified by granite never shows the slightest trace of the effects of fusion; that several of its constituent minerals are in a molecular condition, which they are known never to retain after an exposure to high heat; and, lastly, that every microscopical and macroscopical detail of these rocks allies them in their mode of origin to the crystalline schists which are, beyond all shadow of doubt, the results of low-temperature metamorphism of bedded sediments.

The sole link which unites the granitoid family and that of the volcanic rocks, young and old, is, that chemically they both lie within the rather elastic limits of the law of Bunsen. Richthofen's argument, that the

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* Loc. cit.

obedience of granite to this law at once relegates the birth-place of that rock to a *couche* below the sedimentary crust of the earth, is the only relation founded in fact which links the two crystalline series; but when we consider that the enormous body of Archæan schists, including the gneisses, quartzites, dioritic schists, and limestones, are but the disintegrated products of older rocks, and that their special chemical differences represent mechanical and organic separations during the process of sedimentation, it is clear, first, that all the sediments are the result of disintegration and wearing down of the original crust of congealment formed of the molten surface of the earth; secondly, that, therefore, as a whole, they represent precisely the chemistry of that crust, and if anywhere in the stratified crust a wide considerable body of these differentiated sediments were to be re-fused or commingled, especially if that solution or mechanical mixture took place in the early Archæan horizons below the first appearance of limestone, the product, unless of most restricted dimensions, must necessarily represent something like the average chemistry of the primitive crust, and we need not, therefore, be surprised to find the law of Bunsen asserting its sway over all remelted or extensively commingled rocks.

If the theory to account for the origin of granite advanced in the second chapter of this volume is correct, that rock is simply commingled and metamorphosed sediments, and would represent an approximation to an average of the sedimentary crust, and there seems to be no reason why the commingling of a considerable portion of the lower sedimentary crust might not reproduce the chemical conditions of the average of the early crust of congealment. It is no argument against this possibility to say that single beds of quartzite, of limestone, or gneiss do vary from the Bunsen law. Either in the case of granite or of any extensively developed lake of fused material the confinement of either fusion or metamorphism to a single one of the differentiated detrital beds of the crust is in the highest degree improbable.

Waltershausen and Richthofen have given with greater definiteness than other writers the details of their conceptions of the interior conditions of the earth and the development of volcanic rocks. Waltershausen, in his "Volcanic Rocks of Sicily and Iceland," from the specific gravity of orthoclase, albite, quartz, crystalline limestone, and mica, derives a mean specific gravity for the exterior surface of the earth of 2.66. He assumes the mean density of the whole earth given by Reich as 5.45, a figure which the modern investigations of Airy and others have somewhat increased. He computes the central density of the earth at 9.585, or nearly equal to that of bismuth. He then estimates the actual pressure at different depths and at the centre of the earth, in these estimates assuming the earth to be in a fluid condition. For the geocentric pressure he computes 2,492,600 atmospheres, from which he concludes that if the metals of which he conceives the greater part of the earth to be composed have their melting-point raised by pressure, as he thinks probable, the centre of the earth could hardly be fluid.

If the temperature-gradient deduced by Thomson, or that which would naturally result from the empirical formula derived from observation, may be relied on, as has already been shown when treating of fusion, the fusing-point must be enormously raised at the centre, and a very large part of the globe would probably be thus solidified. At the same time, in using the terms "solid" and "liquid," it should be clearly understood that their significance, when applied to enormous temperatures and enormous pressures which appear in conjunction in the deeper parts of the earth, should necessarily be very seriously modified. It is in every way probable that the deeper regions of the earth are neither solid nor liquid in the sense in which we use those terms on the surface. The experiments of Dr. Andrews, on the passage of water from the fluid to the gaseous state under high pressures, offer instructive suggestions as to the possible mode of hypogeal transition between the fluid and the solid state. If we might confine our use of terms to "rigid" and "mobile," our conceptions of the interior conditions might be rendered less indefinite. Waltershausen (translated) says:

"We may conceive of the Earth either as a metal ball, fluid to the surface, or as having already entered the oxydized state. * * * It is then clear that in the outer crust the lightest bodies are particularly strongly represented, while the others need not be absolutely wanting. In the deeper layers, on the other hand, the heavier bodies will predominate and will seek to displace the lighter ones. Nearest the surface, silica, potassa, and soda assert themselves, while lime, magnesia, alumina, and iron oxyd are present in comparatively small quantities. The gradual increase of the latter is accompanied without doubt by a decrease of the former to the extent of their complete disappearance. At still greater depths, besides the alkaline earths, alumina, iron oxyd, or magnetic iron, new metallic oxyds will tend to increase the specific gravity of certain layers, until finally the pure metals—iron, nickel, cobalt, &c.—which remain in the depths unaffected by oxygen, have replaced the last oxyds.

"Now, as these different layers cool from the surface downward, there will gradually appear in them, without doubt, a different mineralogical character. Inasmuch as the silica as an acid combines with the mentioned oxyds to form the single or double salts, it is self-evident, without going further into the details, that in the upper layers acids or neutral salts with the separation of the acid (free silica) will be found, while in the deeper layers basic salts will gradually appear. While we look upon the earth as developed from a fluid mass, and can at least in general expect a continuous increase in the density from the surface toward the centre, it is unnecessary that in the silicates of the different layers a continuous change should also be perceptible, or that all possible transitions from the acid through the neutral to the basic silicates should be found. Taking a certain group of more acid silicates as the superior, and a certain group of more basic silicates as the lower limit, all those silicates lying between can be considered as transitions of the former into the latter, or as mixtures of the two. Taking into consideration the very slight differences in specific gravity which come in play here, and the density with which the silicates flow, especially at somewhat low temperatures, together with the size of the earth, a wholly homogeneous distribution of the separated elements and a perfectly regular increase of density towards the centre are not to be expected."

Basing his calculation on this increase of density, he derives the lavas of Ætna and Iceland from a depth of about seventeen geographical miles, from which level he estimates a required pressure of thirty thousand atmospheres as necessary to raise them. In his application of this increase of density to the various volcanic species, and as a result of the preceding theory, he says:

"Below the designated depth at which the formation of feldspar has reached its limit, augite will begin to predominate, attain its maximum, then gradually decrease, being replaced by magnetite; finally the magnetite will predominate, and then, without doubt, be gradually replaced by the pure metals, especially by iron, nickel, and cobalt."

To sum up the theory of Waltershausen, the earth is a hot globe, of which a considerable portion is fluid, an unknown fraction of the centre having been rendered solid by the raising of its fusion-temperature by pressure. The downward increment of density is expressed by the chemical increment of the heavy bases, and the fluid region directly under the crust consists, first, of a feldspathic and acidic magma which passes downward by successive replacements of bases into an augitic, and finally into a magnetitic magma.

As far as Waltershausen's idea of the sequence of volcanic species had progressed, this great shell of fused material answered the conditions of the natural succession upon the surface. The trachytic rocks were in general known to be ejected first, and the assumed superior position of the siliceous melted shell naturally accounted for their priority of eruption. The intermediate chemical grades of rock between the acidic trachytes and the basic basalts naturally were held to be products from intermediate depths in intermediate time, and the general question of the genesis of species solved itself on the most simple laws.

Richthofen, following Waltershausen in his assumption of a still liquid interior and of the great fluid shell of acidic and basic magmas, found himself confronted by a difficulty of his own making. Having established the remarkable natural periodic succession of his five orders of volcanic rocks, it was no longer possible for him to follow the simple law of time and depth on which Waltershausen rested. Richthofen, from his wide knowledge of natural succession, realized that if the melted shell of material was arranged according to its density, with the acidic magma overlying the pyroxenic,—since after the comparative basic extrusions of propylite and andesite the highly acidic trachytes and rhyolites had followed, and thereafter the basic basalts,—the loci of eruption must have appeared earliest in the basic magma, then risen into the acidic, and lastly been depressed again into lower levels of the basic region. I have shown that the law of Richthofen was even more complicated than his own statement, and that there have been for each of the four orders an acidic, a neutral, and a basic period; in other words, if the interior is arranged in the two concentric (acid and basic) shells, with a neutral intermediate region, the theatre of eruption has been four times oscillated through the chemical cycle, since the acid and basic products alternate through the whole series of four orders. The difficulties which Richthofen encountered are thus increased fourfold.

Whether we assume for the source of volcanic supply the general melted interior with its graded chemistry, as held by Waltershausen and Richthofen, or whether we admit the residual lakes of Hopkins, the difficulties presented by the remarkable alternation of acid and basic rocks in the full series of successive eruptions become absolutely insuperable on any physical laws which we can now apply.

Richthofen* says in regard to the products of the volcanic era:

"The conditions of the globe must have been very different in the Tertiary from what they had been in the Palæozoic period. A longer time of comparative repose had in most parts of the globe preceded the inauguration of the violent manifestations of vulcanism in the Tertiary period than had ever before elapsed between any two eras of eruptive activity. The globe had cooled down. Volumes of sedimentary matter had accumulated, and added externally to the thickness of its crust, while it had increased in a vastly greater measure by the crystallization of liquid matter below. Those siliceous compounds, especially of low specific gravity, which had formerly yielded the material of the vast accumulations of quartziferous eruptive rocks, would have been consolidated, and the limit, as it were, between the solid and the viscous state of aggregation receded into regions where the matter would be of a less siliceous composition and of greater specific gravity. The similarity in distant countries of the rocks first ejected (propylite and andesite) goes to show that the recession of that

* Loc. cit.

limit into greater depth must have proceeded in a nearly equal ratio in all those regions where volcanic rocks are distributed. When the tension below had increased sufficiently to overcome the resistance, it would now no longer manifest itself in the formation of small and differentiated systems of ruptures. In the direct ratio of the increase of the resistance, the fractures would have to be of greater extent, and those elongated belts of them would be formed which even now are partially distinguished as the belts of volcanic activity. The first rocks ejected necessarily would be of a more basic composition than the predominant rocks of the granitic era, while the repetition, at a later epoch, of the process of fracturing would give rise to the ejection of rocks in which silica would be contained in a still lower proportion. The greater portion, indeed, of the ejected rocks consisted of propylite and andesite in the first and of basalt in the second half of the volcanic era. A notable but only apparent anomaly in the regular order of succession has been the emission of trachyte and rhyolite between the andesitic and basaltic epochs. But if it is considered that these rocks were ejected partly from the same fractures through which andesite had ascended, and partly from others in their immediate vicinity, while the distribution of basalt has been independent, to a certain extent, of all foregoing eruptions, it is evidence that the occurrence of trachyte and rhyolite is closely dependent on that of andesite, and bears only a very remote relation to basalt. 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. There is, within the limits of conjecture based on physical laws, no lack of processes which could coöperate to that effect. The consolidation of the ejected masses within the fissures would probably proceed simultaneously, by loss of heat, from the surface downward, and, by pressure, from below upward. The opening of new branches from the main fractures, the remelting (by the aid of the heat of the molten mass within the latter, and of water finding access to it) of solidified matter adjoining the fracture, the emission of that remelted matter through those branches—all these are secondary processes, depending on the first almost necessarily. The supposition that to these is due the order of time in which trachyte and rhyolite have been ejected to the surface, is corroborated by the fact that these rocks occupy generally a subordinate position in regard to quantity, and have had, to a great extent, their origin in volcanic action."

In this are two assumptions which the extensive field of the western Cordilleras does not bear out: First, that the distribution of basalts has been independent of the other prior eruptions; secondly, that trachytes and rhyolites are subordinate in their quantitative relations to either the andesites or the basalts. As I have already shown, the reverse of both propositions is the rule over the western United States.

According to Richthofen's views of the succession in the case of trachyte and rhyolite, "the seat of eruptive activity gradually ascended to regions at less distance from the surface"; but with the fuller expression of the law of succession the theatre of eruption must have oscillated four times toward the surface and down again.

Upon the theory of a general molten interior with graded chemical shells, the actual vertical distance of this oscillation of the seat of eruptive activity would have to be very great, owing to the extremely slow downward change of density. For the locus of eruption to pass from the level, for instance, of the mean density of augite-andesite up to that of the most acidic trachytes, would be to traverse a wide range of the molten shell, and this distance would necessarily have been traversed eight times in the volcanic age.

Another strong argument weighs against the conception of a general liquid shell. When we come to compare the nature of the true igneous rocks of pre-Silurian time, like those which are exposed on so grand a scale in the region of Lake Superior, we find eruptive quartz porphyries and eruptive diabases and melaphyres whose average chemical constitution and specific gravity differ very slightly from that of the quartz-porphyries and diabases of Jurassic age, as shown in the eruptions of the Cordillera system, and they also betray but very slight chemical and specific-gravity differences from the rhyolites and basalts of the Pliocene and post-Pliocene eruptions. Upon the theory of a generally melted interior, all the rocks of a given specific gravity and average chemical composition must have come from about the same *couche.* The basalts, augite-trachytes, augite-andesites, augite-propylites, middle-age diabases and pre-Silurian diabases, and melaphyres, representing comparatively similar expressions of the pyroxenic magma, must all necessarily come from a single subterraneous shell.

Considering, then, the acidic rocks, we have the rhyolites, quartziferous trachytes, dacites, quartziferous propylites, middle-age quartz-porphyries, and Archæan quartziferous erupted species, representing a second set of products having a close chemical equivalency and almost uniform specific gravity. On the theory of Waltershausen, they, too, must have come from one and the same acidic *couche.*

Carrying back these two types into the very earliest (Azoic) division of geological time, it will be evident that the theatre of eruptive activity must have been throughout this whole enormous interval oscillating back and forth between two permanent trachytic and pyroxenic shells.

If the earth is a hot body undergoing secular refrigeration, and if these rocks, separated by such enormously wide intervals of time, have come from two permanent shells, as they necessarily must have come, on the theory of Waltershausen, then not only has secular refrigeration failed to congeal the uppermost shell, but it must have remained permanently melted over the pyroxenic shell, and all pyroxenic eruptions must have been forced to the surface through the superincumbent melted acidic shell. Either this long-continued oscillation from shell to shell, or, in view of the secular refrigeration, the permanence of these shells, or the eruption of pyroxenic material upward through the siliceous shell, involves physical difficulties which appear to be altogether insuperable. Furthermore, the arguments of physical astronomers against any general interior fluidity remain absolutely unassailed, and those who have derived the eruptive rocks from such a general fluid interior, or from any deep intermediate fluid shell between the rigid interior and a congealed crust, have, besides their other difficulties, to answer the arguments for the earth's rigidity, which they have never even attempted to do.

If, however, either on the theory of Mallett, which I totally reject, or on the hypothesis of the origin of fusion which I have introduced in the preceding pages, or by any other means, temporary local lakes were formed resulting from the fusion of a thin shell of the crust, it would seem that the arrangement into two zones—a lighter overlying a heavier one—would from the nature of things gradually assert itself within the limits of the enclosed fused region.

In the law of succession, as I have stated it in the previous section, in each order the augite eruptions are the later. The same is true as between the middle-age porphyries and diabases of Europe, and the law holds equally good as between pre-Silurian quartz-porphyries, diabases, and melaphyres of the Lake Superior region. If, therefore, according to my supposition, fusion is a function of erosion, and each order is the result of a definite period of erosion, and becomes thus an expression of a recurrent phase of geological history, each fused lake may have its double period of eruptive activity, the acidic magma coming to the surface first, followed by the pyroxenic.

The meaning of this succession seems to be, that wherever fusion is developed on a considerable scale, by whatever mode, the fused material divides itself into two parts, the acidic or lighter coming to the surface before the basic and heavier. There are two methods by which this separation within the limits of a fused lake might be made: first, while in a state of fusion, on well understood principles, the heavier liquid might concentrate at the bottom of the lake, leaving a supernatant *couche* of lighter matter; or, secondly, in the act of crystallization, which all present facts tend to prove is a subterraneous process, the actually formed crystals might separate themselves according to their differences of specific gravity. It is true that, as between minerals composing the acidic species and those entering prominently into the constitution of the basic species, there are no great differences of specific gravity; but they are amply sufficient to permit the free movement of the crystals through the containing magma.

