CHOCOLATE BUTTE, PARIA CREEK, ARIZONA

HELIOTYPE

ENGINEER DEPARTMENT, UNITED STATES ARMY.

REPORT

UPON

GEOGRAPHICAL AND GEOLOGICAL

EXPLORATIONS AND SURVEYS

WEST OF THE ONE HUNDREDTH MERIDIAN,

IN CHARGE OF

FIRST LIEUT. GEO. M. WHEELER,
CORPS OF ENGINEERS, U. S. ARMY,

UNDER THE DIRECTION OF

BRIG. GEN. A. A. HUMPHREYS,
CHIEF OF ENGINEERS, U. S. ARMY.

PUBLISHED BY AUTHORITY OF HON. WM. W. BELKNAP, SECRETARY OF WAR,

IN ACCORDANCE WITH ACTS OF CONGRESS OF JUNE 23, 1874, AND FEBRUARY 15, 1875.

IN SIX VOLUMES, ACCOMPANIED BY ONE TOPOGRAPHICAL AND ONE GEOLOGICAL ATLAS.

PARTS I, II, III, IV, V.

VOL. III.—GEOLOGY.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1875.

TABLE OF CONTENTS.

ERRATA.

Page 43, 12th line, omit "s" in "Plateaus," and add "s" to "lie."
Page 44, 15th line, for "before" read "after."
Page 95, 6th line from bottom, insert "clay" after "Subaqueous."
Page 103, 22d line, for "Anodae" read "Anodonta."
Pages 109 and 116, middle, for "San Francisco" read "Colorado."
Page 172, 6th line, for "Cordillera" read "Basin Range."
Page 173, middle, for "New Mexico" read "Dakota."
Page 180, 2d line from bottom, for "bought" read "brought."
Page 182, 3d line from bottom, for "lobe" read "to be."
Page 239, 8th line, after "lava," insert "(No. 4 of section)."
Page 510, 2d line, for "crust" read "crest."
Page 512, 7th line, for "northward" read "westward."

TABLE OF CONTENTS.

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LIST OF PLATES.

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The frontispiece, and Plates I, V, VIII, IX, X, and XII, were furnished by J. R. Osgood & Company, of Boston, and Plates II, III, IV, VI, VII, and XI by the Graphic Company of New York City. The wood-cuts were engraved by H. H. Nichols, of Washington, D. C., and John Filmer, of New York City.

UNITED STATES ENGINEER OFFICE,
GEOGRAPHICAL EXPLORATIONS AND SURVEYS,
WEST OF THE ONE HUNDREDTH MERIDIAN,
Washington, D. C., November 11, 1874.

GENERAL: I have the honor to forward herewith reports upon geological data gathered by parties of the survey under my charge for publication, in accordance with the act of Congress, approved June 23, 1874. (See Statutes at Large, Forty-third Congress, First Session, page 224.)

This volume is one of the series of six heretofore proposed for the elaboration of the detailed results of the survey.

The geological assistants have usually been members of the field parties, organized to embrace representatives of the several branches of the work, except during occasions incident to a divergence from the routes of travel necessary to carry on the main or topographical branch.

The obstacles attendant upon researches amid the mountain intricacies, rigid plateau contours, and desert-wastes encountered, have largely added to their undertakings, while their reports will attest the manner in which they have prosecuted the arduous duties intrusted to them.

The nature of the survey has necessarily made geological and other scientific inquiry subsidiary to the main object of the work, which, in view of the great area covered by the survey, consists in the determination of positions and the delineation of the surface of the region occupied. Hence the geologists have not had the same facilities they would have had in parties organized especially for geological work; but notwithstanding these deficiencies and the difficulties they entailed, it is believed that these reports extend and connect our geological information over a wide field, embracing areas in several important basins of drainage of six different States and Territories, including portions of the plateau region, and several prominent mountain ranges heretofore conjecturally known, and will not be without their important values and acceptable as a worthy contribution to our geological knowledge of the territorial domain west of the Mississippi River.

It is believed that the geological matter here presented, when supplemented, as it soon will be, by a series of geological maps and paleontological reports, will answer all the present needs of the Government and of the industries of these partially inhabited areas, in which, for years to come, geological or other scientific examinations will find but few localities where sectional industrial interests may be healthfully promoted with economy to them or to the Government.

The time consumed in office labor, as compared with that in the field, has been somewhat inadequate, yet the results appear in the systematic rather than the itinerary form, which it is hoped will prove advantageous to all the purposes to which they may be applied.

Fossil and other geological specimens have been collected from a widespread range, including many well-prospected localities, and their number is large.

Their examination will lead to an extended report upon the paleontology of the area embraced by the survey affording a large number of new forms of the extinct fauna of that region, identifying with certainty geological relations heretofore vague, and defining horizons newly discovered. They have been placed in the hands of Prof. C. A. White, of Bowdoin College, a preliminary examination having been made by Prof. F. B. Meek, a portion of the results of which are incorporated herein. The report upon these collections will form the bulk of Vol. IV of the series. This volume will also embrace, in addition, reports, if they be submitted in time, upon the vertebrate collections of 1874.

The collection of rock-specimens, especially of volcanic varieties, is large and well worthy of special examination for additional evidence, bearing upon lithological characteristics.

The practical or economic features of the accompanying reports will appeal to those interested in the mineral and agricultural industries constantly advancing into these untrodden fields, and that of Dr. Loew, who has, with patient labor, made chemical investigations and analyses in mineral waters, plants, soils, &c., forms an interesting feature of the volume.

Mr. G. K. Gilbert, A. M., geological assistant during three field seasons, contributes more largely than any other to this volume, and besides his purely professional labors, has aided to give form to the work of the geological parties.

Mr. E. E. Howell, geological assistant in the years 1872–'73, presents his individual contribution.

The report of Prof. John J. Stevenson, an assistant with the Colorado party under Lieutenant Marshall in 1873, relates to territory somewhat disconnected from the areas occupied by the others, and treats its subjects in the same systematic manner.

Mr. A. R. Marvine, occupying the position of astronomical assistant in 1871, while on the march to the southward, examined areas contiguous to his route so far as circumstances would permit.

Considering the character and scope of the results from the labors of the geological assistants, the comparative increase of expense attendant upon attaching them to the several parties seems to have been justified, and the advantages of affording opportunities for examinations in this cognate scientific branch are made manifest.

Very respectfully, your obedient servant,

GEO. M. WHEELER,
First Lieutenant Corps of Engineers, in Charge.

Brig. Gen. A. A. HUMPHREYS,
Chief of Engineers, United States Army.

NOTE.—Owing to an omission in the act making appropriation for the publication of the survey reports, the MS. for this volume has been delayed until this date; and meanwhile Dr. Loew has returned from the field and prepared a report upon the mineral springs, of which specimens were collected during the field season of 1874; also a report upon the composition of coal from different localities in New Mexico and Colorado. As both are germane to the subject-matter of his report for 1873, they have been incorporated therewith, not being of sufficient length to justify publication in separate form.

GEO. M. WHEELER,
Lieutenant of Engineers, in Charge.

UNITED STATES ENGINEER OFFICE,
Washington, February 10, 1875.

PART I.

REPORT

ON

THE GEOLOGY OF PORTIONS OF NEVADA, UTAH, CALIFORNIA, AND ARIZONA.

EXAMINED IN

THE YEARS 1871 AND 1872.

BY

G. K. GILBERT, A. M.

COMPRISING

CHAPTER I—OROLOGY;
II.—VALLEYS, CAÑONS, EROSION;
III.—THE GLACIAL EPOCH;
IV.—WATER-SUPPLY;
V.—VOLCANIC ROCKS AND MOUNTAINS; AND
VI.—THE STRATIFIED ROCKS.

UNITED STATES ENGINEER OFFICE,
GEOGRAPHICAL EXPLORATIONS AND SURVEYS
WEST OF THE ONE HUNDREDTH MERIDIAN,
Washington, D. C., July 4, 1874.

SIR: I have the honor to transmit my report of data gathered as a geologist of your expeditions in the years 1871 and 1872, together with drawings for illustrative wood-cuts. The elaboration of the material acquired in the former year was begun in the winter intervening between the two field-seasons, and I submitted to you a scheme for its embodiment in a final report. Before this was accomplished, however, I again took the field for the accumulation of new facts, and, upon my return, it was decided that a single report should present the results of the two seasons' work. In the course of its preparation, I have found it desirable to depart widely from the original programme; omitting some things there contemplated, and giving especial attention to certain others, of which the importance had not, at first, been recognized. The most noteworthy omission is that of the itinerary, which had been designed to include the bulk of the facts, arranged in the order of travel, leaving to other chapters only the discussion of special topics. In the present report all the facts adduced are classified by subjects, and general statements have been put for individual, so far as the material would allow. The chief additions to the plan grew out of the field-work of 1872, and comprise the description of faults and folds, the chapter of the Glacial epoch, and the discussion of hot springs in their relation to vulcanism.