Darwin, in his "Volcanic Islands," gives an interesting account of a certain basaltic flow in the Galapagos Islands, in which he observed that the developed crystals had sunk to the bottom of the lava, leaving the upper portions comparatively free from visible minerals. In my own studies of the lava streams of Hawaii, I have frequently repeated the same observation. During eruption in the crater of Kilauea, at the time of my visit, a fluid stream of basalt overflowed from the molten lake at the west end of the crater and poured eastward along the level basaltic floor of the pit. Numerous little branchlets spurted out from the sides of the flow and ran along the depressions of the basaltic floor for a few feet and then congealed. I repeatedly broke these small branch streams and examined their section. In every case the bottom of the flow was thickly crowded with triclinic feldspars and augites, while the whole upper part of the stream was of nearly pure isotropic and acid glass.

Scrope it was who originally suggested that within the limits of fused lakes a specific-gravity separation might take place by the sinking of all crystals heavier than the magma, and the rising of all lighter. Lyell and Darwin have approved of this theory, and Darwin, in his "Volcanic Islands," gives an extremely clear statement of the *modus operandi* of such separation. Richthofen, in a note in his "Memoir," page 34, rejects this idea of the genesis of volcanic species, deriving his objection from the curious periodic succession of volcanic species. In his conception, however, all of the Tertiary volcanic rocks came from one melted interior, and under that belief it is natural that he should have seen the impossibility of a specific-gravity arrangement which could account for the interpolation of trachytes and rhyolites between andesites and basalts.

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 centres 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. Refrigeration, continuing from that time, would result in the crystallization of the various mineral species. As between the minerals entering the composition of the acid rocks and those of basic rocks, there is, according to my belief, a sufficient difference of specific gravity to account for the separation. The magma through which they moved in the process of separation, and which lingers in the intercrystalline spaces, is partly the isotropic glass which imbues the groundmass and constitutes the base of the various species, partly the groundmass itself. Since this separation would be an affair of some time, and the causes which determined eruption might supervene when crystallization had begun and before specific-gravity separation had completed its work, it would be natural to expect that eruption would frequently occur before the complete genesis of species. In my view, the latest lake of fusion after gravity-separation would result in a layer of rhyolite floating upon a layer of basalt; and if before this separation into rhyolite and basalt an eruption took place, its products should contain the combined minerals of rhyolite and basalt. Accordingly we do find, as in the great field of so-called trachytes in the region of the Elkhead Mountains, an enormous outflow, composed of free quartz, sanidin, and biotite, (the materials of rhyolite), commingled with triclinic feldspar, augite, and magnetite-iron, (the materials of basalt). Supposing a separation to have occurred between these two sets of minerals, from the chemistry of this rock, which places it as to its acidity near the lowest limits of the trachytic magma, a large proportion of rhyolite and a small proportion of basalt would have been formed. Wherever a molten lake should be formed within the acidic shells of the earth, after separation by specific gravity the relative proportions would show a great preponderance of the acidic member.

In the remarks, in the previous section, on the quantitative proportions of all the eruptions of the volcanic rocks of the Fortieth Parallel area, it was shown that the acidic members do greatly outweigh the augite members; but, on the other hand, there are numerous localities where there is either none at all or very little of the acidic members, and a large amount of an augite rock. In explanation of this frequently observed condition, it should be said that the position of the acidic layer within the lake on the top of the augitic shell exposes it first to the effects of refrigeration. Provided there is no eruption, the history of a fused lake will be this: First, its secreted minerals will separate themselves by specific gravity; secondly, as a result of secular refrigeration the upper surface of the lake will congeal, and this solidification will proceed downward. It might easily proceed throughout the entire depth of the acidic zone before an eruption took place, in which case the first appearance at the surface would be from the augite magma, or in extreme cases it might wholly congeal *in situ.*

The rocks of mean composition might be formed in two ways: if at any time before the specific-gravity separation, eruption should occur, a chemical mean product would be obtained, containing the minerals of both the acidic and the basic magmas; on the other hand, after separation had occurred, and when the entire lake was arranged in zones according to the specific gravity of the ingredients, between the masses of highly acidic rocks and the most basic would be an intermediate layer, which in case of eruption would produce one of the transition-types provided for by the law of Bunsen.

In the secular refrigeration of the globe these temporary lakes of fusion would necessarily occur at greater and greater successive depths. The deepest of all would be the latest (neolite) lake, and the secular changes that recorded themselves in the subtle petrographical distinctions by which the various acidic and basic members can be distinguished *inter se*, are in each case the expression of depth.

Hopkins's method of accounting for the maintenance of his residual fused lakes by their superior fusibility to the surrounding crust, might possibly account for liquid augitic lakes surrounded by siliceous boundaries; it could not account for the presence of siliceous lakes; whereas I submit that the formation of lakes underneath the points of maximum erosion, the subterraneous crystallization of minerals within the melted magma, and their final separation by specific gravity, account for all the complicated phenomena of periodic succession of volcanic rocks, with their astonishing time-oscillations between the acidic and the basic magmas.

Besides the theory of Waltershausen, and that here advanced, there is the often discussed possibility of a separation by liquation. That process might be supposed either to act upon regions of relatively low fusibility, or in composite rocks of the granitic type by the melting of the more basic and fusible minerals, leaving the others, which are lighter and less fusible, to float upon the surface of the fused basic material; but upon any such hypothesis the formation of mixed rocks like the Elkhead trachytes, which contain the minerals of rhyolite and basalt, would be unaccounted for.

Doubtless in the actual process of fusion there is sometimes a quasi action of the law of liquation, by which certain peculiarly infusible minerals might altogether escape solution in the fluid magma. It has seemed to me that in the case of the quartz-propylites such an accident might account for the presence of granules of quartz containing fluid inclusions, sometimes double inclusions of water and liquid carbonic acid, in the strictly volcanic ground-mass, by supposing the quartz granules to be fusional survivals. The same supposition would account for the presence of apatite with fluid inclusions in rhyolite.

A further feature of the minerals of the various volcanic species might be held to be accounted for by the specific-gravity theory. Zirkel has shown, in his study of basalts, that numerous augite crystals are made up of a dense crowd of magnetic iron grains held together by augitic magma, the whole group lying within the figure of an augite crystal. In the more basic basalts many of the augites are thus three quarters made up of magnetic iron; when, however, in acidic trachytes or dacites or quartz-propylites, augites are observed, they are always of a pale green or pale yellow-green section, and generally are totally devoid of the included accumulations of magnetite grains. The wide differences of specific gravity and iron tenure within the species augite in volcanic rocks is largely to be accounted for by the presence of these foreign grains, and it is not uninteresting that the highly magnetiferous augites are confined to the most basic rocks, while all the accessory augites of the acidic rocks are of pale color and slight specific gravity, and are free from included iron grains.

In accounting for the assemblages of minerals which go to make up the various species on the ground of specific gravity, the greatest difficulty is found in the case of mica, which varies from 2.7 to 3.1. Here again the heaviest micas are found in basalts, the lightest in rhyolites; but to account for either mica or hornblende in the presence of the light minerals of rhyolite it is necessary to suppose that they failed to sink and work their way down through the crowd of other crystals to the level to which their specific gravity would naturally take them. Now, in the water-separation of minerals of granite, as constantly observed in areas of granite decomposition, feldspar and quartz, from the forms of their particles, settle most rapidly, while the mica flakes, although of a higher specific gravity, from the shape of the particles, continue to float; so that rivers like those which descend the west slope of the granitic Sierra Nevada carry an abundance of sparkling mica flakes long after they have dropped their load of quartz and feldspar sands. It is doubtless the flat forms of mica and of the broad earthy hornblendes which account for their presence in eruptions from the lighter magmas.

One of the most common features of a wide family of basalts is the presence in the interstices between the crystals of plagioclase and augite of a highly acidic glass. We have seen that in the lava streams of Hawaii the few included crystals of plagioclase and augite sank to the bottom of the stream, and that the principal part was glass. One of the most remarkable features of that classic locality is the rivers of nearly crystalless glass-lava which have flowed from an upper crater, distances of thirty and forty miles, to the sea. The occurrence of such volumes of volcanic glass can be accounted for by the supposition of a lake in which the specific-gravity separation has taken place, and the acidic supernatant stratum been drawn off by early eruption or congealed, the residual portion consisting of acidic glass, whose specific gravity is less than that of the plagioclase or augite. In that case those minerals might sink, leaving an upper stratum of crystalless volcanic glass, which, when erupted, in the process of cooling after eruption might develop only those minute crystallitic forms which the microscope discloses in all the glassy lavas. The supposition of Stoppani that all volcanic glasses are the result of a molecular change posterior to eruption has absolutely nothing to warrant it.

As bearing upon the character of subterraneous lava lakes, the breccias should be mentioned. Among the early eruptions of all the volcanic series breccias are given. They usually consist of sharp angular fragments, between which is a magma of the same material. Sometimes the fragments are confined to the size of a marble, and again they reach large masses weighing several tons, but with the exception of obviously foreign inclusions the fragments and magma are the same. There is nothing in the appearance of these breccias which warrants the idea that the fracture took place after the eruption Frequently, as between the containing matrix and the fragments, there are characteristic differences in mode and scale of crystallization. It is in every way probable that the breccias were subterraneous products, that they were crushed in depth, and never remelted, but were given their fluidity by a still liquid magma which flowed in and occupied all the interstices between the broken fragments. I have before maintained that in the process of secular refrigeration and in the absence of the active causes of eruption the uppermost layers of the molten lake would gradually undergo congealment. The upper strata of the acidic lavas, having become solid, would easily crush under any of the unusual tangential strains to which the crust is from time to time exposed, and with the supervention of the causes of eruption the crushed fragments would be swept out with more or less matrix as a subterraneously formed breccia. It is also to be noted that while breccias are very common among the acidic members of the various orders, they are less common among the augitic representatives of each order.

CLASSIFICATION OF VOLCANIC ROCKS.—The reader will now perceive the grounds on which I have coupled two such diverse products as rhyolite and basalt in one order. Regarded chemically, their divergence is no more noticeable than that of the early diabases and quartziferous porphyries of pre-Silurian time; and the petrographical characteristics of the two rocks are not more widely different than are black augite-andesites from dacites or black augite-trachytes from the quartziferous member. In this view, the remarkable and hitherto inexplicable natural sequence of volcanic species becomes comprehensible, and basalt and rhyolite, grouped together as the order neolite, become the last couple or latest formed lake.

It is unnecessary here to repeat the admirable expressions of diagnostic points by which the various orders and their subdivisions may be separated. Richthofen, in his classic memoir, and Zirkel, in his various contributions, including Volume VI. of this series, besides many other German petrographers, have clearly shown upon what permanent and essential differences rhyolite, quartziferous trachytes, dacite, and quartz-propylite may be separated, and the petrographical points by which basalt, augitic trachytes, augitic andesites, and augitic propylites may be distinguished. If the hypothesis of the formation of independent lakes of fusion as a function of erosion and of the subterraneous specific-gravity separation into two groups shall finally be accepted, I submit that the natural succession of volcanic rocks forms, as Richthofen has already indicated, the true basis of a final classification. The characteristic differences between what Richthofen has called orders, become then expressions of time, of depth, and of pressure, since with the secular recession of temperature the critical shell in which fusion would be induced by erosion must constantly retire from the surface downward, and the latest order, neolite, would hence represent the deepest development of a lake. An entire lake, under this view, would bear a relation to its differentiated products not very dissimilar to that which the biological term "genus" bears to its subordinate "species." I propose, therefore, that to each lake or order of Richthofen the term "genus" should be applied, and to the differentiated products, "species." Genera thus become expressions of time and depth, and species the chemically differentiated products due to specific gravity. Within the range of each species there is, as every petrographer well knows, the widest range in texture and physical properties. Consider, for instance, the species rhyolite, which may appear as a nevadite entirely made up of crystalline minerals, with only the slightest traces of vitreous binding-material, or at the other end of the scale of texture may appear as a uniform isotropic obsidian with only the minutest crystallitic inclusions. These variations, altogether within one normal chemical constitution, become the varieties of the species, and it is submitted that any one species may, under favoring physical circumstances, appear through the whole range of varieties from entire crystallization to pure glass. It is true that thus far glassy propylites have not been described, but there is probably nothing in the nature either of the depth in which they were formed or of their chemical constitution to prevent the formation of the glassy types. Of the genus andesite, all three of the species—dacite, hornblendic, augitic—have been described as containing more or less glass. In the genus trachyte, both the extreme varieties show in their microscopic features the presence of glass. In the ordinary sanidin-trachyte, that glass has generally undergone the process of devitrification or is full of ferrite and opacite, yet, both in the black augite-trachytes and in the sanidin varieties, there are occasional large developments of pure glass. Within the genus neolite, in both species, basalt and rhyolite, is the greatest development of glass, and the entire chemical range of the species basalt is also represented by glasses varying from the basic tachylite to the relatively acidic hyalomelane. In conformity with the views thus expressed, I propose the following classification of volcanic rocks:

CLASSIFICATION OF VOLCANIC ROCKS.

TERTIARY FAMILY.

GENERA.	SPECIES.	VARIETIES.
Expressions of time according to Richthofen's Law of Succession, and of depth owing to secular refrigeration.	Expressions of chemical differentiation by specific gravity of mineral ingredients, grouping under the Law of Bunsen.	Expressions of range of texture according to predominance of secreted crystals, groundmass, or base.
PROPYLITE.	Quartz-Propylite. Hornblende-Propylite (rarely micaceous). Augite-Propylite.	Varieties wholly dependent on quantitative relations of secreted crystals and groundmass (no base yet observed).
ANDESITE.	Dacite. Hornblende-Andesite (rarely micaceous). Augite-Andesite.	Varieties dependent on quantitative relations of secreted crystals, groundmass, and base.
TRACHYTE.	Quartz-Trachyte. Mica-Trachyte (rarely hornblendic). Augite-Trachyte.	Varieties dependent on quantitative relations of secreted crystals, groundmass, and base.
NEOLITE.	Quartz-Rhyolite (nevadite). Mica-Rhyolite (very rarely hornblendic). Basalt.	Varieties dependent on quantitative relations of secreted crystals, groundmass, and base. Isotropic base far exceeds that of any other genus.

This will be seen to deviate but slightly from the scheme of Richthofen, substituting the word "genus" for his term "order," and following exactly his time-scale of periodic succession, but throwing together into the genus "neolite" the hitherto separated rhyolite and basalt. The part in this classification played by the law of Bunsen is, that that principle governs the range of chemical constitution of species within the limits of each genus. The part played by the remarkable law of Richthofen is, that it places the various genera of volcanic products in their natural time-order.

The oldest genus, propylite, differs from the next succeeding genus, andesite, and indeed from the three other genera of the family, by two important mineralogical characteristics: first, as Richthofen early pointed out, the character of the propylitic hornblendes, which are green like those of the earlier diorite, and are made up of microlitic staffs, and hence not cleavable on crystalline planes—a feature which extends through the whole genus, and seems to be a survival of the earlier types of hornblende; secondly, the abundant quartz of the quartziferous member carries fluid inclusions and no glass, thus further linking the genus with the long anterior diorites.

With the genus andesite first appears a cleavable brown hornblende surrounded by a characteristic black border, and the quartz of the dacites carries glass inclusions but no fluid.

Mica, rarely replacing hornblende in propylite, appears among the andesites in rather more noticeable proportions; and with the andesites also comes in abundant glass, both as inclusions within the bodies of crystals and as a base imbuing the groundmass.