I have endeavored to acknowledge, in presenting the material, the contributions that have been made to it by gentlemen of the expedition and others; but it is proper to add that these acknowledgments fall far short of expressing my indebtedness to the work of assistants, Messrs. A. R. Marvine and E. E. Howell. The interlocking of our routes has brought their data into such relation to mine, that all my more general statements are, in part, based upon them.

Very respectfully, your obedient servant,

G. K. Gilbert.
Geological Assistant.

Lieut. George M. Wheeler,
United States Engineers, in Charge of
Geographical Explorations and Surveys.

CHAPTER I.

OROLOGY.

SECTION I.—THE BASIN RANGE SYSTEM.
SECTION II.—THE COLORADO PLATEAU SYSTEM.
SECTION III.—THE BORDER LAND BETWEEN THE RANGES AND THE PLATEAUS.
SECTION IV.—GENERAL CONSIDERATIONS.

Topographical reliefs are due to three causes—dislocation, denudation, and eruption, giving rise, as typical forms, to ridges, tables or plateaus, and cones. The term "mountains of dislocation" applies to such ridges as are due to the re-arrangement of strata, either by bending or fracture. Mountains of denudation are the remnants of undisturbed and otherwise continuous strata, that have been in part removed by erosion. While these agencies so commonly combine with each other, that illustrations of their separate action are rare, it is nevertheless possible to divide our field into two great provinces, characterized severally by ridges of dislocation, and by tables. Eruption has produced great local modification in both regions, but more especially in the former; its phenomena will be treated in a separate chapter. The material presented in the present chapter will be arranged in four sections, of which the first will describe the Range System, or province of ridges; the second, the Plateau System; the third, the border land between the Ranges and Plateaus, and the fourth will discuss the bearing of the facts on general orology.

SECTION I.

THE BASIN RANGE SYSTEM.

The traveler who passes westward over the Pacific railway, descending from the lofty plateaus which, on that line, occupy the traditional position of the Rocky Mountains, passes, by a transverse cañon, through the Wahsatch range, and enters a region that for a considerable area has peculiar characteristics. Across the remaining portion of Utah, the entire State of Nevada, and a narrow strip of California, the train winds in and out among a system of short, narrow ranges, inferior in altitude to the Sierra Nevada and Wahsatch Mountains, which limit the series at the west and east. These ridges are distributed with tolerable regularity and parallelism throughout an extended area of which the northern and southern limits have not yet been determined. Between them are valleys floored by the detritus from the mountains, which conceals their depth and leaves to the imagination to picture the full proportions of ranges of which the crests alone are visible, while the bases are buried beneath the *débris* from the summits. For such portions of this inland region as do not find drainage to the ocean, the name of Great Basin was given by Frémont, and it has passed into general use. Wishing to treat of an orographic province which has its type in the Great Basin, but is not coincident with it, I have selected for it an allied but not identical title. The terms *Basin Range System* and *Basin Ranges* will be applied to all that system of short ridges separated by trough-like valleys which lies west of the Plateau System, without reference to its drainage conditions. In Utah, the basin of the Sevier River is a part of the Great Basin, but only a small share of it falls in the province of the Basin Ranges, and the remainder is included in the province of the Plateaus. On the other hand, the Basin Range System extends southward in Arizona far beyond the limit of the Great Basin.

While the ranges are locally parallel, there is considerable change of direction in the system as a whole. On the line of the railroad the trend is nearly north and south, varying at the east toward the northeast, and at the west toward the northwest. Farther south there is a general deflection toward the southeast, after passing the southern limit of Nevada, and through the southwestern portion of Arizona, and adjacent parts of California, the general trend is south 30° east. It should be understood that the trend here intended is that of the lines of structure of upheaved ridges, and does not refer to volcanic outflows, which are less symmetrical in arrangement, and serve to obscure, upon the merely topographical map, the almost perfect parallelism of the ridge system.

The precise geographical definition of the Basin Range area is, at present, impossible. Its longer dimension, like those of its constituent members, is in a meridional direction, and its width, where best known, is from two hundred and twenty-five to five hundred miles. Where crossed by the fortieth parallel, it has been defined by King as extending from the Sierra Nevada eastward to the Wahsatch range, which latter it includes.* South of this line the Sierra Nevada may be regarded as its western limit, and on the east it is bounded, with less regular outline, by the Colorado Plateau System. The line of demarcation, after following the Wahsatch southward to Mount Nebo, bears toward the west along the Pahvant Range to Beaver, whence, still deflected westward, it passes to the west of the Pine Valley Mountains and enters Arizona at the mouth of the Grand Cañon of the Colorado. From this point its course is due south for thirty miles, and then turns southeast, touching Music Mountain, (of Lieutenant Wheeler's map,†) the Black Hills, near Prescott, Sierra Ancha, and Apache Mountains, beyond which our explorations have not followed it.‡ The area thus partially described is narrowest in latitude 36° 20′, where, from Owen's Lake to the Grand Wash, it measures but two hundred and twenty-five miles, and it expands to the north and south.

The ridges are composed of, first, sedimentary strata, in part unaltered, and in part subjected to various degrees of metamorphism; second, granite and cognate rocks; and third, volcanic rocks. The lines of structure are in general parallel in each range to the trend of the range. The granite occupies various positions. Often it is the nucleus of the range against which inclined strata rest. Elsewhere it appears in dikes, traversing either the sedimentary rocks or other granites. In a few instances it was observed to overlie the sedimentary rocks, while in a number of localities the evidence of its eruptive character is unequivocal, in others it is plainly metamorphic, and in by far the majority of cases it appears to have assumed its relation to the undoubted sedimentary rocks before the upheaval of the combination. The volcanic rocks are seen to be of more recent date, since

* Geol. Expl. Fortieth Parallel, vol. iii, p. 1.

† See note on Music Mountain a few pages farther on.

‡ For further description of the southern boundary of the Plateau System see chapter xix of this volume.

they overlie both granites and sedimentary rocks, and are found as dikes intersecting them.

Age of the ridges.—The data to be sought for the determination of the geological date at which a range has been uplifted, are the age of the newest rocks uplifted with it, and the age of the oldest rocks which rest unconformably upon them. These afford the anterior and posterior limits between which is included the epoch of elevation. When these limits are approximate in point of time the determination is concise; but this can happen only when the mountain has arisen from the water or its immediate shore, so that the conditions of sedimentation can have prevailed on its flank just before and just after its formation. In the case of the majority of the ranges under consideration, these limits are so widely separated in time as to give only the most indefinite idea of the epoch of upheaval. Throughout Southwestern Arizona the ranges consist of highly crystalline schists, in which no fossils have been found, and against them no beds are found to lie of greater determined age than the Quaternary gravels. A few of them, which are adjacent to the Plateau System, are demonstrated to have been first upheaved at some time anterior to the Carboniferous, and again at some time subsequent to the Carboniferous. Farther north, in Southern Nevada and adjacent portions of Utah and California, Silurian and Carboniferous strata have been identified at numerous points in the upheaved masses, and it is presumable that their principal elevation was coeval with that of the first and chief elevation of the Wahsatch Mountains and the Sierra Nevada, proved by Whitney and King to have occurred at the close of the Jurassic period.* There is further evidence on the borders between the Basin Range System and the Plateau in Utah, that disturbances acting along the original line of Jurassic elevation have occurred later than the Eocene Tertiary, but of the geographical limits among the Ranges of these movements little can be predicated from the stratigraphical data now at hand. Their distribution in the Plateau country is better understood and will be considered in the succeeding section.