With the trachytes mica far exceeds hornblende. Quartziferous members are rare, and the quartz is always present as macroscopic secreted granules, but never enters the constitution of the groundmass. A noticeable feature of ejections which have been classed as trachytes is the occurrence of what appears to be the non-separated neolite magma, representing a period after the secretion of crystals, but before their separation by specific gravity. This is perhaps to be accounted for by the supposition of extreme viscosity near the temperature of congealment or of a rather heavy magma, wherein the crystals of mica, augite, hornblende, and sanidin would have less tendency to move than in a melted magma of lower specific gravity. It might also be explained by active convection within the lake, which prevented separation of minerals.

The augitic species of each of the first three genera are rare, and their volume inferior to their companion species. Within the genus neolite the most perfect separation seems to have taken place, only the very rarest augite appearing in rhyolite. In the genera propylite and andesite, throughout the whole range of species, triclinic feldspars exceed the sanidin, and hornblende exceeds mica. In the two later genera, with the single exception of the earliest trachytes, mica exceeds hornblende, and in the quartzitic members sanidin exceeds triclinic feldspar. While the quartziferous members of each group approach the same tenure of silica, the augite members grow steadily more basic up to the point of the heaviest basalts.

CHAPTER VIII.

OROGRAPHY.

ARCHÆAN — POST-CARBONIFEROUS — POST-JURASSIC — POST-CRETACEOUS — TERTIARY — CONCLUSION.

For a comprehensive discussion of the general orographical problems presented by the Fortieth Parallel Exploration, nothing less than the full dimensions of a volume like this would suffice. In this brief final chapter I purpose to do no more than chronicle the succession of the grander dynamic events, and give such current notes of their date, area of operation, and general characteristics as shall enable the reader to correlate the mechanical history of our section of the Cordilleras with the great strata-section outlined in previous chapters.

On the one hand, it is to be regretted that such condensation is required by the construction of this volume; on the other, I am compensated by the consideration of our provokingly defective knowledge of the very rudiments of terrestrial thermodynamics, from which alone we might hope to bridge the chasm still separating our phenomenal knowledge from the vague land of causes.

Already in the previous chapter, while advancing and discussing a hypothesis to explain hypogeal fusion and the genesis of volcanic species, I have trodden far enough, perhaps too far, on the thin crust of physical conjecture.

It is my general belief that the suggestions of Herschel and Babbage as to the reactions upon the hot interior from superficial transportation will yet prove to be a key for unlocking some of the closed doors of geological dynamics, but it is useless to pursue this line of investigation as mere speculation.

In spite of the discrepancy between different determinations of the coefficients of contraction, it is apparently quite within the range of probable physical experiment to determine the true differences of specific gravity between volcanic products in their fused and in their congealed state, and to obtain the latent heat of fusion of the same materials. Their specific heat has in many instances been already satisfactorily obtained, and we are in possession of a formula by which to ascertain the pressure at any subterranean point. With these constants and an approximation to the temperature of fusion, we shall be able to reach, by a formula akin to that of Prof. James Thomson on the quantitative lowering by pressure of the freezing-point of water, a determination of some value on the nature of that critical shell of fusion which I have advocated as a possibility, and the quantitative amount of deepening and shallowing which that liquid shell would suffer by known loading or unloading of the surface.

In addition to a knowledge of the laws of contraction of the globe, it is required to ascertain not only the conductivity of rocks but the different rates of conductivity of given materials in the solid and in the liquid state at the same temperature.

Firmly convinced that the phenomena of the geological section are expressive of two laws—the statics of the revolving sphere, and the dissipation of energy from its original and existing inner temperatures, and granting the rigidity required by the tidal argument, I find, until the hypothesis of a critical shell within an immediately superficial region of the globe and the effect upon that shell by the processes of degradation and transportation are disposed of, no physical suggestions whose probable, not to say possible, application could account for the known operations of the crust. Mere deformation of a solid globe under tangential strain is totally inadequate to account for a vertical fault of 40,000 feet, nor does it explain the remarkable historic sequence by which loaded regions gradually subside foot for foot, while regions lately unloaded subside paroxysmally. No theory of the expansive force of imprisoned elastic gases can account for the variability of upheaval and subsidence. And, lastly, no strictly chemical theory yet advanced, when brought into contact with stubborn facts, has the slightest shadow of applicability. I can plainly see that, were the critical shell established, its reactions might thread the tangled maze of phenomena successfully, but I prefer to build no farther till the underlying physics are worked out. I therefore refrain from a discussion of the causes of crust-motion, but in the interest of the completeness of this volume as a piece of history give a short and rather cursory examination of the mechanical phenomena, leaving their minute discussion to a day in the near future when it can be done on a firmer physical foundation

Archæan Orography.—The extended section embraced within the Fortieth Parallel area offers abundant evidence of repeated periods of orographical disturbance separated by intervals of comparative calm.

It has been already shown in Chapter II. that beneath the post-Archæan covering of rocks lies a tremendous mountain system built up of folded and faulted ranges of Archæan rocks If the whole series of unaltered sediments from the bottom of the Cambrian were to be removed, we should come upon the most remarkable mountain system which has been thus far developed in the world.

The Archæan sediments, of which perhaps 60,000 feet have been recognized in two great groups separated from each other by a period of disturbance, represent stratified rocks in a most extreme state of compression. In comparing the changes of thickness and accompanying physical condition of various of the later strata, it has been seen that between the loosely aggregated state of a newly made sedimentary bed, and the more compact but still uncrystallized condition of the same bed, there may be a diminution of half the original thickness. In passing from the compact condition to the highly crystalline state of the Archæan schists, there would doubtless be a still further very great loss of thickness of beds. It is safe to say that the 60,000 feet of Archæan sediments represent an original thickness of 120,000 feet of uncompacted sediment. Indeed, they probably represent nearer 150,000.

It is evident that all these rocks were altered into their present crystalline condition prior to their being folded up into mountain ranges. This is proven from the fragments of the bedded schists that are enveloped in plastic granite, which appears as distinct intrusions in rifts and fractures of the crystalline beds, caused at the time of their folding and upheaval. The included fragments of stratified schists, lying like islands within the granite, often have a length of 1,000 to 2,000 feet, and their physical condition, their state of crystallization, and even the minutest microscopical characteristics of their component minerals, are precisely the same as the solid masses of schist into which the granite intruded. They were, therefore, crystalline rocks prior to their upheaval. In view of the necessary compression required to convert a bed of arkose sediments into a crystalline schist, it is evident that when crystallized these Archæan beds must have been overlaid by a very great thickness of rocks, which in general remained unaltered and have been entirely swept away, leaving no traces except evidence of their former downward pressure.

The actual orographical features of the Archæan ranges correspond very closely with those of modern manifestations of the same forces. Colorado Range, for instance, is a broad, single anticlinal thrown into a low, flat arch. Medicine Bow and Park ranges were also anticlinals. The three together form a folded group of ranges which prior to Cambrian time were deeply dislocated. The anticlinal of Park Range was cleft down the axis, and the eastern half depressed at least 10,000 feet. Colorado Range was severed by an enormous southeast-northwest fault, which dropped the region of the Laramie Hills 6,000 or 7,000 feet lower than the southern continuation of the same ridge.

At the little Archæan body on Red Creek, in the northern foot-hills of the Uinta, was a precipice, the result of a fault of which we now recognize 10,000 feet, the bottom and top having never been reached.

The inclined easterly dipping Palæozoic and Mesozoic rocks of the Wahsatch, in the region of the Cottonwood, rested against the abrupt precipitous face of a granite cliff, of which 30,000 feet are now exposed.

West of the meridian of the Wahsatch there has been so much crumpling and vertical faulting since Archæan time that it is very difficult to separate the earlier effects from subsequent ones. It is only possible to reconstruct the Archæan topography and orography from the limited exposures of the early rocks which occur in the various ranges. They were evidently folds of crystalline schists which here and there had suffered abrupt faulting, and which toward the west were more and more invaded by successive intrusions of the four granite periods.

Tangential strains resulting in folds, and radial strains resulting in vertical faults, are the general characteristics of the orography of the Archæan age. In observing the contact of the Palæozoic strata where they abut against the old Archæan slopes, it is seen that the ancient surface in the region of contact of crystalline schists and granite had been planed down by a very general erosion.

POST-CARBONIFEROUS OROGRAPHY.—The entire Palæozoic time over the Fortieth Parallel field was an age of subsidence, of sedimentation, and of rest from orographical disturbance. I have before shown that the main source of detrital material for the thickest development of Palæozoic rocks was an elevated and extended land-mass which rose in western Nevada about the meridian of Havallah Range. Directly east of that land-mass the thickest body of Palæozoic sediment, of 40,000 feet, was formed. Between the different beds of the Palæozoic are none of those nonconformities which in the Appalachian field denote orographical movements. After the folding of the Archæan ridges there was no mechanical violence until the close of the Carboniferous age. The movement which then took place has been already briefly described as a necessary step to the comprehension of the general grouping of sediments; but the exact physical character of that disturbance is one of the most puzzling and most interesting features of the orographical history of the whole region.

The Palæozoic sediments having accumulated against that western shore 40,000 feet thick, a fault occurred reversing the arrangement of land and water. The ocean bed became the land, and the former land sank to a very great depth, becoming the bottom of an ocean, in which 25,000 feet of Mesozoic rocks accumulated. The marked and peculiar feature in this occurrence is the fact that the region which went down was the region which had been unloading during the entire Palæozoic. Throughout the Palæozoic series are evidences of repeated subsidence in the occurrence of sheets of conglomerate which could only have been transported in comparatively shallow water. We have here, therefore, two types of subsidence:

First, the long recognized type of a loaded area displacing subjacent crust and sinking into the solid earth, a process which suggests the mere restoration of statical equilibrium. It is evidently gradual, and comparing depth of subsidence with thickness of deposit, it is seen that sinking is in the direct proportion of volume. This type of subsidence, so justly insisted on by James Hall in the case of the Appalachian Mountains, is here paralleled on a wider scale, the area of great subsidence being much broader than that of the Appalachian system, embracing a width of not less than 500 miles.

Secondly, when, at the close of the Palæozoic, the land-mass began to subside, its area, lightened of the whole of the Palæozoic sediment, went rapidly down by a distinctly catastrophic process analogous to that of the modern faults which are seen to form in earthquake regions. The sudden sinking of an area which has been relieved of a considerable portion of its load bears, of course, no relation to the equilibrium of the figure of the earth, but its origin must be sought in the obscurity of geological thermodynamics. With the subsidence and accompanying oceanic submergence of what had been the Palæozoic land, came the emergence of the thickest portion of the Palæozoic ocean beds, which was rapidly lifted above the water and became the first considerable land area of a new western continent.

Northward and southward we know little of the extent of this young continent. In the Fortieth Parallel area it stretched from the meridian of Battle Mountain eastward to the neighborhood of Wahsatch Range; its western border lifted in a general elevated region, while toward the east it gradually declined to the ocean level. Over the sea-bottom directly east of the eastern shore there was no disturbance whatever, as is shown by the absolutely conformable superposition of the Permian and Triassic beds on the undisturbed Carboniferous floor. That it was higher along the west, is demonstrated by the enormous amount of Mesozoic sediment which was derived from its degradation. It was a land-mass with its extreme elevation and extreme disturbance at the west, inclining gently to the east, and passing under the level of the sea, where its beds had never been disturbed.

The Mesozoic oceans washed the shores of this continent, whose outlines are as yet only partially traced. Southward from the region of Salt Lake City the distribution of Triassic rocks gives a clew to its shape, and shows that the eastern coast of the continent trended southwest. Northward from Salt Lake the outline trended northward into Montana. From its western shore in the region of Battle Mountain the continental coast trended nearly due north and south. A very few years will suffice to indicate its full outline. From the passage westward of the Mesozoic rocks through Arizona and northern Mexico it is clear that this post-Carboniferous continent did not continue south and east of the system of the Colorado. It was the first nucleus of land in the West, newer than the then sunken Archæan Nevada land and the Archæan island peaks of the Rocky Mountain region.

On the five Analytical Geological Maps, Nos. VIII., IX., X., XI., and XII., accompanying this chapter, it will be seen that the ranges west of Salt Lake are given but three colors—post-Archæan, post-Jurassic, and Tertiary. The post-Carboniferous disturbances are not colored on the maps, for the reason that at present it is impossible to separate their actual orographical effects from the enormous system of folds which took place at the close of the Jurassic age.

Post-Jurassic Orography.—Immediately upon the close of the Jura the sediments, which since the end of the Carboniferous had accumulated at the west of the new continent, were folded with an enormous development of horizontal compression, creating a belt of land lifted above the level of the sea for 200 miles out from the shore-line of the post-Carboniferous continent. The most elevated and most western of these post-Jurassic folds is the Sierra Nevada. East of that range the new addition to the continent, and the body of the post-Carboniferous continent as well, are now seen to be composed of a series of corrugated ridges, having northeast and northwest strikes.

The folds of the post-Jurassic extension of the continent do not differ in their mode of compression, in the character and magnitude of their anticlinals, from those which succeed them to the east, and which are entirely composed of Palæozoic beds. It is impossible to decide on the present evidence whether the post-Carboniferous disturbance produced folded ridges, and the post-Jurassic added more to the west, or whether the post-Carboniferous elevation was simply a plateau-like uplift, and all the foldings between the Wahsatch and the Sierra Nevada, including the latter range, were made in post-Jurassic time. When we realize that passing westerly from the Wahsatch region the folds grow more and more extensive and more and more complex, and betray greater and greater circumferential pressure, reaching a maximum in elevation and compression in the Sierra Nevada, it seems probable that the post-Carboniferous uplift simply defined an island without much crumpling, and that the whole Great Basin region received its corrugation at the close of the Jura.

This view of the case is not without its difficulties. In the region of the Wahsatch, if the folding had been already post-Jurassic, we should naturally expect to find evidences of a discrepancy between the rocks disturbed at the close of the Jurassic and subsequent Cretaceous series; but as far west as the Cretaceous extends, the two series are seen to be in general quite conformable. But it should be borne in mind that in the complicated sequence of disturbances which have occurred in the region of the Wahsatch the actual shore of the Cretaceous ocean is not now seen; that the most western developments, viz., those along the eastern slope of the Wahsatch, are really well in the Cretaceous sea; and that the Cretaceous rocks certainly extended some miles west of their present termination.

The strict and extended nonconformity which appears between the Cretaceous and the Jurassic in California is not repeated on the eastern side of the land-mass. When we come, therefore, to consider the special orographical structure of the ranges of the Great Basin between California and the Wahsatch, there is, counting from the west, a region extending from the Sierras out to the meridian of 117° 30′, in which the folded strata are demonstrably of Triassic and Jurassic age, thrown into their positions by a period of compression at the close of the Jurassic. Between longitude

117° 30′ and the Wahsatch is a region which was lifted above the level of the sea at the close of the Carboniferous, but whose bold axes were very probably made contemporaneously with the western addition, at the close of the Jura. With this understanding I proceed to examine something of the detailed structure of this province of what have been called the Basin Ranges.

These remarkable, quasi-parallel mountain bodies separated from each other by depressed valleys, which are occupied by fresh-water Tertiary and Quaternary beds, are a series of mountain islands lifted above desert plains. They have given rise to considerable discussion, and there is already some difference of opinion between Powell and Gilbert on the one hand and myself on the other. In Volume III. of this series, in a brief sketch of the Green River Basin, I alluded to the Basin Ranges as a series of folds.* Powell and Gilbert have called attention to the abundant evidence of local vertical faults and the resultant dislocation into blocks. One of the most common features of the Basin Ranges is a mountain body composed of a steeply or gently dipping monoclinal mass, edged on both sides by the horizontal desert formations, the back of the monoclinal mass consisting of inclined planes of strata, while the other face of the mountain body consists of an abrupt cliff, evidently the result of a vertical fault, which has been more or less modified by a comparatively recent erosion. The frequency of these monoclinal detached blocks gives abundant warrant for the assertions of Powell and Gilbert that the region is one prominently characterized by vertical action; yet when we come to examine with greater detail the structure of the individual mountain ranges, it is seen that this vertical dislocation took place after the whole area was compressed into a great region of anticlinals with intermediate synclinals. In other words, it was a region of enormous and complicated folds, riven in later time by a vast series of vertical displacements, which have partly cleft the anticlinals down through their geological axes, and partly cut the old folds diagonally or perpendicularly to their axes.