Descriptions of ridges.—By reference to the maps of the geological atlas it will be seen that the routes followed by the geologists ran obliquely east

*Geol. Exploration, Fortieth Parallel, vol. iii, p. 3.

and west across the Range System, so as to intersect a great number of the component ridges.* It was principally in crossing the ranges that the data for cross-sections were acquired; but the distant views obtained in approaching and leaving them often enabled the observer to determine to what distance longitudinally on the range the phenomena of the section extended. The study of these cross-sections, both in the field and afterward, has led the writer to change materially his preconceived ideas in respect to the structure of the mountains, and, that the grounds for his present opinions may be better comprehended, the principal data upon which they depend will be here premised by describing some of the best understood ranges. The sections given to illustrate them do not always represent the precise line of crossing, but were frequently sketched from profiles visible at a little distance to one side. It will be understood that they are of merely local application; a change of a half mile in the choice of the line of section would frequently very materially modify its character. So far as practicable the vertical scale in the several sections has been made equal to the horizontal, and special note has been made wherever it has been found necessary to depart from this rule. With few exceptions, the sections of mountain-ridges have been drawn on a scale of $\frac{1}{72000}$, or 1 inch = 6,000 feet.

The Oquirrh range, next west of the Wahsatch, from its northern extremity to Fairfield Pass, is built of folded and fractured Paleozoic strata, rang-

* A brief definition of my route is here appended.

In 1871 it ran from Halleck Station, Nevada, west to Carlin; north to the Bull Run Mining District; south to Tuscarora, Battle Mountain, Galena, Austin, Ophir Cañon, and Belmont; southeast to Reveille and Hyko; northeast to Pioche and return; southwest to Oasis Spring and Boundary Cañon; then, in California, northwest and west to Palmetto and Big Pine; south to Camp Independence, Owens Lake, and Desert Wells; east to Pilot Mountain, Saratoga Spring, and Ivanpah; north to Camp Cottonwood, Nevada, and return; southeast to Camp Mojave, Arizona; then, by boat and the Colorado River, to the mouth of Diamond Creek; then, in Arizona, south to Truxton Spring; east to Mount Floyd and Mount Bill Williams; south to Prescott; northeast to Mount San Francisco; south and southeast to Camp Apache; and south-southwest to Tucson.

In 1872 it ran from Salt Lake City to Bingham Cañon, Tooele, E. T. City, and return; southwest to Lehi, Fairfield, Lewiston, Ophir City, Faust's and Cherry Creeks; west to Fish Spring; south to Dry Pass; northwest to Deep Creek; west to Schellbourne; south to Rubyville and Young's Ranch; east to Dome Pass; south around Sevier Lake, and north to Deseret; south to Beaver, via Fillmore, Black Rock Spring, Shenandoah, and Lincoln District; southeast to Panquitch and Paria; west and north to Johnson's, Upper Kanab, and Asay's; west and south to Little Zion and Rockville; east to Mount Carmel; south and west to Toquerville; southeast to Pipe Spring; south to the mouth of Kanab Creek; north to Kanab; east to the mouth of Paria Creek, and return, (via Tenney's;) and north to Salt Lake City via Mount Carmel and the Sevier and Sam Pitch Valleys.

ing from Lower Silurian to Upper Carboniferous. A few dikes of trachyte are to be seen, but no extended eruptive masses. While our examination was too brief to unravel the structure of the range, we were enabled to note with some confidence a system of parallel folds, comprising two anticlinals and an intervening synclinal. The general trend of the range is north and south, and that of the axes of the folds north-northwest, so that they traverse it obliquely. The western anticlinal terminates southward near Fairfield, and crosses Ophir and Dry Cañons. The eastern has its northern end near and a little north of Tooele, but a monoclinal uplift, confluent with its eastern half, extends to the north end of the mountain. The range terminates abruptly in a fault succeeded by a few strata with a dip of 75° to 90° to the north. Lithologically the rocks of the Oquirrh comprise about 2,000 feet of quartzite, (vitreous sandstone,) overlying 3,000 to 4,000 feet of limestone, with intercalated sandstone toward the top. The highest discovered fossiliferous horizon is near the base of the quartzite, where some thin limestone seams contain Carboniferous fossils. The lowest horizon—observed at Ophir City—contains Primordial trilobites. In the interval were found numerous fossils, all referable to the Carboniferous, and the lowest of these are separated from the Primordial by less than 400 feet of conformable limestone strata.

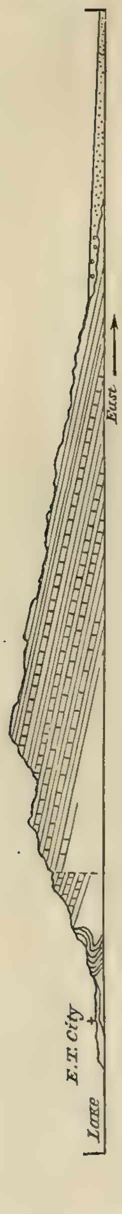


FIG. 1.—Section of the Oquirrh range at E. T. City. Scale, 1-72000. Base line = level of Great Salt Lake.

The Onaqui range, next in order westward, appears from distant views to be a simple monoclinal uplift, with consistent dip to the west. It was crossed by Mr. Howell, to whose report the reader is referred for further information in regard to it.

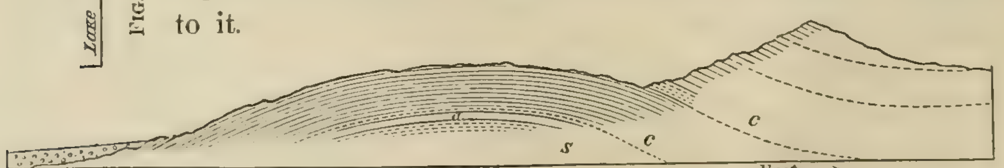
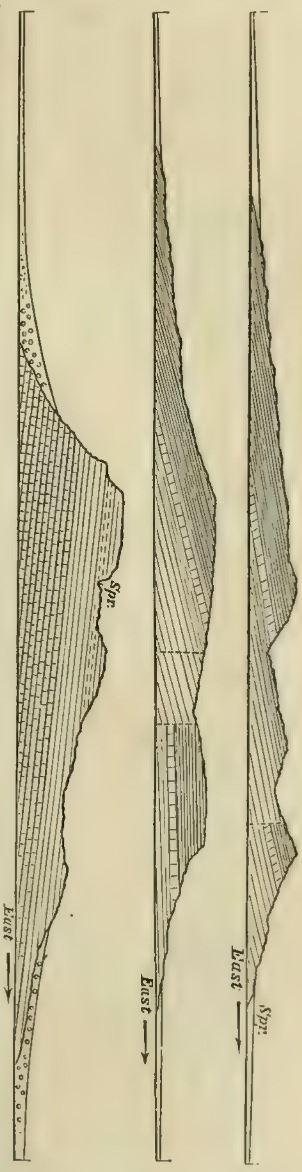


FIG. 2.—Section of west front of Oquirrh range at Ophir City. Scale, 1-72000. Base line = level of Great Salt Lake. *a.* Ophir City. *s.* Silurian. *c.* Carboniferous.

The Thomas range, like the Onaqui, is a simple uplift, presenting throughout its extent a bold escarpment to the east, while at the west its slope is that of its strata, which dip beneath the desert. At Dugway Pass, where we crossed it, its rocks are calcareous, but were not found to contain fossils. There is reason, however, to surmise, from stratigraphical data, that they belong to the Silurian series. A short distance north of the pass is an outflow of gray trachyte, and south of it the range is entirely buried beneath a similar lava. Between this and the House range, but nearer the former, are two low ridges parallel to the first, of like condition and dip, and similarly accompanied by volcanic eruptions.



FIGS. 3, 4, 5.—Sections of the House range, at Fish Spring, two miles south of Fish Spring, and at DomeCañon. Scale, 1-72000. Base line = level of Great Salt Lake.

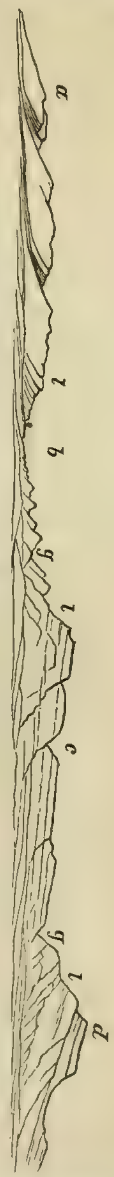


FIG. 6.—Diagram of the House range, as seen from the west. *a*. Fish Spring. *b*. Dry Pass. *c*. Dome Cañon and Antelope Spring. *d*. Notch Mountain. *ll*. Silurian limestone. *gg*. Silurian quartzite.