* Vol. III., page 45. "These low mountain chains which lie traced across the desert with a north-and-south trend are ordinarily the tops of folds whose deep synclinal valleys are filled with Tertiary and Quaternary detritus."

Analytical Geological Maps X., XI., and XII., accompanying this chapter, show in three colors the main orographical features of the Basin region. The post-Archæan, or, as they might more properly be called, pre-Cambrian folds, are indicated in brown; the main ridges of the Basin Ranges are shown as post-Jurassic, which is to be accepted with the qualifications already detailed; and the disturbed Tertiaries, both Eocene and Miocene, are included within the yellow color.

Leaving out of consideration now the Archæan structure, I will call brief attention to the most interesting and characteristic details of the great folds of which all are supposed to be, and those west of longitude 117° 30′ are known to be, post-Jurassic.

Proceeding from the region of the Wahsatch westward, there is, first, the Oquirrh Mountains, whose topographical axis is north-and-south, but all whose geological lines of strike are northwest-southeast. The range, as will be seen at a glance by the lines of axis and arrows of dip, is composed of two parallel anticlinals with intermediate synclinal. The great northern synclinal, which is traced diagonally across the northern half of the Oquirrh group, when produced southward, is seen to lie through the middle of the Pelican Hills west of Utah Lake. The Oquirrh body, although interrupted by numerous small local faults, nowhere shows one of those deep, powerful dislocations which are characteristic of ranges farther west.

Aqui Range and its northern extension, Stansbury Island, show a very peculiar curved anticlinal throughout the main mass of hills, but toward the southern extension only half the anticlinal is present, and a powerful fault-plane invades the axis.

Promontory Range also shows a defined anticlinal, flanked both on the east and west by synclinals.

An interesting instance of the complexity and obscurity of these ranges is shown by the Ombe Mountains. The southern extension of the range is a distinct anticlinal, having a northeast-southwest strike, its beds dipping from 15° to 17° on both sides. Northward this is succeeded by a parallel synclinal with far steeper dip, and still farther northward the entire range consists of a block of quartzites and limestones dipping altogether to the west, with a tremendous fault-face exposed to the east, where a sharp escarpment displays six or seven thousand feet of the edges of the ruptured beds.

Gosiute Range next west is essentially a single anticlinal, which has been tremendously distorted and thrown into horizontal curvature by longitudinal compression of the ridge. The northern and southern portions show distinct anticlinals, but a wide middle region is composed of a single monoclinal ridge, which is the westerly dipping half of the anticlinal. An explorer passing over this middle part might easily suppose the range to be a single monoclinal rock-mass dislocated from its geological connections, but at the points indicated on the map the true anticlinals make their appearance.

The adjoining Peoquop Range shows throughout its long north-and-south member a monoclinal structure, being composed entirely of beds dipping to the west, but in the southern portion these beds are seen to pass under a distinct synclinal, and then west of the depression to rise and pass over a well defined anticlinal in the region of Antelope Buttes. The northern part of Egan Range also shows a true anticlinal, which is obviously the southern continuance of the Antelope Butte anticlinal; but in passing southward the Egan Range axis passes out of the mountain group, and the whole southern portion is a monoclinal ridge, being a relic of the westward dipping part of the anticlinal. Here, again, an explorer visiting only the different ends of the range would gain a totally false view of its general structure. It is truly an anticlinal, having a northwest-southeast strike, which in the southern portion has been cut by a meridional fault, the entire eastern half of the anticlinal having been dislocated downward out of sight. It is thus never safe to generalize as to the structure of one of these ranges from an interval of forty or fifty miles of its dips.

A very false conception would also be arrived at whenever geological examination was confined to one of the single detached bodies. Egan Range, Antelope Buttes, the Cedar Mountains, and a part of Tucubits Range are all portions of one anticlinal fold of sinuous strike. At the northern end of Egan Range the northwest anticlinal axis has curved to a slightly northeast position, which strike is taken up in Antelope Buttes, and there describes a double curve, ending near Eagle Lake with a northwest strike. The same axis recurs directly north in the Cedar Mountain group, and describes a broad curve with its convexity to the west, finally reaching a northeast trend. Relics of the synclinal axis which lie along the east side of this prolonged anticlinal are to be seen in the lower portion of Peoquop Range, directly east of Antelope Buttes, where there is a distinct downward curve of the continuous strata, which rise again into the great monoclinal range of Peoquop. The same synclinal recurs between the northern end of Peoquop and the Cedar Mountains. West of this long anticlinal another companion synclinal is to be traced in the Ruby group, and again in the depression between Euclid Peak and the Tucubits Mountains. Here, then, we are able to trace a single anticlinal, with but slight local breaks where the Quaternary valley deposit sweeps over the low passes of the axis, with synclinals both to the east and west shown at several characteristic points. In the case of the Egan group the entire fold has been abruptly cut off by a fault in the latitude of Gosiute Peak, the fissure having a trend slightly east of north. Nowhere in this long interrupted anticlinal are the geological exposures deep enough to lay bare the Archæan rocks.

The main mass of Humboldt Range is made up of a central core of Archæan schists and granites, from which on either side dip away the flanking Palæozoic bodies of a great anticlinal fold. The Humboldt was one of the greater Archæan ranges, and the subsequent Palæozoic rocks are deposited unconformably, abutting against its steeply inclined flanks, leaving unsubmerged insular Archæan summits. The modern axis of fold is not laid down on Analytical Map XI., but the Palæozoic bodies are seen on either side dipping away from it, the greater body in the latitude of Ruby Valley inclining about 15°, and the fragments of the westerly dipping mass which appear along the northern portion of the range declining at angles from 20° to 25°. Where the southern Palæozoic body terminates northward, between Ruby and Franklin lakes, the edges of its bed approach the region of a great fault, in the neighborhood of which they are turned up into a vertical position. From that point northward as far as Eagle Lake the eastern face of the mountain fold is the result of a powerful fault, the dislocated eastern half of the fold having sunk out of sight.

The next system of folds is developed in Piñon, Elko, and River ranges. The central portion of the Piñon is formed of an anticlinal, displaying a magnificent arch of Cambrian, Silurian, and Devonian strata. This axis, although in general meridional, describes a broad curve with a convexity to the west. At its southern termination it is cut by a transverse fault of northeast-southwest trend, and the further southward continuation of the fold of rocks disappears by subsidence. The same powerful northeast-southwest break has cut off the end of the lofty Diamond Mountain range which enters the map from the south and occupies the region between the lower end of the Humboldt Mountains and the southern portion of the Piñon. This is a great anticlinal, composed of Carboniferous and Devonian strata, which is possibly the southward continuance of the curved fold of the Piñon, its beds having been horizontally dislocated and thrown to the northeast. The main Piñon axis near latitude 40° 30′ is again severed by a powerful northwest-southeast fault and its further continuance lost, the dislocated northern portion of the range having gone down and its summit become covered with great outflows of volcanic rocks. North of the Humboldt the same axis continues in River Range, but its appearance as an anticlinal is only for a very short distance. There again the axis is cut, this time not across its trend, but by a longitudinal fault which has cleft the heart of the fold, the entire eastern half for forty miles having been dropped out of sight.

The little Elko group of mountains south of the Humboldt is shown as a body dipping to the southeast with a northeast strike. This is evidently no part of a regular fold, but is a simple monoclinal block dislocated upward from the easterly dipping half of the main anticlinal. In River Range, north of Penn Cañon, where the mountain group considerably widens, the fault which has divided the axis up to that point passes out on the east side of the range and a relic of the complete anticlinal is left, a small portion of the easterly dipping beds appearing distinctly on the eastern face of the range, while the main body is composed of the westerly dipping member. Passing still farther north, this westerly dipping member develops a defined synclinal and again reappears with an eastern dip at the northern extremity of the range. The main anticlinal is therefore traceable for a hundred miles, although cut by longitudinal, diagonal, and transverse faults.

The synclinal which accompanies it on the west appears north of Penn Cañon at the point indicated, and again in the region of Piñon Pass, where a distinct downward curve of the Devonian beds is developed. South and west of the latter point the beds again rise with an easterly dip and develop the eastern part of the anticlinal, whose westward member is again cut off by a longitudinal fault and displaced downward. Besides the dislocations mentioned, it will be seen that the general strike is remarkably sinuous, passing from a northeast to a southeast direction. The general axis, continuing from the Diamond group through the Piñon into River Range, makes a single great curvature with a convexity to the west, approximately parallel to the great curved strike developed in Humboldt Range.

West of the Piñon group the whole country for some distance is deeply shattered and cleft into great mountain blocks, many of which relatively to the others have gone down, leaving only a few isolated high points of stratified rocks. It is impossible in these to make any connected system of strike. At Nannie's Peak in Seetoya Range, around a central nucleal mass of Archæan rocks there is an interesting oval quaquaversal.

In the Cortez, which is almost altogether covered and masked by volcanic outbursts, two distinct axes are developed—one a limited synclinal between Cortez and Tenabo Peaks, the other a fragmentary anticlinal in the region of Dalton Peak.

On Map XII. the eastern portion, including Battle Mountain, and Shoshone and Toyabe ranges, shows singularly discordant axial lines. The Toyabe is a distinct anticlinal approaching the meridian, but it does not continue northward, and a little south of latitude 40° is cut off by an east-and-west fault, the further continuation being lost. Shoshone Range develops an exceedingly slight exposure of an anticlinal in the region of Ravenswood Peak, which is entirely surrounded and its continuation masked by floods of rhyolite. The main mass of Shoshone Range north of Reese River Cañon consists of the easterly dipping continuation of this Ravenswood anticlinal, the western half appearing in Battle Mountain. These two enormous masses of quartzitic beds represent the eastern and western half of the anticlinal whose axial summit is exposed at Ravenswood, the prolonged axis lying deeply buried beneath the valley of Reese

River. It is evident that a tremendous series of faults and subsidences has depressed the main part of this great fold, the sunken member being covered by the Quaternary and Tertiary of the Reese River valley and the great rhyolitic flood.

West of this fold, as seen upon Map XII., there are but three considerable bodies of stratified rock. They are Havallah, Pah-Ute, and West Humboldt ranges. Little fragments of sedimentary rocks, it is true, appear here and there in points of deepest erosion of the great rhyolitic field, as in the Desatoya Mountains and the southern part of the Augusta group. The first body of importance is the Havallah, which is a distinct anticlinal formed of Alpine Trias strata. The general trend of the main part of the anticlinal is northwest, but in the Signal Peak ridge the axis deflects around a curve and passes into a northeast direction. A minor and altogether subordinate synclinal appears parallel to the main axis and to the west of it. After the axis has passed into its northeast trend it encounters a powerful fault, by which its continuance is cut off and dropped. The companion synclinal of this fold appears in the cañon between Iron Point and Golconda.

The structure of Pah-Ute Range is rendered even more obscure by faults and dislocations. The anticlinal which is the foundation of the system appears at the northern point of the range in the region of Dun Glen Peak, and is observable southward nearly to the latitude of 40° 30′. Only a small portion of the easterly dipping beds are seen, and they are soon cut out by a longitudinal fault which cleaves down the heart of the ridge as far south as Granite Mountain, where the easterly dipping beds have totally disappeared. From Granite Mountain the axis is deflected into a sharp southwesterly curve, and another system of faults has, from that point to the southern termination of the range, cut off the westerly dipping member. North of Granite Mountain the main bulk is composed of the westerly dipping half of the fold, and south of Granite Mountain altogether of the easterly dipping member. At the extreme western base of Granite Mountain, cropping through the Quaternary valley deposits, are the summits of the sunken body of the westerly dipping part of the anticlinal, which have been faulted down.

West Humboldt Range repeats the same peculiar and interesting condition. The main anticlinal axis is developed from the region of Sacramento Cañon diagonally across the topographical axis of the range. Near the mouth of Sacramento Cañon a northwest-southeast fault has occurred, with a powerful horizontal displacement, by which the axis is faulted about five miles. From the region of Buffalo Peak northward nearly to Humboldt River a meridional fault has occurred, cutting diagonally across the geological axis, dropping its northward continuation out of sight, and giving to the topographical form of the mountain body a north-and-south trend, which is at an angle of 30° with the geological strike. West of the West Humboldt the exposures of the sedimentary rocks are of so limited an area, and their geological relations and continuations are so masked by floods of volcanic rocks, that it is unprofitable to pursue their details further.

While this brief description, from the complicated nature of the facts, may fail to convey a full idea of the state of things on the Basin Ranges, yet a careful scrutiny of the axis-lines, as laid down upon Analytical Maps X., XI., and XII., will show: *a.* that the region is one displaying a continuous series of folds of Palæozoic and Mesozoic rocks; *b.* that the general trends of these axes approach more nearly a meridian than an east-and-west line; *c.* that the axes themselves often display broad general curves traced through a hundred miles, their grander convexities being turned to the west; *d.* that in detail the axes are further subject to minor sinuosities obviously due to longitudinal compression; and, *e.* that the whole region has been most irregularly invaded by a series of faults which are east-and-west, north-and-south, northeast-southwest, and northwest-southeast. The result of this complicated interlacing system of dislocation is, that all the ranges of the Great Basin are broken into irregular blocks, sections of which have sunk many thousand feet below the level of the adjoining members. It frequently happens that anticlinal or synclinal axes have been the loci of the fissure-planes, and that in the accompanying dislocations halves of folds are left in long, well defined monoclinal ridges. When a fold is cut, either diagonally or transversely, by a fault, there is not infrequently a considerable horizontal displacement, as may be seen in the case of the West Humboldt, where the anticlinal axis is displaced five miles horizontally, and in the case of Piñon Range, where there is a still greater lateral movement.

That these faults were not contemporaneous with the great folding period, is obvious from their relations to the axis. Parallel faults often cut transversely or diagonally across a completed fold, dislocating anticlinal blocks which could never have been formed if the faults were contemporaneous with the folding. When we remember that the Eocene and Miocene Tertiary rocks which have been laid down within the hollows of these post-Jurassic folds, have themselves been thrown into waves and inclined positions up to 40°, and that these Tertiary beds are often violently faulted, it is evident that in extremely modern geological history there has been sufficient dynamic action to account for the system of faults. Furthermore, the enormous volume of volcanic products which is directly related to the subsided, dislocated blocks would seem to indicate that much of the faulting took place within the Tertiary age.

Whether we consider the country in lines transverse to the main axes of flexure, or parallel with those axes, it is evident that horizontal compression or actual diminution of area has occurred.

Tracing one of the great curved anticlinals like that of the Piñon, or that of Egan-Peoquop Range, with its northward continuation, and counting in the diminution of length of fold due to longitudinal compression, it will appear that there is not less than ten or fifteen per cent. of actual contraction. This law of longitudinal compression, so ably brought out by my colleague, Mr. S. F. Emmons, in his account of Toyabe Range, in Volume III. of this series, is a rule which holds in every single range of the Great Basin we visited.

When the country to the south and north of the Fortieth Parallel area comes to be carefully examined geologically, it will no doubt be possible to connect the main geological axes over the whole Great Basin, and to show with entire precision both the longitudinal and the lateral contraction which the surface of the region has suffered. From what I have seen in the Fortieth Parallel field, I am confident that the whole area has suffered a linear diminution of ten per cent. It is evident from the sections, also, that all or nearly all of the diminution of area or compression of surface took place at the time of folding. In the phenomena of the dislocated blocks which are the result of the great system of vertical faults, there is no evidence whatever of contraction of surface. Wherever we get a clew to those faults they are long continued planes of dislocation, often 60 to 100 miles in length, approximately vertical, and in the phenomena of irregular subsidence which has resulted from their action there is absolutely no proof of contraction.