In the northern portion of the House range its strata dip to the west and the eastern face is precipitous. The first of the sections given was made at Fish Spring, near the northern end of the range, and the second two miles farther south; the same general structure continues for twenty miles, to Dry Pass, where there is an abrupt change of dip from west to east. The third section was made at Dome Pass, ten miles farther south, and represents the general character of the range for twenty miles south of Dry Pass. But the rocks met with in going south are successively newer, owing to a southward dip, there combined with the easterly. By reference to the sketch—Fig. 6—these peculiarities will be more readily understood. It represents the range as it might be seen from a remote position at the west. The dip of the portion at the left of Dry Pass is toward the observer. At the right it is in the opposite direction, and a bold escarpment is presented over the whole face. In this escarpment the most northerly rocks (those nearest to Dry Pass) are quartzite, constituting the base of the series. These gradually descend to the south, and finally disappear, being replaced upon the crest of the ridge by a massive gray limestone 1,000 feet in thickness, which constitutes the walls of Dome Cañon. The limestone is in turn covered by a series of calcareous shales not less than 200 feet thick, in which were found numerous trilobites, indicating the position of the series in the Silurian system; and these are covered by a second limestone. Finally, a second cross fault brings the quartzite once more to the surface, and the limestone above it is lifted, in Notch Mountain, to its greatest altitude.

Fig. 7.—Section of Beaver Creek Range. Scale, 1-72000. Base line = level of Great Salt Lake, *a*, Sevier Lake.

The Beaver Creek range on the opposite—*i. e.*, eastern—side of Sevier lake, agrees with the southern portion of the House range in dip, and presents the lower portion of the stratigraphic series exhibited in that range. Its western base along the entire eastern shore of the lake is of quartzite, and its crest of massive gray and black limestones. Its strata, for the most part, maintain their easterly dip, so as to pass beneath the gravels of the Sevier desert; but at one point, near the sink of Beaver Creek, there is for a short distance at its eastern base a ridge with opposed dip, presenting an escarpment toward the east, and making with the principal mass a synclinal fold. Farther south it is continuous with the Picacho range, the structure of which is less simple.

In the North Star mining districts a cross-section reveals an arrangement of strata suggesting a combined anticlinal and synclinal structure. If this surmise is correct the granite would appear to be in this case an axial rock, but at other points in the neighborhood it was observed in dikes intersecting the limestones which constitute the principal mass of the range, and it is noteworthy that, while the calcareous rocks immediately associated with the granite are highly crystalline marbles, without determinable stratification, they are in other localities, not remote, so little altered as to be fossiliferous. My own observations were too brief to suffice for the determination of the relations of a system of rocks so greatly disturbed, but I am disposed to consider the axis at the west of the range as synclinal, and thus adopt a view held by Mr. J. E. Clayton, who has enjoyed facilities for a more thorough examination.

I visited the Mineral range only at the southern end. There it consists of somewhat metamorphosed sediments—limestone at base, succeeded by quartzite, quartzose schists, and finally, a second series of limestones. In the upper limestones are found a few fossils, referable probably to the Jura. This rock-system terminates abruptly a few miles from the southern end of the range, and is replaced by a section composed almost entirely of granite. At the Granite mining district, five miles north of Adamsville, the section at the eastern base of the range consists of a white crystalline marble, with traces of a westerly dip, overlaid by granite, which extends unbroken, so far as can be judged by the distant view, to the summit of the range, and indeed to the opposite base. Along the line of contact between the marble and granite is a great vein of quartz, dipping 54° to the west. Parallel to it, and alternating with bands of marble, are two somewhat similar veins, which serve to confirm the impression that their direction indicates the dip, not merely of the contact, but of the beds of limestone from which the marble has been formed. The crest of the range from this point nearly to its northern extremity has the peculiar ragged outline of a granitic ridge, but at the extremity there are reported other beds of limestone, in which the mining operations of the Antelope district are conducted.

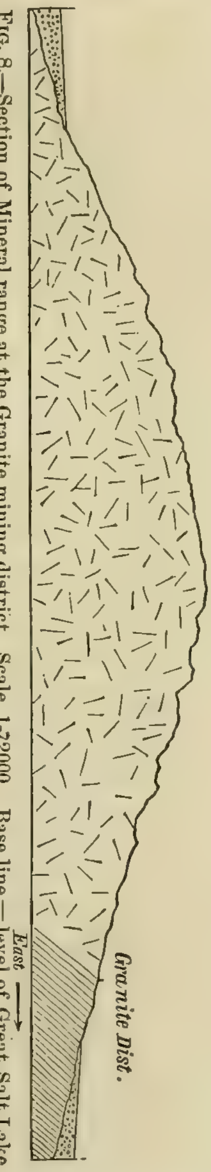


Fig. 8.—Section of Mineral range at the Granite mining district. Scale, 1-72000. Base line = level of Great Salt Lake.

The Snake range, on the borders of Utah and Nevada, is the most easterly of the high series that intervene between the desert depressions of Great Salt Lake at the east and the Humboldt sink at the west; it overlooks all the ranges of Utah to the Wahsatch. Its axis, which is exposed for nearly the whole length, consists of quartzite and limestone, with a limited amount of crystalline schists and granite. In the neighborhood of Clifton mining district, the most northerly point visited, rhyolitic lavas and syenite make up a great portion of the surface, but limestone masses are visible toward the eastern flank of the range, with eastward dip. At Uiyabi Pass there are slight exposures of limestone and sandstone, which indicate an anticlinal structure; but a few miles south the mountain rises rapidly in a single mass of westward-dipping strata. These are quickly replaced upon the crest of the ridge by granite, which constitutes the high peaks immediately east of Deep Creek Valley. The western base, however, at that point shows stratified rocks with the same dip. South of Pleasant Valley a portion of the range, locally known as Kern Mountains, has been greatly disturbed, and perhaps presents a reverse dip; but the interruption is only a few miles in extent, and beyond, in the main Snake range, the westerly dip is resumed, and continues for thirty miles, to Sacramento pass, a few miles north of Wheeler's Peak, the highest summit of the range. The peak appears to be the center of a fractured quaquaversal, the rocks upon its flanks dipping from it, not merely to the east and west, but to the north and south. The quartzite of its crest is covered at the north by the limestone of the Sacramento mining district, and at the south by heavy limestone beds; the base, at least, of the series belonging to the Silurian system. The mountain is deeply scored by cañons heading near the peak, and in the *debris* brought down through these on the western side Mr. Howell found granite boulders, but the portion of the range from which they were derived was not visible from any of our lines of examination. In that part of the range between the Sacramento district and the Kern Mountains, where the structure is most regular, the principal mass of the mountain consists of strata inclined to the west, but there are at the eastern base a few hundred feet of rocks with opposed inclination.

The next range at the west is the Schell Creek. Where we first touched it, near Schellbourne, it is flooded with rhyolitic lavas, and the structure of its sedimentary beds is not readily apparent; but both north and south of this point they appear in great inclined masses, which present escarpments to the east. In Ruby Hill Cañon, quartzites are shown at the eastern base, and these are overlaid by several thousand feet of limestones, intersected by dikes of quartz-porphyry, and so far metamorphosed that their lines of bedding are obscured. Farther south, at White's Peak, where the crest of the range was climbed, the quartzites have risen so far as to constitute the upper ridge, and display a thickness, together with their associated schists, of over 11,000 feet. This entire series, together with the superimposed limestones, is tilted in one mass to the west, and the superior and less durable limestone beds have been so far eroded as to remain merely as secondary ridges or foothills to the west of the quartzite. Southward, the latter maintains its ascendency for ten or fifteen miles, and then gradually sinks to the south, and is once more replaced by the superior limestone. Paleontological data are by no means full, but by the aid of some collections made by Mr. J. E. Clayton, at Rubyville and Schellbourne, the conclusion is ventured that the base of the series, including the entire quartzite series and the lower portion of the limestone, may be set down as Lower Silurian; while the upper limestones are as recent as Devonian, and perhaps Carboniferous.