The geological province of the Great Basin, therefore, is one which has suffered two different types of dynamic action: one, in which the chief factor evidently was tangential compression, which resulted in contraction and plication, presumably in post-Jurassic time; the other of strictly vertical action, presumably within the Tertiary, in which there are few evidences or traces of tangential compression.

The two grandest fault-lines shown in the Great Basin are those which define its east and west walls. Whoever has followed the eastern slope of the Sierra Nevada from the region of Honey Lake to Owen's Valley cannot have failed to observe with wonder the 300 miles of abrupt wall which the Sierra Nevada turns to the east. That wall is no other than a great continuous fault by which the Nevada country has been dropped from 3,000 to 10,000 feet downward. In this low trough east of the Sierra Nevada and Cascade Range is laid down the thick series (amounting to 4,000 feet, as already described) of Miocene beds. It is therefore evident that this was a depression which was defined before the beginning of Miocene time. On the western base of the Sierra Nevada, the marine Miocenes are found far down abutting against the extreme foot hills of the range. As yet in the depressed area east of the Sierra Nevada no Eocene beds have been discovered, from which it seems highly probable that the great fault occurred either within the Eocene or at the close of Eocene time, and was the direct cause of the subsidence whose area was immediately occupied by the Miocene Pah-Ute lake.

Since the Sierra Nevada along its crest and eastern wall is chiefly formed of granitoid rocks, it is impossible to determine the amount of the drop which the downward movement has caused; for if, as is evident, the fault occurred before the Miocene, there has been the enormous erosion of all subsequent time to reduce the crest of the great range.

In the case of the long Wahsatch fault we have a line of dislocation traced across the entire breadth of the Fortieth Parallel belt of 100 miles from north to south. As to the date of this fault, we are somewhat in the dark. The present Wahsatch Range, let it be remembered, was upheaved at the close of the Cretaceous, and during the Vermilion Creek period of the Eocene the country directly to the west of the Wahsatch was a high land whose abundant detritus was swept down into the Eocene lake. At the close of the Vermilion Creek period this region suffered a sudden and remarkable depression, which permitted the waters of the Eocene lake to flow westward over what had been high lands as far as the middle of Nevada, as shown by the middle Eocene strata extending to Elko. It seems, therefore, not improbable that the great Wahsatch fault occurred with that subsidence of central Utah which we may place at the close of the lower Eocene epoch and prior to that of Green River. If the Sierra Nevada fault was contemporaneous, it is not a little curious that we have failed to find any fresh-water Eocene beds in the depression east of the great range, either in Oregon, Idaho, or California. The country is so masked by volcanic rocks, and there are such enormous deposits of Quaternary, that they may yet exist without our having detected them; and it is not impossible that evidence will be found of the synchronism of the two great faults.

Fortunately, in the case of the Wahsatch fault we have, in the Cottonwood region of the Wahsatch, a magnificent exposure of folded stratified rocks through which the plane has cut, and from the direct, evident reading of the section it is clear that the fissure which traced itself throughout the axis of fold of the Wahsatch in this particular neighborhood caused the westward member to sink fully 40,000 feet. A relic of the eastern half of the great arch of Palæozoic and Mesozoic rocks still remains in position, its summit members deeply worn away by post-Cretaceous erosion, but all the details of the sequence of rocks are so clear and so perfectly exposed that there can be no doubt of the quantitative correctness of my reading of this tremendous dislocation. In passing northward we have less direct evidence of the amount of the fault, but through the northern part of the range it cannot have dropped less than two miles. The action is simply a vertical one by which the western half of the Wahsatch and the country lying west for some miles was, relatively to the eastern part of the range, dropped, and the dislocation took place on the axial line which cut the region of the extreme topographical heights of the Cottonwood group, where the maximum downfall was, as announced, 40,000 feet.

It is interesting to recall here that this region of the great Wahsatch fault had also been a theatre of enormous dislocation in the Archæan age, for the most remarkable single feature of pre-Cambrian topographical development in the Fortieth Parallel area is the great Archæan fault-face against which the Palæozoic members were made to abut in the process of deposition, and, as has already been seen in the discussion of the Pliocene, the same line of weakness yielded to a strain at the close of the Pliocene, by which the valley of Salt Lake suffered a depression of over 1,000 feet. G. K. Gilbert shows further subsidence along this line during the Bonneville period, and announces post-glacial activity on this historic line of weakness. It is evident, therefore, that this remarkable topographical feature of the great steep wall of Wahsatch Range has been from the earliest geological history a plane of recurrent displacement.

We are not surprised when an underlying Archæan ridge is found to be the determining cause of a modern range, but it is extremely striking to find a line of actual dislocation maintaining itself throughout such an enormous length of geological time.

If I am right in placing the Wahsatch fault at the close of the Vermilion Creek epoch of the Eocene, it is further of the greatest interest that the country which went down was the country which had been elevated to the most extreme heights, and which had furnished the enormous sediments of Vermilion Creek Lake. Here is a repetition of the law illustrated in the great displacement at the close of the Carboniferous already described in western Nevada, according to which a region of extreme elevation that had been enormously eroded immediately thereafter suffered paroxysmal depression.

Post-Cretaceous Orography.—The same difficulties which attend the separation of the effects of post-Carboniferous and post-Jurassic disturbance in western Nevada, accompany the attempt to disentangle the action of the post-Cretaceous from the earlier disturbances in the region of the Wahsatch. It is clearly seen from the conformity of the series that the great fold of the Wahsatch occurred at the close of the Cretaceous. It is also evident from the non-continuance of all the Mesozoic rocks west of Salt Lake, and the total difference of the eastern Mesozoic series from this development in western Nevada, that the continental mass raised at the close of the Carboniferous intervened between the western Nevada Mesozoic region and that east of and including the Wahsatch. The non-continuance of the Mesozoics west of the Wahsatch and the remarkable sedimental change between the Upper Coal Measure limestone beds and the purely detrital rocks of the Triassic would indicate a considerable change of level connected with the post-Carboniferous upheaval in the region of the Wahsatch. It must be remembered that the actual shore of the post-Carboniferous upheaval of land was a little west of the present Wahsatch.

The conformity of the Trias, Permian, and Upper Coal Measures in the Wahsatch is proof that, whatever may have been the character of the topography of the shore, no orographical disturbance touched the area of Mesozoic deposition. It was this absence of all plication in the Carboniferous sea-bottom, up to the very edge of the post-Carboniferous continent, together with the paucity of Triassic sediments, as compared with those west of the Mesozoic land area, that led me to infer for the character of the land in the Wahsatch or east shore region a low, unfolded surface lifted gently from the mediterranean ocean, where, as we know, the Carboniferous beds lay undisturbed.

Whether the post-Jurassic system of folds which threw up the great ranges of western Nevada, including the Sierra Nevada, continued its action as far east as the Wahsatch, it is impossible to tell.

At the close of the Cretaceous the Wahsatch itself was uplifted, and the country as far east as the Mississippi Valley felt the effect of the great dynamic impulse. As far as the evidence within the Fortieth Parallel area goes, the action of the post-Cretaceous uplift is simple in its general effect. The close of the Cretaceous found a continuous sea from the base of the

Wahsatch to the region of the Mississippi Valley. It was that mediterranean ocean whose outlines were defined by the post-Carboniferous uplift. It is clear that in the late Carboniferous an uninterrupted ocean at times extended from the Archæan shore in western Nevada to the Appalachian Range. The main effect of the post-Carboniferous upheaval was to lift two land-masses, one east of the Mississippi and one west of the Wahsatch, leaving the intermediate mediterranean sea. The great effect of the post-Cretaceous upheaval was to lift the bed of that mediterranean sea completely above the marine plain, thus uniting the two separated parts of America and making it a single continent. The effect of post-Cretaceous action in the immediate Fortieth Parallel region was, first, the development of a broad level region, now occupied by the system of the Great Plains; secondly, the outlining of the basin of the Vermilion Creek Eocene lake; thirdly, the formation of distinct folds, of which the Wahsatch and Uinta are the most powerful examples; fourthly, the relative upheaval of the old Archæan ranges, whose highest points had through all geological time since Archæan ages existed as island-points lifted above the marine plain.

The system of the Rocky Mountains, composed here of its three subordinate ranges, was, as regards the bottom of the Eocene lake basin, generally elevated. The lake basin itself was thrown into a series of broad, gentle folds and local quaquaversals, determined by underlying Archæan bodies, and its area was prominently divided by the great east-and-west Uinta fold. A correct idea of the magnitude of the grander post-Cretaceous folds may be gathered from the sections of the Wahsatch and Uinta. The fold of the Wahsatch involved a conformable series from the base of the Cambrian to the summit of the Cretaceous, in all about 44,000 feet, and from the present position of the rocks it is clear that a full section of the fold was above the present level of Salt Lake; so that, since the ocean level was banished to somewhere near its present position, the fold itself was not less than 44,000 feet in altitude. The Uinta was not so imposing a body, but its summit before erosion began was certainly 30,000 feet above the sea-level.

Relatively to the surrounding country all Archæan ranges within the area involved were lifted, so that the Cretaceous strata which overlay their passes and the rocks which abutted against their mountainous flanks were thrown either into continuous arches over the depressed parts of the Archæan ranges or into inclined belts along their flanks.

Before the commencement of the post-Cretaceous erosion, and before the basin of Colorado River began to be covered by the fresh-water lake of the Vermilion Creek Eocene period, the general topography, the result of the post-Cretaceous fold, was that of enormous arches which were locally broken and dislocated into irregular blocks, and these folds were separated from each other by wide areas of gentle undulation or entire horizontality. One of the most interesting features in the whole orographical phenomena of America is the development of broad inclined planes south of the Fortieth Parallel work, in what is known as the Colorado Plateau. Here are areas which have been and are being ably described by Messrs. Powell and Gilbert, in which the sea-bed becomes an undisturbed plateau 5,000 and 6,000 feet above the level of the subsequent ocean. When we come to examine the relations of the post-Cretaceous folds with these adjacent undisturbed plateaus, it is evident that there were large regions in which no superficial contraction or diminution of area took place, whereas there were others in which occurred the most enormous and complex plications. Any theory, therefore, which attempts to account for the superficial results of geological dynamics will have to account for the existence of wide regions which, relatively to the sea, are suddenly upheaved without the slightest contraction, plication, fold, or fault, and of other regions within the same stratigraphical province which suffered the most extreme local compression, and all the complexities which can ensue from fold and fault.

When we study critically the underlying geology in connection with each of the great folds, it is evident that wherever an Archæan mountain range underlay the subsequent sheets of sediment, there a true fold has taken place. If the reader will look at the sheet of sections in the General Atlas, he will see that the old Archæan ranges of Rocky Mountains are flanked upon each side by conformable Palæozoic and Mesozoic beds dipping away from the Archæan bodies. For example, on a line drawn northwest-and-southeast across the end of Park Range, Medicine Bow, Laramie Plains, and Colorado Range, the three Archæan bodies form the loci of three distinct uplifts, the later sedimentary beds being thrown into inclined positions. When we observe the continuity of the strata across such a valley as that of Laramie Plains, and then see them sharply and suddenly rise against the foot-hills of the Archæan, it becomes evident that the entire area of the Rocky Mountains has suffered actual lateral compression, and that the diminution of surface amounts to from six to ten per cent. When we further consider that the post-Archæan sedimentary rocks must be regarded as a mere thin covering over the solid subjacent crust, this diminution of area of actual surface means an actual compression of the solid Archæan shell of the earth.

In the case of the Wahsatch it is seen from the relations of the old Archæan underlying range that that enormous mountain body determined the existence and character of the post-Cretaceous fold. In the case of the Uinta it is impossible to say how far underlying Archæan rocks have played a part. The single limited outcrop of pre-Cambrian rocks at Red Creek, however, is certainly at the most ruptured and actively dislocated point of the whole Uinta Range.

The entire thickness of conformable rocks from the Cambrian to the top of the Cretaceous does not amount in the region of the Laramie Hills to more than 5,000, or at the most 6,000, feet. East of Colorado Range stretches the uninterrupted Great Plains. With this shallow covering of rock the non-protrusion of Archæan peaks over the surface of the Plains is ample proof that no hills of considerable height existed at the close of Archæan time over that whole area. The Archæan rocks of Missouri are the first of the series to the east that rise above the limit of the later sedimentary beds. In other words, a region that was not a region of Archæan mountains in the great orographical period which lifted the whole of that country above the level of the sea, suffered neither plication, nor fault, nor local disturbance. It is also noticeable that much of the great undisturbed Colorado plateau shows only low Archæan forms underlying its sedimentary series, and those, although plainly eroded into hills, as described by Newberry, Powell, and Gilbert, are never accidented into considerable mountain chains, the law evidently being, that over what was comparatively flat Archæan country the subsequent orographical movement has the effect of wide-spread bodily upheaval without local disturbance. This law, which is carried out so distinctly and so powerfully over the Cordilleras, is again shown in the Mississippi region, where a comparatively thin coating of sedimentary beds lies on a generally smooth underlying Archæan territory, and the result is no considerable fold; but where, in the Appalachian chain, we again arrive at a system of old Archæan mountains, they have again in post-Carboniferous time determined the production of great modern ranges. From these relations of pre-Cambrian and more modern topography, it seems to be a general law that the configuration of America is almost wholly due to the topography of the primeval pre-Cambrian continent. The power of underlying ranges to determine the position of modern uplifts is not confined to those lofty ridges whose summits were lifted as islands above the plane of later deposition, but is equally shown in the case of ranges whose summits were deeply submerged. It is demonstrable that the highest of the Archæan Wahsatch ridges were covered by at least 10,000 feet of sediment, yet in the post-Cretaceous fold the more modern rocks were thrown into a distinct enormous arch over the previously defined Archæan ridge; and in the case of the Laramie Hills, which were covered by from three to five thousand feet of horizontal sediment, the post-Archæan sediments were thrown into an anticlinal over the top of the Archæan body.

In connection with these post-Cretaceous folds over the Archæan bodies are some very interesting effects of compression and distortion of the central Archæan mass. Fortunately, in the case of those Archæan points which were sufficiently raised to continue as islands during the whole of the Cretaceous, we have, from the accidents of modern erosion, an exhibition of the planes of contact between the old Archæan and a variety of horizons of the Cretaceous. Along the shores of these islands, making all allowance for variation in depth of the waters, it seems probable that a given horizon of the Cretaceous represents something like an old horizontal shore-plane. In the present condition it is interesting to observe how this once horizontal plane has been thrown into vertical sags. From the modern positions of these old shore-lines it is seen that the Archæan body suffered in the post-Cretaceous orography not only an irregular uplift resulting in vertical waves, but a true torsion by which the body of the island has actually yielded to a twisting force amounting in some places to a shear of 5,000 feet. Wherever an Archæan ridge was flanked by horizontal abutting strata, and these strata were afterward thrown into a position inclined to each other, it is evident that the interval of Archæan rock must have been compressed, and in yielding to this force the Archæan bodies have developed an amount of plasticity which, in view of their crystalline nature, is very surprising.

The writer has observed that slabs of marble when supported by their ends sag in the middle, taking a permanent set. Similar observations have not to my knowledge been made on granite, but it is evident from the modern stratigraphical relations of these Archæan islands and Archæan ridges that they have suffered a shear and taken a permanent set, with a surprising development of plasticity.

Among the more interesting detailed features of the post-Cretaceous uplift in the Rocky Mountains are the following: All the Laramie hills north of the 41st parallel were clearly overarched by a continuous anticlinal fold of the conformable series from the Cambrian to the close of the Cretaceous. A little south of the 41st parallel the Archæan heart of the range rises, there forming the great island which continued for many miles to the south. North of that point the post-Cretaceous erosion has removed the whole top of the anticlinal arch, leaving only a narrow band of sedimentary rocks margining the east and west flanks of the Archæan central ridge.