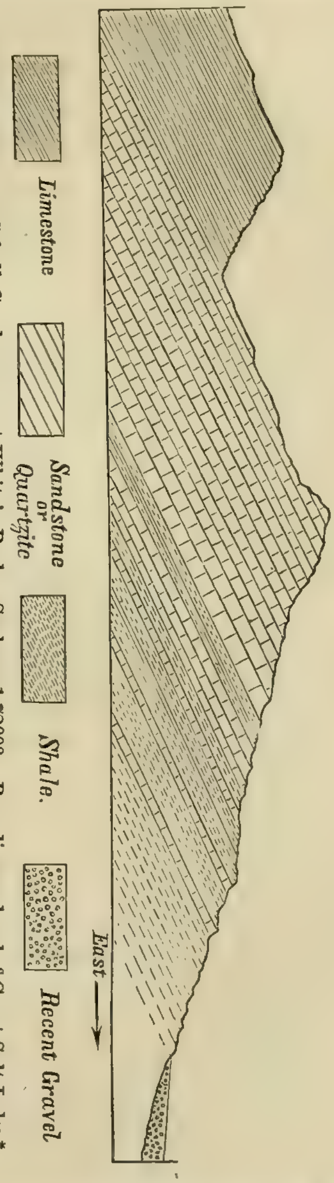


Fig. 9.—Section of Schell Creek range at White's Peak. Scale = 1-72000. Base line = level of Great Salt Lake.*

The Spring Mountain range in Southern Nevada is continuous for a great distance, and was intersected at two points. The section given was

* The symbols for limestone, &c., given with this cut, are adhered to in the other mountain sections of this chapter.

observed just north of the pass by which the Los Angeles and Salt Lake road crosses the range. The strata appear to be conformable throughout, and but little altered. They are in chief part fossiliferous limestones of Carboniferous age, but comprise several bands of sandstone, one of which constitutes the principal escarpment toward the east. At Olcott Peak, ten miles farther south, the rocks are almost exclusively limestone; and, while they were found to contain Lower Carboniferous fossils, were not definitely coördinated with those shown in the section. An abrupt change of structure occurs at the pass already alluded to, and, while that at the north is tolerably uniform, so that the section given applies for a distance of ten miles along the range, immediately south of the pass the rocks have been subjected to a greater amount of disturbance. Fifteen miles farther south, near Ivanpah, the rocks are chiefly limestone, of which the age was not determined, and they present opposed dips on opposite sides of the range, the interval being occupied by a mass of granite. The latter rock forms a belt, intersecting the range obliquely from northwest to southeast, and for a few miles south of Ivanpah constitutes the eastern face of the mountain. The western mass of limestone, however, rises far above it, presenting the precipitous face upon which the imagination of early prospectors read the mystic +ILD.* The northern section of the range will be given in detail in the chapter on the stratified rocks.

FIG. 10.—East front of Spring Mountain range at Cottonwood Creek. Scale, 1-72000. Base line = sea level. *a*, camp on Cottonwood Creek. *c*, cross-stratified sandstone.

Bare Mountain stands east of the Amargosa desert, near its northern end, and presents for a distance of ten miles, nearly its whole extent, a bold escarpment toward the desert. We were unable to visit it, but its entire destitution of vegeta-

*A fortuitous arrangement of stains or lichens suggests at a distance rude letters, several hundred feet in height, and gave rise to a fable that early Jesuit explorers had painted a sign to guide them back to a rich mine. Some capital has been made of the story in the prospectus of a mining company.

tion, and the precipitous character of its face, enabled me to sketch its structure from a distance. The accompanying diagram represents the south-western face of the ridge, and shows the dip of the strata longitudinally, as modified by transverse faults. The transverse dip of the rocks is to the northeast, or *from* the face represented in the sketch. In the diagram the topographical reliefs are omitted, that they might not be confused with the geological features, but the contrasts of strata and the faults are no more strongly drawn than they appeared in nature on the naked face of the mountain. It was extremely tantalizing to see there not less than 8,000 feet of bedded rocks so beautifully displayed, and yet be unable to examine a single stratum. The plain upon which we stood was composed of their *débris*, but its sandstone and limestone pebbles could not be referred to their parent beds.

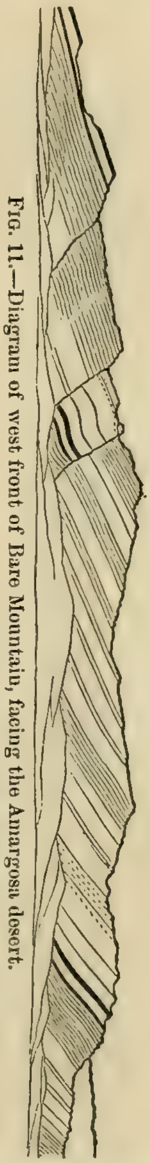


FIG. 11.—Diagram of west front of Bare Mountain, facing the Amargosa desert.

A section of the Amargosa range was obtained at Boundary Cañon. It is there composed entirely of altered sedimentary rocks, limestones, schists, and quartzites, and, so far as can be seen to the north and south, its crest is similarly constituted. A few miles north of the point of section, however, it is flanked both east and west by rhyolitic beds, and these, too, form foot-hills, on the east side at least, toward the south. The strata are greatly disturbed and dislocated, but are not arranged in systematic folds. Fractures not only longitudinal, but transverse, divide the rock into a great number of

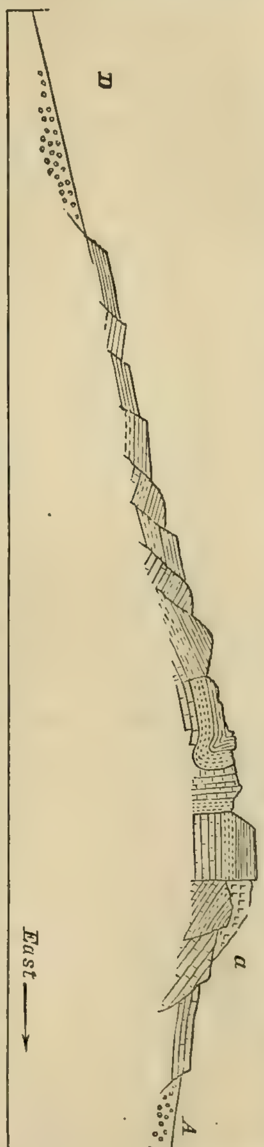


FIG. 12.—Section of Amargosa range at Boundary Cañon. Scale, 1-72000. Base line=sea-level. *a.* Rhyolite. *A.* Amargosa Desert. *D.* Death Valley.

comparatively small masses. The cañon, by which we descended from the summit of the range to Death Valley, winding among these, rarely reveals the same arrangement on its opposite walls. A very slight change in the position of the section would affect its details in great amount, but the confusion of strata represented is typical of the range, so far as it was seen. Only imperfect fossils were found, but these sufficed, with stratigraphical data, to connect the rock series with Silurian beds observed farther at the east. The Panamint range, on the opposite side of Death Valley, appeared from the distant view to be similarly constituted. Another section of very different character was obtained from the same (Amargosa) line of upheaval, fifty miles farther south, where the title of Funeral Mountains maintains. Their extreme southern end at Saratoga Springs shows a system of hornblende rocks and slates, without fossils, between which and the northern series no connection was established. They are perfectly conformable, and dip in a single body to the east.

FIG. 13.—Section of Funeral Mountains at Saratoga Springs. Scale, 1-72000. Base line = sea-level. *A.* Amargosa Desert. *D.* Death Valley. *S.* Saratoga Springs.

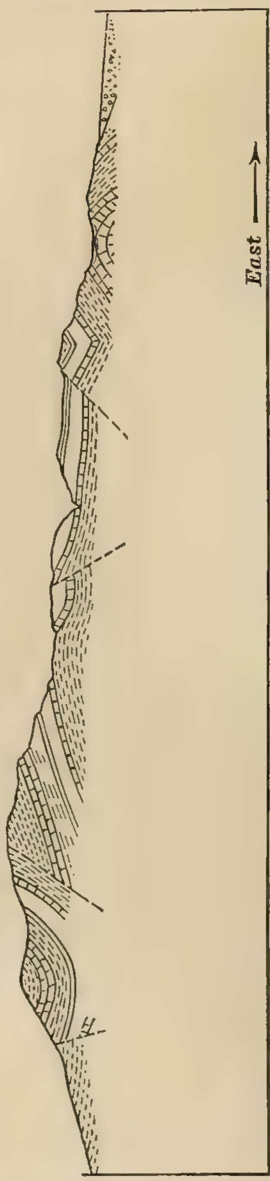


FIG. 14. Section of the Inyo range near Deep Spring Valley. Scale, 1-72000. Base line=sea-level.

The Inyo range, lying next the Sierra Nevada, to which, in the grandeur of its proportions, it is a fit neighbor, is too important and complex to be characterized from our meager data. But a single section was obtained, and that at the comparatively low pass between Piper's ranch and Big Pine, California. At this point the range is double, so as to include an undrained hollow—Deep Spring Valley—ten miles long and five broad, that might contain a lake a thousand feet deep, without overflowing. Where we crossed the eastern ridge, it consists of granite, in part a protogine with imbedded bowlders of dark, micaceous granite, and in part a syenitic granite. Farther south, near Deep Spring, gneissic rocks were observed, associated with the granite. In the western branch are dislocated and somewhat altered limestones, sandstones, and slates, as shown in the accompanying section. No fossils were found.