Throughout the hundred miles of easterly dipping sedimentary beds along Colorado Range exposed within the Fortieth Parallel area, the narrow foot-hill zone dipped always from the Archæan nucleus, varying at angles from 16° to 80°. This belt of inclined rocks is very narrow, usually comprised within a width of four miles. Passing eastward it suddenly flattens to the horizontal and extends in that position out upon the Plains. This angle of flexure is always visible where not masked by the subsequent Tertiary rocks. The character of the bend is extremely sudden, and the superficial exhibition is usually within the limits of the

Colorado Cretaceous clays, the overlying sandstones having been worn off from the immediate top of the curve.

An interesting feature of this foot-hill region is the manner in which the narrow band of inclined sedimentary beds follows all the minor sinuosities of the Archæan topography. This is clearly shown on Big Thompson Creek and the Chugwater Promontory.

The Laramie Plains form a horizontal area of Cretaceous, lying like a bay in the angle of Medicine Bow and Colorado ranges. This undisturbed plain of Cretaceous, in approaching the two mountain ranges, rapidly bends up to dip-angles of from 2° to 30°.

In the broad Cretaceous exposures between the 106th meridian and that of 107° 30′, Analytical Geological Map VIII. shows an interesting combination of anticlinal and synclinal axes. At Rawlings Peak occurs the oft-mentioned quaquaversal ridge, the longer axis striking northwest-southeast, being evidently the continuation of Park Range.

Decidedly the greatest of the features of the Cretaceous uplift are Uinta and Wahsatch ranges. The Uinta, especially, forms a type of orographical structure elsewhere very uncommon. It consists of a broad central plateau, a hundred and fifty miles long by thirty miles wide, in which there are slight sags and local undulations, but the average dip of the strata is from the horizontal only up to 4° or 5°. This broad flat-topped arch suddenly gives way along the north and south edges to two distinct axes of flexure, where the horizontal rocks bend over, accompanied by distinct faulting, and dip from the northern axis north, and from the southern axis south, at angles varying from 10° to 70°. In the region of Green River Cañon the southern line of flexure becomes immensely complicated, and develops three local anticlinals. A glance at Analytical Geological Maps IX. and X. shows the position and average dip of angles along the northern and southern axial lines.

In the Wahsatch the most remarkable features are, first, the development of a curved strike around a nucleal mass of granite in the Cottonwood region, where the rocks describe the complicated bends shown by the dotted line of the geological axis. Although partially covered with Tertiary strata, the next northern exposure of Archæan rocks—that near the 41st parallel—is again surrounded by a semicircular zone of inclined rocks which dip away from the nucleus in every direction. The northern end of the Wahsatch develops a very singular complexity. The easterly dipping rocks of the immediate mountain flank, besides suffering longitudinal fault, which partially duplicates the series, pass under a broad synclinal and rise again over a prominent anticlinal in the region of the meridian of 111° 30′.

All the post-Cretaceous folds are more or less dislocated into detached blocks. A part of this action, as in Ogden Ridge, was a feature of the original uplift, but others, as the Great Wahsatch fault, were long after the creation of the fold.

TERTIARY OROGRAPHY.—From the close of the Carboniferous the region immediately west of the Wahsatch had been the shore of the Mesozoic ocean. After the post-Cretaceous folding of the Wahsatch and Uinta there is no reason to suppose that the old continental mass followed the law of paroxysmal subsidence of lightened areas. We arrive at the knowledge that the old post-Carboniferous land remained relatively superior to the newly folded country, including the Wahsatch and the country east of it, from the fact that the Vermilion Creek (Ute) lake formed in the basin directly east of the Wahsatch, and its beds overtopped the lower portion of that range and continued a little farther westward, abutting against a highland. This highland, which at first was certainly in places more than 40,000 feet above the sea-level, suffered the rapid and intense erosion which produced the 5,000 feet of Vermilion Creek sediments. That series, during deposition, was a subsiding series, as is evident by the successive shore conglomerates which recur along the western development of the group at intervals through the whole 5,000 feet of thickness. At the close of the Vermilion Creek age a new orographical period ensued, whose effects are only chronicled in the area of the Fortieth Parallel between the Rocky Mountains and Havallah Range. The Vermilion Creek rocks are thickest next to Wahsatch and Uinta ranges, which formed their chief source of supply, and thinnest farther east, where the edges of their beds overlap the nearly horizontal Cretaceous toward the Rocky Mountains;

and in the post-Vermilion Creek orographical epoch, the eastern part of the basin, where the beds were thinnest, was left undisturbed.

But a remarkable change of level was effected in the region of the Uinta and Wahsatch. Along both of these ranges the edges of the rocks, viz., the shore regions, were upturned; in other words, the basin portions in the angles between these ranges became relatively depressed. But the most singular act of this epoch took place within the land region immediately west of the lake. Here, the lofty country west of the Wahsatch, which had formed the main source of supply for the Vermilion series, suddenly sank and permitted the waters of the lake to extend themselves over 200 miles westward into Nevada. This was another instance of that remarkable law of paroxysmal subsidence taking place in the highest lands immediately after they have suffered extraordinarily rapid erosion.

Between those disturbed Vermilion Creek rocks and the next ensuing Middle Eocene sediments, viz., those of the Green River age, there is a nonconformity in the basin of Green River, where the Vermilion Creek rocks were thrown into folds amounting sometimes to 20° and even 40°, and an overlap of 200 miles to the west.

The deposits, as already described, were comparatively uniform over the whole lake. Events at the close of the Green River period embraced the relative uplift of all the western half of the Gosiute Lake—that very region which had been added by subsidence to the area of the Vermilion Creek lake; the plication of rocks of the Green River series at various points over the area of the lake resulting in folds of 40° and 50° in western Nevada, and the folding of Cherokee Ridge with a dip of 25°.

The Bridger period north of the Uinta is represented by a lake wholly within the limits of Vermilion Creek lake. To the series of orographical events which closed the Bridger period, drained the area of its lake, and established a small, local, fourth Eocene (Uinta) lake south of Uinta Range, we have little clew.

During the Eocene the whole Great Plains was a land area, and at the close of that interval of time a general subsidence of the region took place, deepest along the Rocky Mountain foot-hills. The result of this was to define the great Miocene basin of the Sioux lake. Probably at the same time occurred the subsidence and outlining of the Miocene Pah-Ute Lake, which, as before described, stretched from Washington Territory east of the Cascades and Sierra Nevada southward through Oregon into California. It is probable that the great eastern fault of the Sierra Nevada took place at the moment of subsidence of the basin of the Pah-Ute lake. It is impossible to decide how far the rocks covered by the area of the Pah-Ute Miocene lake were folded during this subsidence, since even at the close of the Jurassic we know of their being thrown into enormous waves. The Miocene lake occupied all the hollows and valleys of this post-Jurassic upheaval, the tops of the high Jurassic folds forming islands in the lake.

In the case of the Great Plains, we are warranted in assuming that the subsidence which formed the Sioux Miocene lake was not accompanied by any considerable disturbance, since, wherever the deposits of that lake are cut through by modern erosion, and the underlying formations displayed, they are found to be nearly in horizontal positions.

This method of general subsidence without fault or fold is further illustrated by the events which took place in the region of the Great Plains at the close of the Miocene period and before the Pliocene. At this date the whole area of the Great Plains—not only that embraced within the Sioux Miocene lake, but a vast amount of its surrounding lands to the north and south—suffered so gentle and gradual a depression that, although the subsequent deposits of the Pliocene Cheyenne Lake enormously overlapped the sediments of the Miocene lake in every direction, yet wherever they are observed in contact, their angular conformity shows that the Miocene was not locally disturbed by the general subsidence. Contemporaneously with this gentle wide-spread subsidence of the area of the Plains, that of the Pah-Ute Miocene lake was thrown into folds, the Miocene rocks reaching in many instances a dip of 25°. At the same time, however, the entire Great Basin area sank and became the receiver of the waters of an enormous lake, covering much of Nevada, Idaho, eastern Oregon, and a part of California. The feature of general, gentle subsidence and enlargement of lake area is common to the eastern and western post-Miocene disturbance. Folding and compression are confined to the Pah-Ute Lake area.

At the close of the Pliocene the last prominent dynamic events occurred. Both in the region of the eastern and western Pliocene lakes, wide areas were thrown into the attitude of inclined planes without either fault or fold. This important fact, as I have before mentioned, was first described by General G. K. Warren, in his "Preliminary Report of Explorations in Nebraska and Dakota in the years 1855, 1856, and 1857." On page 24 General Warren says:

"The question of the slope of the plains is a subject to which I have given much attention, from its scientific as well as practical interest. Our barometric observations have enabled us, in some measure, to fill up the gap between those of Governor Stevens on the north and Captain Frémont on the south, and thus give us the connected levels over a very large area. The observations upon the great Tertiary formation have developed the fact that since the close of the Pliocene period the eastern base of the mountains, which is the western limit of this formation, has been elevated from 2,000 to 3,000 feet above the eastern, and this without there being anywhere visible signs of upheaval, such as inclination of the strata. The only direct evidence is in the immense denudation which the Tertiary has undergone, probably while this elevation was in progress, and which causes of denudation must have been gradually extinguished, as there is, at the present time, no force at work sufficient to have affected them. The evidence goes to show that the elevation which has taken place since the close of the Pliocene period has been in Nebraska remarkably uniform, and along a line in a general direction northwest-and-southeast, and nearly coincident with the ranges of mountains previously upheaved."

This Exploration has shown that the highest point to which the Pliocene strata of the Great Plains rise is in the region of the head of Horse Creek, where they attain fully 7,000 feet. From this culmination they slope to the north, south, and east, passing under the Gulf waters in Texas, and declining to the level of Missouri River to the northeast. By this movement the horizontal bed of the great Pliocene lake was tilted from 3,000 to 7,000 feet, forming the great inclined system of the Plains. Undulations and faults have not yet been detected.

Contemporaneously with this, the Pliocene deposits which covered

Utah and Nevada suffered a similar disturbance. From the highest Pliocene level in the region of Thousand-Spring Valley, at an elevation of about 6,000 feet, the sheets of Pliocene strata descend in a gentle inclined plane east and west—east to the foot of Wahsatch Range, where, upon a north-and-south fault, the edge of the Pliocene sheet was depressed 1,000 feet; and west to the eastern base of the Sierra Nevada, where by a similar fault the western edge of the sheet was depressed 2,000 feet below its natural level. In both the Plains and the Great Basin regions this wide inclined tilting of sheets was executed without a fault or a rupture, save at the two edges of the western lake, against the Wahsatch and the Sierra Nevada, where the old lines of weakness again became the loci of fault, in one case of 1,000 feet and in the other of 2,000 feet.

Regarded chronologically, the periods of orographical activity occurred as follows:

1. Post-Laurentian.
2. Post-Archæan.
3. Post-Palæozoic.
4. Post-Jurassic.
5. Post-Cretaceous.
6. Post-Vermilion Creek Eocene.
7. Post-Green River Eocene.
8. Post-Bridger Eocene.
9. Post-Eocene.
10. Post-Miocene.
11. Inter-Pliocene.
12. Post-Pliocene.
13. Faults of the historic period.

The work of the post-Laurentian period was to throw the horizontal beds of crystalline sediments into waves wholly within the present province of the Colorado River, viz., from the Rocky Mountains to the Wahsatch, inclusive of that range. The general post-Archæan orographical period covered not only that which was folded at the close of the Laurentian, but extended itself westward over the whole breadth of the Cordilleras. This enormous crumpling was accompanied by the great faults at Red Creek

(Uinta) and at Cottonwood (Wahsatch). Elsewhere faults and dislocations were accompanied by enormous and repeated intrusions of plastic granite. In general, it was the west half of the post-Archæan uplift which resulted in the grandest mountain forms.

The post-Carboniferous movement defined a continental body from the Wahsatch to the longitude of 117° 30′, its greatest elevation being upon the west, as is shown by the enormous amount of sediments delivered directly under those western heights and by the excessive dislocations of the crust at that longitude.

The post-Jurassic period had its action altogether confined to the post-Carboniferous continent, and a till then submerged region extending 200 miles west of the continent, which at this period became crumpled and upheaved above the level of the sea. It is also noticeable that the westernmost limit of the post-Jurassic upheaval was that of the most powerful compression.

The post-Cretaceous period covered the present province of the Colorado and that of the Great Plains. Its result was the obliteration of the mediterranean ocean, and the development of powerful folds and of great elevated plateaus whose surface was comparatively undisturbed. The most intense crumpling and local disturbance was at the extreme western edge of the area acted upon, viz., in the region of the Wahsatch and Uinta.

These three periods—post-Carboniferous, post-Jurassic, and post-Cretaceous—taken together, were the main building-times of the modern American continent, and each of these orographical disturbances was most violent at the western edge of the region involved. All of the three disturbances have been confined to regions of marine sedimentation, and in each case the age of the upheaval came immediately at the close of a long interval of conformable sedimentation.

The continent having been completed with the exception of the Pacific Coast Ranges at the close of the Cretaceous, subsequent disturbances of whatever character are not to be measured by their relations to the sea-level, but are simply the foldings, upheavals, and subsidences within a continental area, and may only be measured by their relations to contiguous land or lakes.

Each of the great groups of conformable sediments during the process of their formation covered regions of successive gradual subsidence, and in the nature of this subsidence it is evident from the relations of the lower and upper members of the same series, first, that the beds are thickest next the source of supply, according to the ordinary rule, so that the formation as a whole has the section of a wedge, the greatest subsidence always taking place at the thickest end of the wedge, and the descent being directly proportioned to the amount of material. This is clearly shown in the conformable body of Palæozoic rocks, and in the Mesozoic series east of the Wahsatch. A subsidence of at least 10,000 feet evidently took place during the deposition of the Mesozoic east of the Wahsatch. Now, this local sinking represents one of two processes: either the bending down of a thin crust underlaid by yielding material, or else the actual displacement of solid subjacent material, which, under the loaded spot, acted as a comparatively plastic body.

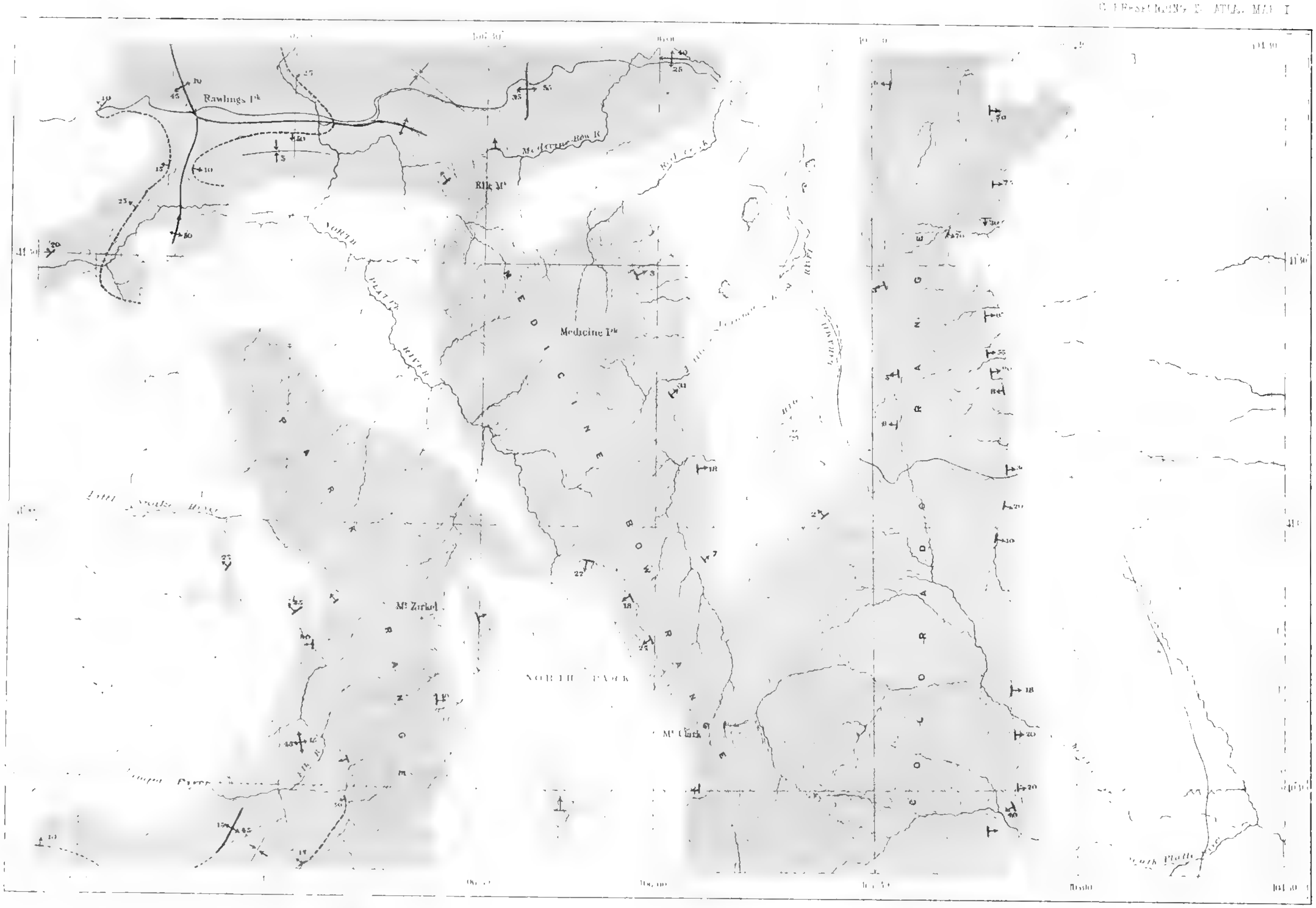
There are, therefore, two entirely different types of subsidence, one the gradual sinking of a region by loading, due to sedimentation, in which the most heavily loaded locality goes down deepest. This subsidence, from the nature of the sedimentary sections, is seen to be of the slowest and most gradual type. The other is a sudden paroxysmal subsidence on a plane of fault, in which the region lightened by erosion and removal is the one that goes down.

In the upheaval of wide areas there are two main noticeable types of operation—one the lifting relative to the sea-level of broad regions which, after upheaval, may be left horizontal or in gently inclined planes, their surface showing neither fault nor fold; the other, the well known operation of plication, by which actual deformation of the crust takes place, resulting in folds and faults and the tangential crushing of rocks.

In the case of such an action as that which tilted the whole province of the Great Plains into its present inclined position, it is evident that there was both upheaval and subsidence relative to the sea. The sheets of strata which formed the surface of the plain are of lacustrine Pliocene. Their highest point, of 7,000 feet, is higher than all but the highest summit of the Appalachian system There was no mountain barrier along the eastern

ANALYTICAL GEOLOGICAL MAP _ VIII

EXPOSURES OF SUCCESSIVE OROGRAPHIC DISTURBANCES



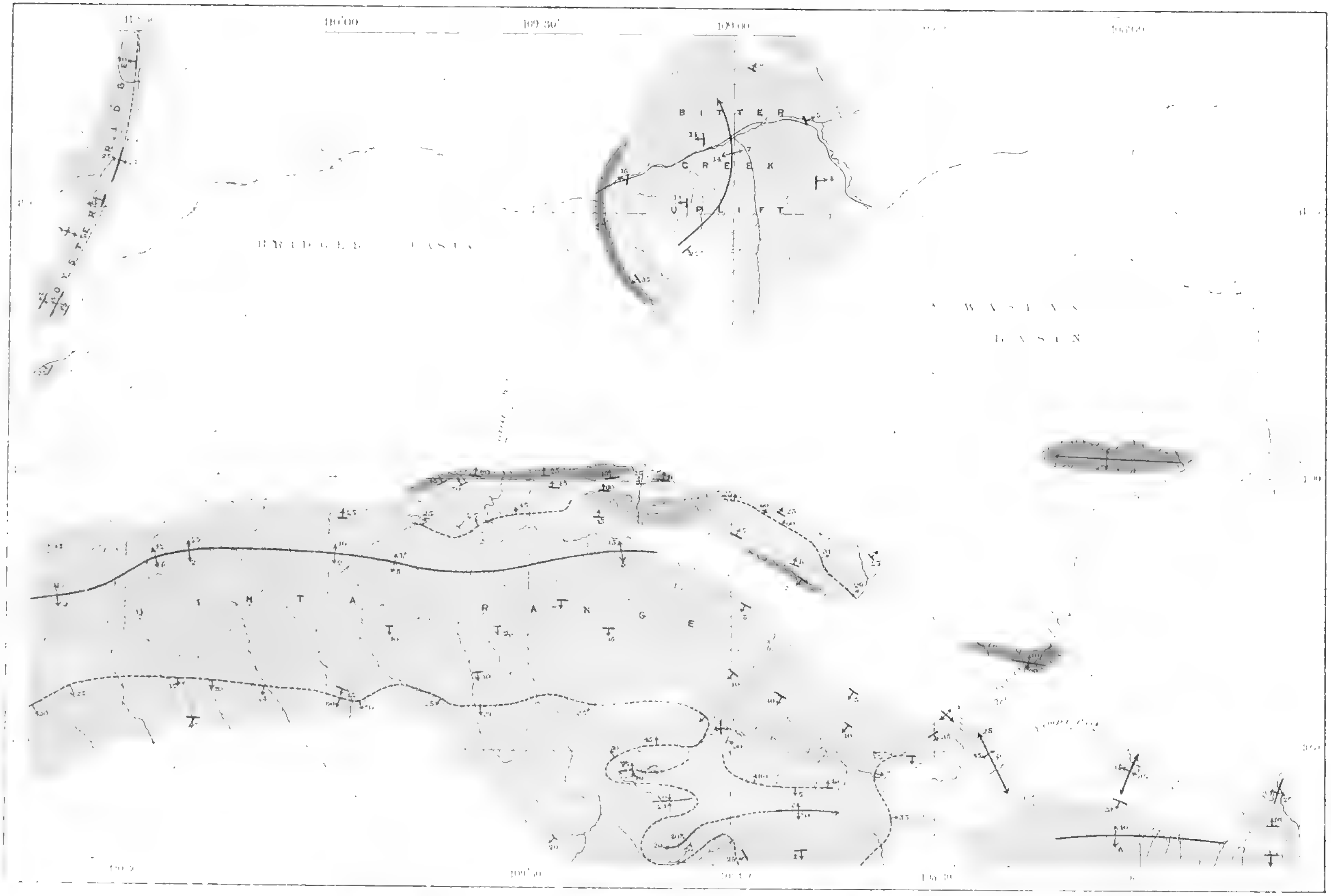
POST ARCHÆAN

POST CRETACEOUS

Continuous heavy black lines indicate geological axes; dotted lines indicate strike; arrows dip figures angle in degrees

ANALYTICAL GEOLOGICAL MAP IX.

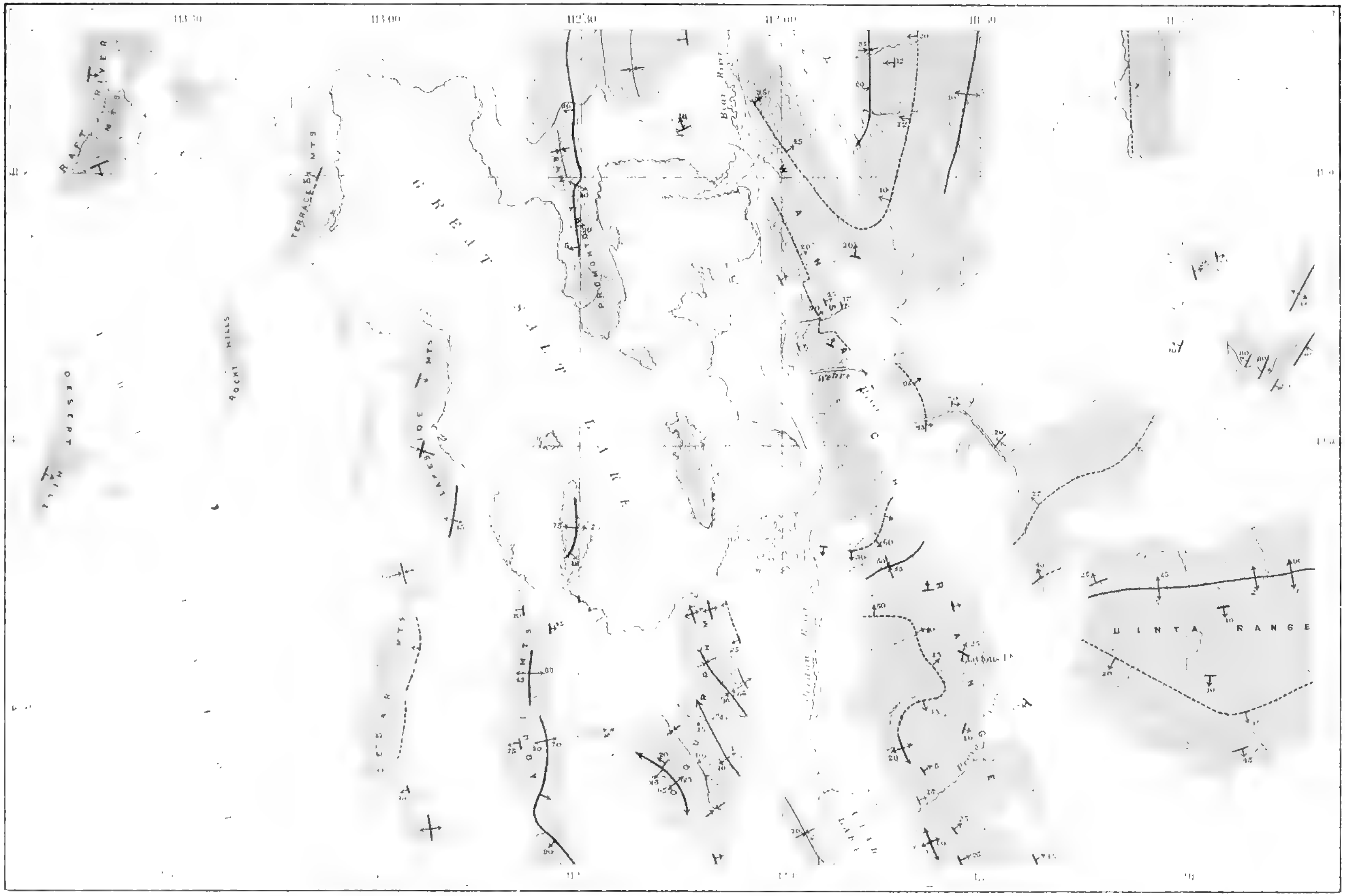
EXPOSURES OF SUCCESSIVE OROGRAPHIC DISTURBANCES



Continuous heavy black lines indicate geological axes, dotted lines indicate strike, arrows dip, figures angle in degrees.

ANALYTICAL GEOLOGICAL MAP X

EXPOSURES OF SUCCESSIVE OROGRAPHIC DISTURBANCES

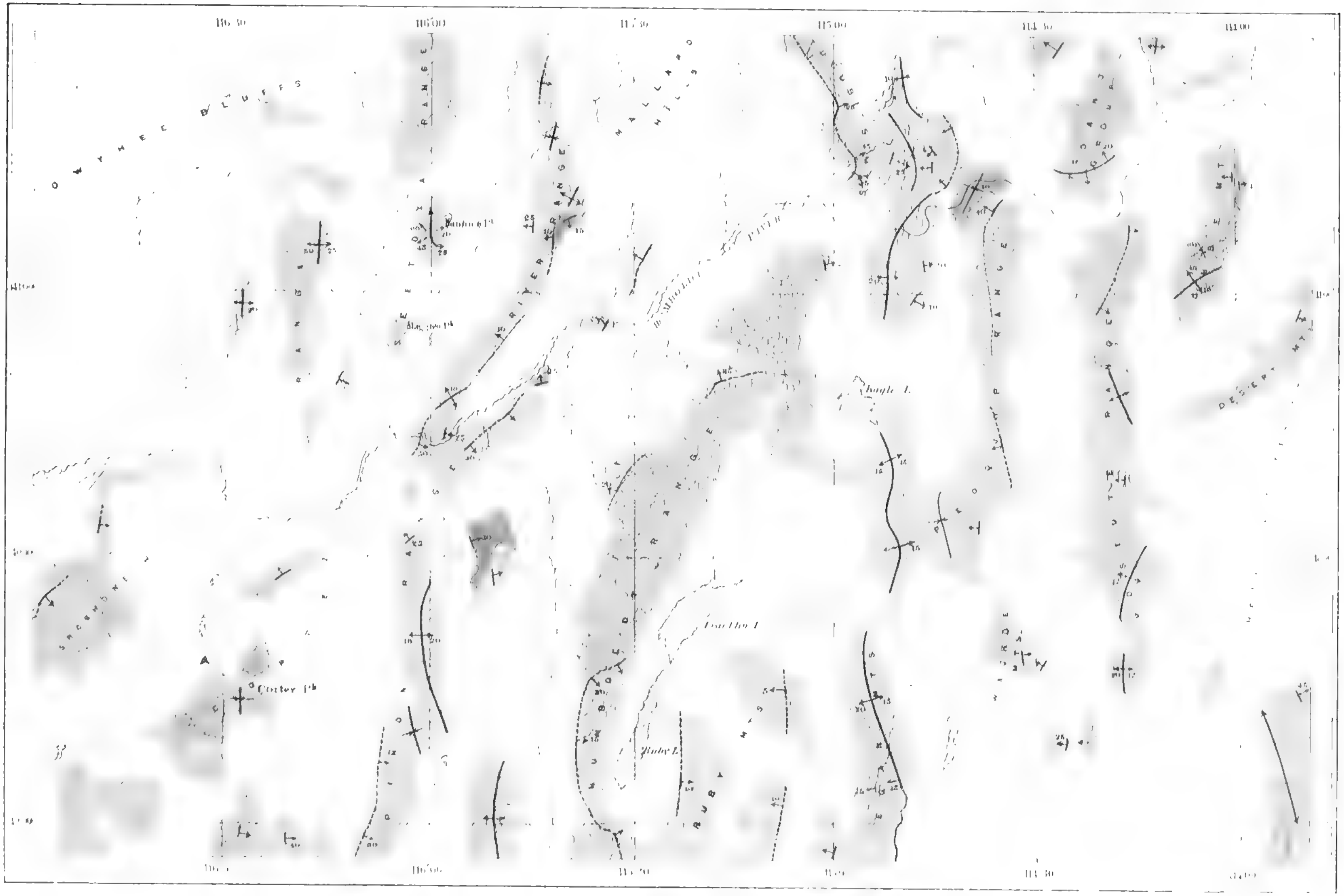


POST ARCHÆAN — POST JURASSIC — POST CRETACEOUS

Black lines indicate geological axes, dotted lines indicate strike, arrows, dip; figures angle in degrees