The axis of the Black and Colorado Mountains, in northwestern Arizona, is of granitoid rocks and highly crystalline schists. These are in great measure concealed by extensive eruptions of trachyte and rhyolite, which determine the bold scenery of the range. At the north, the Colorado River intersects two spurs, giving rise to Black and Bowlder cañons. A few miles farther up, by Virgin Cañon, it crosses also a spur of the Virgin range. The materials and structures exhibited in these three sections are very closely related; that of Bowlder Cañon, represented in the diagram, being most clearly made out. The nucleus there is of syenite, against which rest plicated crystalline schists; and over the whole are successive massive layers of trachyte, flanked at the east by basalt. The syenite is remarkably homogeneous in character, and there is nothing to indicate its origin, whether from fusion or metamorphism; but throughout its observed contact with the schistose rocks it is the inferior member. In Virgin Cañon no granitoid nucleus is apparent, the entire exposure being gneissic, with a general anticlinal structure, modified by considerable minor plication. The overlying lavas were seen only in the distance; but, as judged by their habit, belong to the group of trachytes. In Black Cañon the visible nucleus is a tolerably homogeneous rock, resembling pegmatite, but probably metamorphic in its origin. It is a comparatively inconspicuous feature, the greater part of the walls of the cañon being composed of red, purplish, and brown trachyte, in beds of great thickness, and in many places brecciated with fragments of similar character to the matrix, as well as with bowlders of gneiss and other schistose rocks.

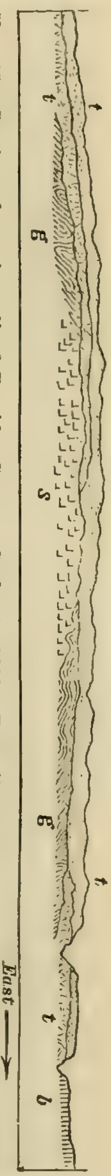


FIG. 15.—Section of north wall of Bowlder Cañon. Scale, 1-72000. Base line=sea-level. s. Syenite. gg. Gneiss. tt. Trachyte. b. Basalt.

In the Black Hills, north of Prescott, Arizona, a series of crystalline rocks similar to those of Bowlder Cañon, are overlaid by unaltered sediments belonging to the Carboniferous series. The latter are unconformable, and appear to have been deposited after the principal upheaval of the schistose ridge; but from a later uplift have been themselves somewhat tilted. The phenomena could not be very thoroughly observed, on account of the numerous eruptions of the trachyte and basalt in the neighborhood of the line of section. A section obtained by Mr. Marvine at a point farther south, and given in his report, is incomplete for the same reason.

FIG. 16.—Section of Verde Valley. Scale, 1–200000. *g.* Granite and schists. *b.* Basalt. *N 20° E* *B.* Black Hills. *V.* Verde River. *A.* Aubrey Cliff.

The axial rocks of the Toquima range were seen only in the neighborhood of Belmont, Nevada, where they are exposed for a distance of five to ten miles, the area being limited both north and south by a heavy mantle of rhyolite. The component rocks are granite and argillaceous slate, the latter somewhat metamorphosed, but not to such an extent as to entirely destroy its fossils, which are of Silurian forms. The boundary between the two, crosses the range obliquely from southeast to northwest, and is tortuous in detail. The granite apparently intrudes in irregular bodies in the mass of the shale, which, in a general way, rests against the granite, and is inclined at a high angle. The shale contains some intercalated beds of limestone and sandstone, and has an apparent thickness of four or five thousand feet, but there is so much plication observable as to render it probable that some reduplication has taken place. It lies to the north and east of the granite and contains the metalliferous veins of the Philadelphia mining district. The granite forms the eastern face of the mountain, from Belmont south for not less than five miles. It was examined at few points, but appeared, while presenting considerable variety, to be characterized by an unusually large percentage of quartz, the yellow color of which imparts its hue to the general mass. Its eruptive character is intimated, not merely by its intrusion between bodies of slate, but by the presence in its mass of huge bowlders of gneiss, as well as of dissimilar granite.

The axis of the Reveille range is covered by volcanic material throughout nearly its whole extent. So far as my own observation revealed, it is to be seen at but two points. The first of these is at Reveille, where for a few miles the crest and eastern face to the foot-hills are of limestone and quartzite, so dislocated that their sequence is hard to establish, but agreeing in a westerly dip. Sixty miles farther south the sedimentary rocks are again exposed, forming a simple monoclinal, with westerly dip at a high angle, and with unusual continuity of strata along the strike.

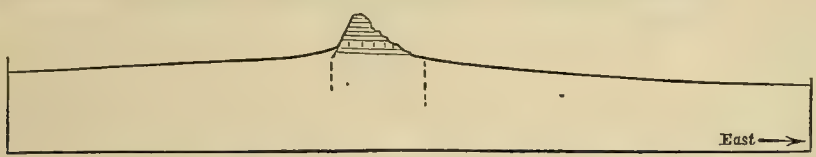


FIG. 17.—Section of Mount Worthington. Scale, 1–72000. Base line=level of Great Salt Lake.

Worthington Mountain, in Eastern Nevada, stands by itself, is fifteen miles long, and is remarkably acute in its cross-section. The strata are nearly horizontal, but incline slightly to the east, and pass completely through, so as to appear on both sides. Its northern end, according to Mr. C. R. Ogden, who visited it, is flanked on the east by beds of rhyolite, associated with which are the Freiberg silver mines. At the southern end the limestones of its section are uncovered, and spring abruptly from the talus of gravel. I can conceive of no erosion that should have left this thin segment as the remnant of an inclined table or of a fold. Its narrowness, its straightness, and its isolation, mark it as a mass of strata thrust upward between two faults—strata, of which the companion parts lie beneath the *débris* at its foot. Lithologically it consists principally of limestone, interspersed with some sandstone, and containing abundant fossils, which are probably referable to the Silurian. Our collections were, however, destroyed, and the reference is made merely from memory.

The portion of the Pahranagat range, which lies north of the pass at Logan Spring, consists of a principal and tolerably continuous mass of strata, forming the crest of the ridge, flanked at the east by a great number of irregularly disposed bodies, all of which have the same westerly dip, and are separated from each other by faults, along which the downfall has been uniformly on the eastern side. While the trend of the main range is with the meridian, a line of hills, consisting of similar faulted rock masses, extends northeasterly to the next general line of upheaval, where they culminate in Fossil Butte. These, as well as the immediate foot-hills of the range, are composed of westerly dipping strata. At Logan Pass, the axis of the range is hidden by rhyolitic outflows for a few miles, and south of it the strata re-appear in a single monoclinal with an easterly dip. The crest of the range in the vicinity of Silver Cañon is of vitreous sandstone that overlies a limestone series of great thickness, in the upper part of which are the chief metalliferous veins of the Pahranagat district.

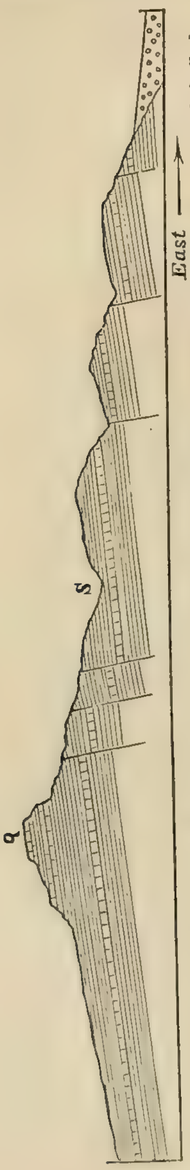


FIG. 18.—Section of the Pahranagat range at Silver Cañon. Scale, 1–72000. Base line=level of Great Salt Lake. *Q.* Quartz Peak. *S.* Sanders Cañon.

The Timpahute range lies next west of the Pahranagat, and is its close counterpart in point of structure. In its northern portion the dip is westward, and a series of ridges, *en echelon*, stretch northeast to the north extremity of the latter range. The main ridge, however, is comparatively low, and is even surpassed in size by the first parallel ridge at the east. In its southern portion the rocks incline to the east, and are divided by a series of vertical faults, the effect of which, as shown by the diagram, is to reduplicate the several beds upon the surface and increase the lateral extent of their outcrops. The quartzites at the west, and the limestones at the east, by their superior hardness, maintain parallel ridges, while the intervening shales have been denuded so as to form a valley within the range. Vertical faults within these shales contain the galena veins that have been

FIG. 19.—Section of Timpahute range at the Groom mining camp. Scale, 1–72000. Base line=level of Great Salt Lake. Mines at *M.*

mined by the proprietors of Groom district As in the Pahranagat range, the point at which the dip changes has been the seat of volcanic activity, one result of which has been the uprearing of Timpahute peak, the loftiest summit of the range.

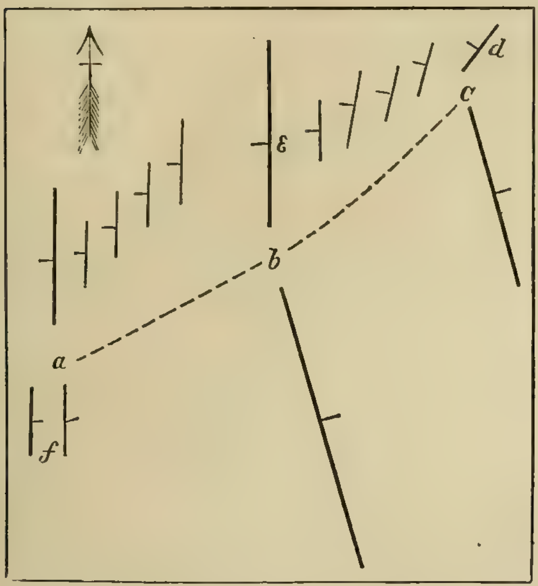


FIG. 20.—Chart of monoclinal ridges in Southern Nevada. 1 inch=12 miles. The long and cross lines show direction of strike and dip. In the Timpahute range, *a*=Timpahute peak, and *f*=Groom mining camp. In the Pahranagat range, *e*=Quartz peak, and *b*=Logan pass. In the Hyko range, *d*=Fossil Butte.

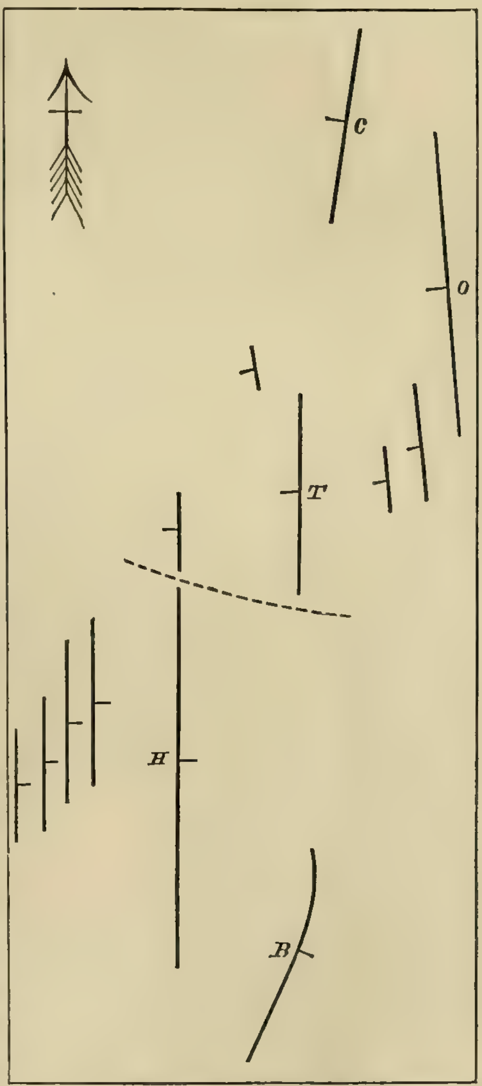


FIG. 21.—Chart of Monoclinal ridges in Western Utah. 1 inch=30 miles. *B.* Beaver Creek range. *C.* Cedar range. *H.* House range. *O.* Onaqui range. *T.* Thomas range.

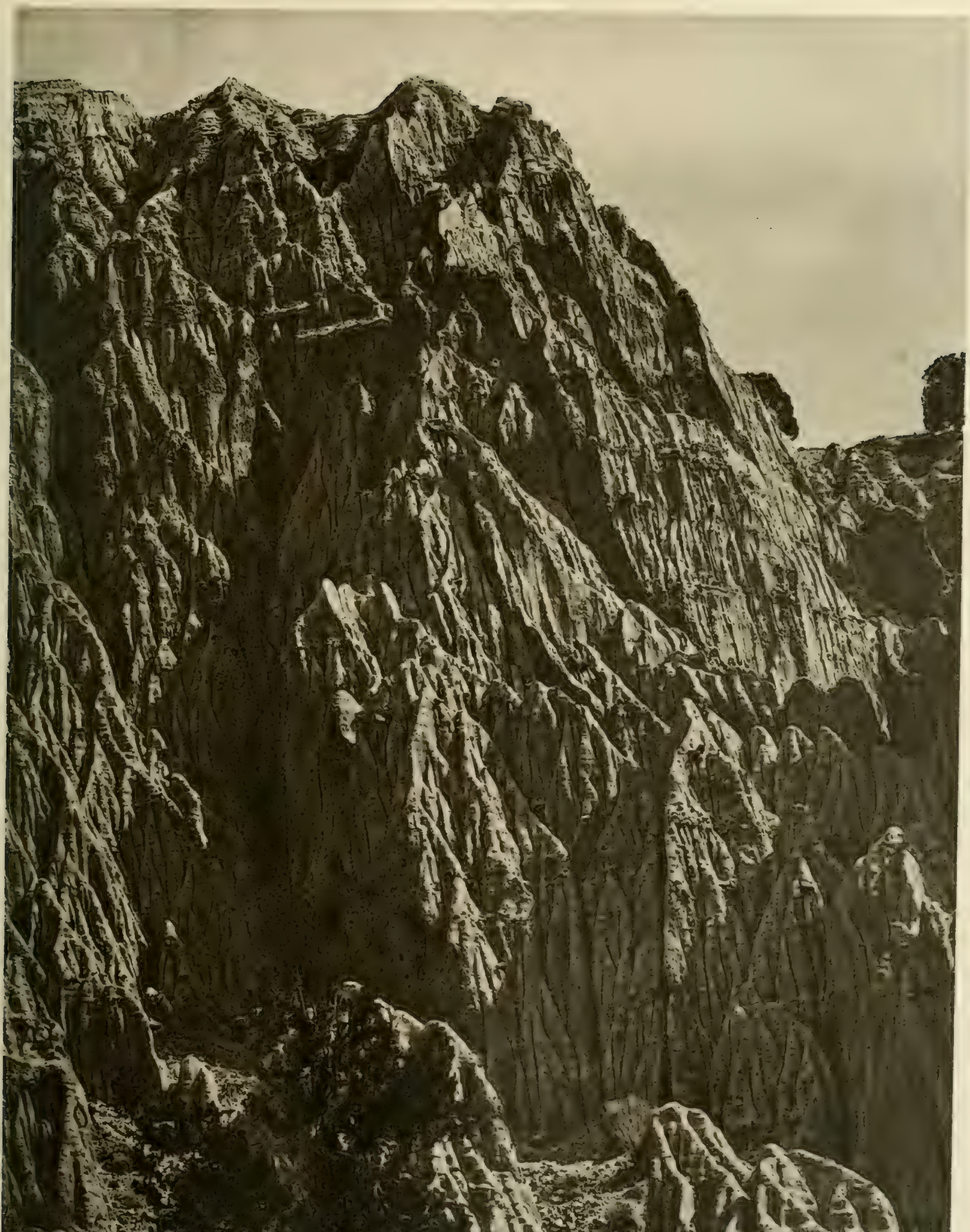
The features exhibited by these two ranges appear to me of great interest. Taken with the Hyko Hills at the east, they constitute a group most closely related in structure. The accompanying diagram (Fig. 20) represents merely the positions and strike of the upheaved masses. North of the dotted line *a*, *b*, *c*, all the strata dip to the west, and their several masses are separated by faults along which the downfall is invariably to the east. South of the dotted line the reverse is true; the dip is eastward, and the downthrow westward. There are no folds. There are three main ridges, or maxima of elevation, about fifteen miles apart, and persistent through both phases of dip. In the lines of these maxima there are volcanic outflows, at *a*, *b*, and *c*., where the dip is reversed. The most patent immediate deductions from these phenomena are that the ridges are due to forces uniform in kind, and probably synchronous in action through the whole group, and that the directions in which the forces acted have horizontal components, opposite phases of which are exhibited in the areas of opposite dip. The further conclusions that the forces were deep-seated, that the parallel main-ridges recur with subequal interval, and that the volcanic eruptions are associated phenomena, are suggested; but, as their application is much broader, so, too, their demonstration depends on a greater array of facts.