ANALYTICAL GEOLOGICAL MAP. XI

EXPOSURES OF SUCCESSIVE OROGRAPHIC DISTURBANCES

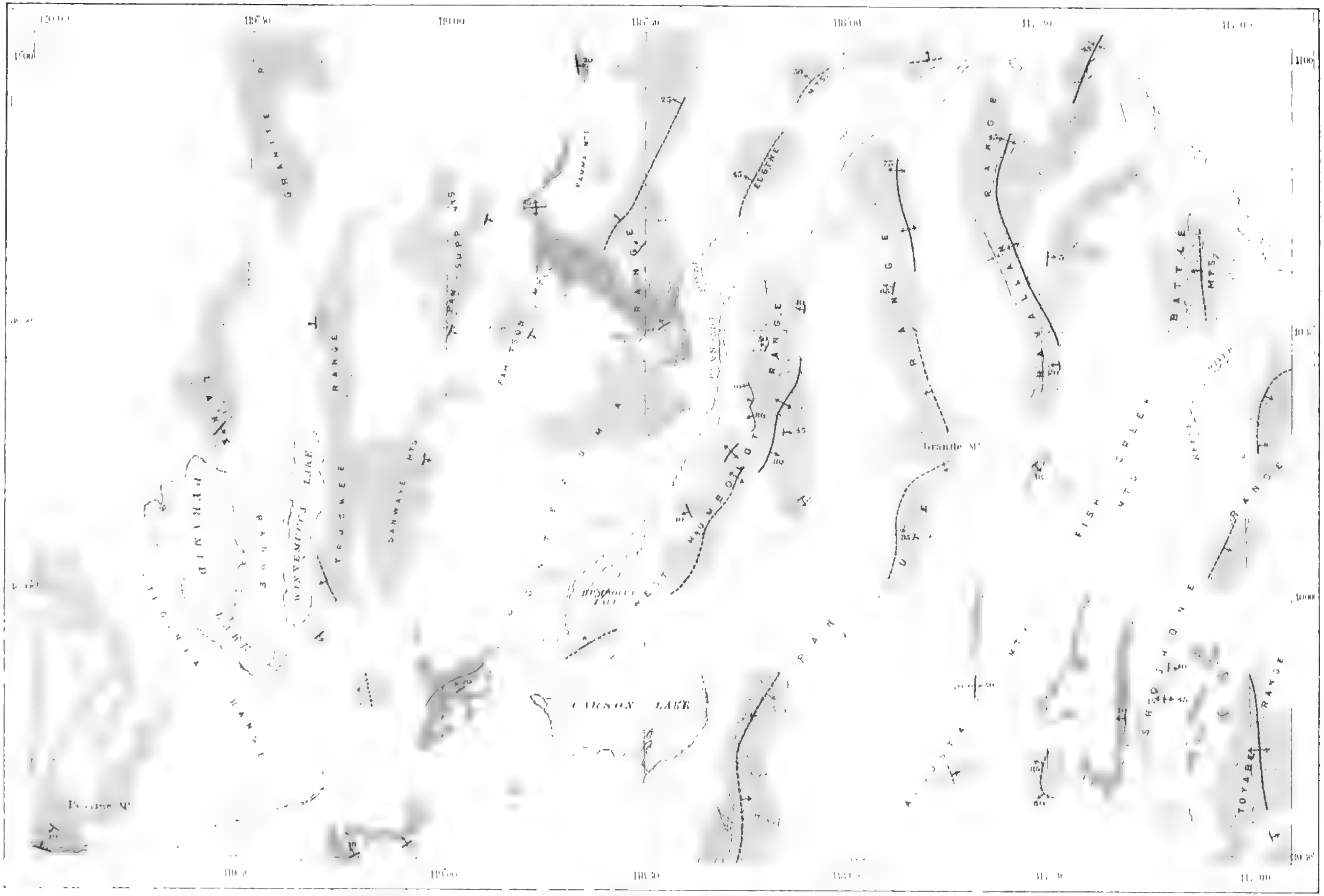


POST ARCHÆAN — POST JURASSIC — TERTIARY

Continuous heavy black lines indicate geological axes, dotted lines indicate strike, arrows, dip, figures, angle in degrees

ANALYTICAL GEOLOGICAL MAP XII.

EXPOSURES OF SUCCESSIVE OROGRAPHIC DISTURBANCES



POST ARCHÆAN | POST JURASSIC | TERTIARY

Continuous heavy black lines indicate geological axes, dotted lines indicate strike, arrows dip, figures angle in degrees.

margin of the great Pliocene lake. Had that lake been at 7,000 feet, its fresh waters must have extended over the whole of eastern America and over the top of the Appalachians, which is impossible. On the other hand, when we approach the Gulf shore of Texas, in the region of Galveston, these fresh-water Pliocenes are seen to pass under the salt water of the Gulf. There has been, therefore, between the two sides of the lake, actual depression below the sea-level and actual lifting far above the former altitude of the lake.

In the case of the post-Cretaceous upheaval a very wide part of the area involved, including the province of the Plains, although lifted above sea-level, was not locally plicated or faulted, but the extreme western limit of the same area of dynamic action suffered the enormous folding of the Wahsatch and the Uinta. It is, therefore, possible to have contemporaneous general uplift without any local disturbance, passing and merging into a region of great horizontal contraction.

In this complicated history, therefore, have occurred both upheaval and subsidence as related to the sea-level; plication, always greatest at the western edge of the area disturbed; the formation of folds 40,000 feet from summit to base; the development of faults with at least 40,000 feet of dislocation; the tilting of horizontal regions into broad inclined planes without a disturbance; and the division by complicated fault-systems of wide areas into numerous separate blocks, of which some are depressed below the level of their adjacent companion blocks.

It is also a general law that those regions which experience elevation without local disturbance are the regions of relatively thin sediment superposed on a comparatively unaccidented Archæan foundation, whereas those which suffer the extremest plication are covered by the thickest deposits overlying and adjacent to the greatest Archæan mountain ranges.

APPENDIX.

GEODETICAL AND TOPOGRAPHICAL METHODS USED ON THE GEOLOGICAL EXPLORATION OF THE FORTIETH PARALLEL.

By James T. Gardner,

Assistant in charge of Surveying.

The territory surveyed is a belt about 107 miles broad and 800 miles long, extending from the eastern foot of the Rocky Mountains to the Sierra Nevada of California, or almost across the Cordilleras of North America, where they are broadest. It is included between the meridians of 104° 30′ and 120°, and the parallels of 39° 30′ and 42°. The western half of this region is an arid mountainous desert. The eastern half, having a much greater elevation, is not so dry, although in large part desert. The Union and Central Pacific railroads, which now traverse this section, were not built when the Fortieth Parallel Exploration was begun, and no maps of the mountain ranges existed upon which even the roughest geological work could be based.

For the purpose of studying and drawing the geology of this area, it was therefore necessary to make maps on a scale sufficiently large to show in their true relations the principal topographical features and their characteristic differences of form. This duty was assigned to the surveying department, with instructions to produce a map of the territory examined, on a scale of an inch to four miles, on which should be laid down the general contours and elevations of the mountains and plateaus, the drainage-systems, roads, towns, &c., with such accuracy that errors in relative positions and distances between points should not be apparent on the given scale. It was evidently impossible to accomplish the result by ordinary modes of reconnoissance; and with the time and means at command it was equally impossible to carry over this great area of 87,000 square miles a topographical survey like those of Europe. Maps for the geological purposes in view, however, must be similar to European ones in character, only much less accurate in detail. It was, therefore, considered best to use in the Fortieth Parallel Exploration the general plan of a regular trigonometrical survey, modifying methods to obtain the desired grade of precision and detail. The work is consequently based on a connected system of primary, secondary, and tertiary triangles, by means of which all topographical features were determined.

PRINCIPAL TRIANGULATION.

The peculiar form and climate of the region greatly facilitate triangulation, abounding as it does in sharp rocky peaks bare of vegetation, enough of which rise to altitudes of 10,000 to 13,000 feet to furnish intervisible points 60 to 80 miles apart, so situated as to form well conditioned triangles, while the purity of the atmosphere renders distinct seeing possible at long distances.

Stone cairns were placed on the peaks selected for stations, and were the only signals used; but these being invisible, except on shorter lines, exactly the highest points of the mountains were usually observed. These culminating points of Cordilleran summits can generally, by a practised eye, be determined within a very few feet. Along three quarters of the belt triangle-sides have an average length of about 70 miles. In the remaining portion the average length is about 54 miles. The longest line is 115 miles.

From Peavine Mountain (long. 120°) to Medicine Butte (long. 111°) the average error of closure, after reduction for spherical excess, is 13″; from Medicine Butte to Separation Peak (long. 107° 30′) the average error of closure is 80″; from Separation Peak to Sherman the average error of closure is 15″.

The errors of closure in triangles were distributed among the angles according to judgment of the weight of observations from the number of pointings, special characters of the objects sighted, and agreement between independent values. The whole figure of the scheme was thus adjusted and fixed in the relations of all its parts, without reference to any bases of verification or resulting geographical position of stations.

Most of the angles were observed with an eight-inch Wurdemann theodolite reading to 10″. Some were measured with a six-inch Wurdemann circle reading to 10″.

From Peavine Mountain to Medicine Butte the observations were made by myself in the years 1867, 1868, and 1869. Between Medicine and Separation peaks they were made by Mr. A. D. Wilson in 1872. From Separation to Sherman the observations were made by myself in 1872.

At twenty-one of the principal stations azimuths of Polaris were observed, the time being determined with a sextant. The latitudes of five stations were determined with a zenith telescope by myself. The latitudes and longitudes of three others, Verdi, Salt Lake, and Sherman, were determined by the United States Coast Survey with the utmost precision. Two of these stations, Verdi and Sherman, are at the extreme ends of the chain of triangles, and Salt Lake is in the middle.

The triangulation was developed from an astronomical base just west of the 118th meridian.

This base is a line about 64 miles long between the summits of Tarogqua and Star peaks, which lie very nearly north and south of one another. The latitudes of these two stations were carefully determined with the zenith telescope, and the azimuth of the line joining them observed at each end. These azimuths, corrected for difference of longitude, agreed within 14″.

The length of this base, as computed from the observed latitudes of its extremities and its azimuth, is 3369″.7 or 64.6613 miles at sea level, to which all results are reduced.

When the attractions of surrounding mountain masses on the plumb-line at the ends of the base were calculated by formulæ used on the British Ordnance Survey, it was found that the base required a plus correction of .004 of itself, the computed attraction amounting to about 4″ to the north at Star Peak, and 9.5″ to the south at Tarogqua. On account of the well known uncertainty of these formulæ, it was decided not to make the full correction obtained by them, but to multiply the astronomically measured distance by 1.00263, because this corrected base would give a geodetic difference of longitude between Verdi and Sherman exactly equal to the astronomical difference of longitude as determined by the United States Coast Survey.

The adopted length of the base from Star Peak to Tarogqua Peak is therefore 64.8313 statute miles, and the geographical positions on Maps III., IV, and V. were calculated from it, as it was necessary to proceed with their engraving before the eastern end of the belt was surveyed.

Checks indicating the probable uncertainty of results were obtained by comparison of observed azimuths with the geodetic, and by comparison of geodetic and astronomical latitudes.

The Salt Lake azimuth being carried through to the most western stations, the azimuth there observed differed from it +18″. The differences between observed and geodetic azimuths at intermediate points, going from east to west, were — 4″, 0″, + 10″, + 7″, — 3″, + 15″.

The following table shows the agreement of observed and geodetic latitudes:

COMPARISON OF OBSERVED AND GEODETIC LATITUDES.

Name of Station.	Observed latitude.	Geodetic latitude calculated from observed position of Salt Lake.	Station-error.	Observed latitude corrected for attraction of mountain masses.	Geodetic latitude calculated from observed Salt Lake position corrected— +2″ = 46′ 8″.5.	Disagreement between corrected astronomical and geodetic latitudes.
	° ′ ″	′ ″	″	′ ″	′ ″	″
Salt Lake, Tabernacle Staff	40 46 06.0	46 06.0	0.0	46 10.5	46 08.50	−2.00
Pilot Peak	41 01 12.2	01 09.70	+2.5	01 12.2	01 12.20	0.00
Ruby Valley astronomical station	40 02 47.4	02 41.36	+6.04	02 43.4	02 43.86	+0.46
Star Peak	40 31 13.5	31 14.10	−0.60	31 16.7	31 16.60	−0.10
Tarogqua Peak	39 35 03.8	34 55.60	+8.20	34 53.8	34 58.10	+4.30
Wadsworth astronomical station	39 37 30.0	37 24.59	+5.41	37 28.0	37 27.10	−0.90
Peavine Mountain (Verdi)	39 35 18.7	35 18.47	+0.23	....	....	....

From the final column of this table it appears that the difference in latitude between results by triangulation and zenith telescope observations, corrected for attraction of mountains on the plumb-line, is much too small to be seen on the maps.

In 1872 a base of verification was measured with a steel tape near Fort Steele, in longitude 107°. When reduced to sea-level it is 4.7900 statute miles long.

The length of this base, as computed by triangulation from the Star Peak base, is .0004 greater than by measurement.

When the geodetic difference of longitude between Salt Lake and Sherman was calculated by the Star Peak base, it proved to be .00256 smaller than the astronomically measured difference. Owing to the positions of the mountain masses in relation to the United States Coast Survey astronomical stations at Verdi, Salt Lake, and Sherman, it is probable that the astronomical difference of longitude between Verdi and Salt Lake is too small, and that between Salt Lake and Sherman too large. It therefore seemed probable that the discrepancy between the astronomical and geodetical difference of longitude from Salt Lake to Sherman was partly due to the Star Peak base being too small, and partly to the astronomically measured distance being too long.

For this reason the triangulation for Maps I. and II. was calculated with the Star Peak base, multiplied by 1.0013. There remains a disagreement of 30″ between the two methods of measurement of the distance from Salt Lake to Sherman. The agreement between observed and computed azimuths showed that no large errors existed in the adjustment of the triangles.

Geographical positions on Map I. are computed by triangulation from the United States Coast Survey astronomical station, Sherman, while those on Map II. are reduced from Salt Lake as the initial longitude. Between these two maps there must therefore be a disagreement in geographical positions. The error in either will be equal to the true station-error at the initial astronomical station, combined with the error of the triangulation.

I am inclined to believe that the probable uncertainty in distances measured by the principal triangulation does not exceed 0.001.

SECONDARY AND TERTIARY TRIANGULATION.

Secondary points were located by cuts from the principal stations, and from these a smaller system of triangles was carried over the country by the topographers. The angles were measured with the gradienter, a light instrument having a very effective telescope and a four-inch circle reading to minutes. Rocky peaks, five to ten miles apart, commanding the best views of surrounding country, were chosen as stations. Signals were seldom used, the summits being generally sharp enough to be observed with sufficient precision Elevations of stations were determined with the mercurial barometer of James Green.

Base stations, where the barometer was continually observed while the survey progressed in the neighborhood, were established at intervals of 100 or 150 miles along the line of work. Field observations were all referred to one or more of these bases, and the bases afterward connected by synchronous barometric observations with the levels of the Pacific railroads.

TOPOGRAPHICAL METHODS.

Regarding its trigonometrical foundation, the Fortieth Parallel work is allied to regular surveys; but the topographical methods employed were more like those of the best reconnoissances.

From each occupied station the adjacent territory was carefully sketched, in plan of drainage, in leading horizontal contours, and in profiles. As many points on these sketches were located as could be cut by intersecting lines from the occupied stations, and their altitudes determined by angles of elevation and depression; these points fixed by measurement are confluences of streams, lakes, buildings, and conspicuous rocks, knolls, and peaks on mountain spurs and crests.

In a dry region of sparse vegetation, where the ridges are serrated and water-courses and ravines deeply marked and clearly visible in the distance, where every mile of territory is overlooked from bare commanding summits, and where the atmosphere is remarkably clear, this method of taking topography gives a far closer approximation to the truth than would be possible in a country where drainage-lines and details of form are masked by foliage or dimly seen through moist hazes. The sharply cut features of the Cordilleras stand out so boldly that the topographer has only to locate enough points and make careful contour, profile, and drainage sketches, in order to produce a very fair representation of the country.

The maps were made by laying down on polyconic projections the geographical positions of principal and secondary points, then plotting by intersections the tertiary stations and located points. Between such of these as are on streams the water-courses were filled in from drainage sketches, and from profile sketches the slope angles were estimated and the contours spaced in between points whose altitudes were determined instrumentally.

The contours, therefore, are located by barometrical and trigonometrical measurements at certain points and sketched between these with the eye.

GENERAL INDEX.

OBSERVE SPECIAL LISTS OF AUTHORS, CAÑONS, FOSSILS, LAKES, MOUNTAINS, PASSES, PEAKS, AND RANGES.

END OF VOLUME FIRST.