The systematic uniformity shown by this group of ridges does not stand alone. Another illustration, and one on a grander scale, is to be found in Western Utah. The strata of the Onaqui and Stansbury ranges, of Cedar and McDowell Mountains, Granite Mountain, of the Thomas range, and two small ridges west of it, and of the north part of the House range, dip to the west. South of Dry Pass (below the dotted line in the diagram) the case is reversed, and the continuation of the House range, the Beaver Creek range, and a number of small ridges known as the Confusion range, show an easterly dip.

Structure of Ridges.—In the great majority of the ranges I have just described, and in an equally large porportion of others, in regard to which my observations were too cursory to warrant individual mention in this connection, the beds exhibit in cross-section but a single direction of dip. Either (Figs. 5, 7, 9, and 13) the strata in a single body incline from the crest to one base of the range, or (Figs. 1, 3, 4, 18, and 19) they are divided by a system of faults, trending parallel to the range, into several bodies, which dip in one common direction. In these cases the ranges may be called simple and compound monoclinals.

Next in frequency are sections in which (Fig. 97) there appear at the base of the monoclinal escarpment strata dipping in the opposite direction.

Pure anticlinals (Figs. 2 and 15) are exceedingly rare, but in a number



of instances greatly shattered and dislocated rock-masses assume a quasi-anticlinal form, (Fig. 12.) Anticlinals and synclinals also occur as subsidiary features within some ranges, (Fig. 14.)

A few most remarkable ranges present escarpments on both faces, (Fig. 17.)

The labors of the Pennsylvania geologists have rendered so familiar the structure of the Appalachians, that it has been by many accepted as typical of all mountains, and a comparison will facilitate an understanding of the basin ranges. Indeed, I entered the field with the expectation of finding in the ridges of Nevada a like structure, and it was only with the accumulation of difficulties that I reluctantly abandoned the idea. It is impossible, by any hypothetical denudation, to formulate the basin ranges as remnants of a system of anticlinal and synclinal folds. The simple monoclinal may indeed be explained as the side of an anticlinal, by the harsh assumption that the remaining parts have been removed below the level of the adjacent valley, but the explanation will not apply to the compound monoclinal, (Figs. 18 and 19,) nor is the erosion conceivable that would carve Worthington Mountain (Fig. 17) from an anticlinal.

The question, what is, then, the general structure of the basin ranges? admits of less dogmatism; but if it cannot be completely answered, some light, at least, may be thrown on it.

To begin with the simplest generalization, the ranges are a system; not indeed formed at the same time, but exhibiting certain common characters, over a great area. They are parallel; they recur with some regularity of interval; they are of moderate dimensions.

Second. The ridges of the system occupy *loci* of upheaval, and are not mere residua of denudation; the valleys of the system are not valleys of erosion, but mere intervals between lines of maximum uplift. Within the ranges there are indeed eroded valleys, and the details of relief show the inequality of erosion due to unequal resistance, but there is not on a grand scale that close dependence of form on durability that must maintain were the great features of the country carved by denuding agents. An easy illustration of this is afforded by the southern portion of the Timpahute range, (see Fig. 19.) The range terminates near the line of section, and is surrounded at the east, south, and west by a gravel plain. The valley in the range, due to the occurrence of soft shales between harder beds, opens to the south, and is deepening very slowly, because it is little elevated above the plain. If the depression occupied by the gravels of the plain had itself been not only emptied, but excavated, it is inconceivable that the shale in the mountain should have escaped deep erosion. Furthermore, ridge lines are more persistent than structures. In the same continuous ridge are monoclinals with opposed dip, as in the Timpahute, Pahranagat, and House ranges—or monoclinal and anticlinal, as in the Spring Mountain and Snake ranges. The section at Ivanpah is peculiarly in point. The mountain there shows an axis of granite, flanked on each side by limestone, but the trend of the anticlinal is oblique to that of the range and it quickly runs out, the granite giving place at the north to the eastern mass of limestone, which rises and, as an eastward dipping monoclinal, constitutes the entire range, while the western limestone mass becomes, in the same manner, supreme at the south. And, finally, the character of the ridges, as main lines of structure, is indicated by the association of volcanic phenomena, as will appear when, in another chapter, the distribution of the lavas is described.

Third. The movements of the strata by which ridges have been produced have been in chief part vertical along planes of fracture, and have not involved great horizontal compression. There are some notable local exceptions to this, but considering the prevalence of faulted monoclinals, which demand no horizontal motion, the existence of the feature as a distinctive one need not be questioned.

Fourth. We may say, without fairly entering the field of speculation, that the forces which have been concerned in the upheaval of the basin ranges have been uniform in kind over large areas; that whatever may have been their ultimate sources and directions, they have manifested themselves at the surface as simple agents of uplift, acting in vertical, or nearly vertical, planes, and that their *loci* are below the immediate surface of the earth's crust.

SECTION II.

THE COLORADO PLATEAU SYSTEM.

The province of plateaus is characterized by a system of tabular reliefs, consisting of strata little disturbed. What falls within our field is but a portion of a large area known as the Colorado Plateaus or Colorado Plateau System. It derives its name from its partial coincidence with the hydrographical basin of the upper portion of the Colorado of the West, but the two are far from identical. On one hand, the chief tributaries of the Colorado—the Grand, the Green, and the San Juan—rise beyond the Plateau region; and, on the other, the waters of a part of the system find their way, as the Sevier River, to the Great Basin; while the Rio Virgen, which rises among the Plateaus, passes into the province of the Ranges before reaching the Colorado.

The Colorado Plateaus lie between the Rocky Mountain System and the Basin Range System at the east and west, and stretches northward to the Uintahs. Of the political divisions, it includes Southeastern Utah, Northeastern Arizona, and adjacent portions of Colorado and New Mexico.

The simplicity of its structure, the thoroughness of its drainage, which rarely permits detritus to accumulate in its valleys, its barrenness, and the wonderful natural sections exposed in its cañons, conspire to render it indeed "the paradise of the geologist." There he can trace the slow lithological mutations of strata continuously visible for hundreds of miles; can examine, in visible contact, the strata of nearly the entire geological series, and detect every nonconformity, however slight, and can study the simpler initiatory phases of an embryo mountain system.

To the reports of Professor Marcou, who accompanied the expedition of Lieutenant Whipple in 1853–'54, and of Dr. Newberry, the geologist of Lieutenant Ives's expedition in 1858, we owe our first knowledge of the geology of the Plateaus. In the following year, Dr. Newberry, with Captain Macomb, traversed the region east of the Upper Colorado, as far north as the junction of the Green and Grand; and since 1868, Mr. J. W. Powell has been engaged in the geological exploration of the Colorado and its western tributaries, including the Green. The reports of these gentlemen, though in so great an area they leave some fields untouched, will make known, when they shall have been published, all that is most important of the Plateaus.

Our own explorations have pertained to the western margin of the system, and a belt within the margin from twenty-five to one hundred and twenty-five miles broad.

At the south we intersected routes of Professors Newberry and Marcou, and at the north visited numerous fields of the labors of Mr. Powell.

So far as our own explorations have shown, the strata composing the tables range from the fresh-water beds considered as Eocene Tertiary to the Tonto group, a Paleozoic series, which underlies the recognized Carboniferous rocks of the Grand Cañon of the Colorado.

In the most southerly section the entire series is conformable, but at the northwest there is evidence of a disturbance before the deposition of the Cretaceous.

The areas drained severally by the Sevier River, and by those tributaries of the Colorado which rise in Southern Utah, are geologically and topographically, as well as hydrographically, somewhat distinct. The *general* dip of the strata throughout both regions is at a low angle to the north. The main forks of the Sevier rise upon the extreme southern edge of the Tertiary strata, and flow northward almost entirely upon them, until, passing through the Cañon range, they empty into a desert valley of the Range System.

The tributaries of the Colorado, on the contrary, rising along the same line, descend through the successive beds to the Grand Cañon, which traverses Paleozoic rocks, and exhibit on their banks a complete section. The country which they cross is divided into a series of great terraces, by lines of cliffs trending east and west, facing south, and composed severally of the harder strata of the geological series. A system of faults, having a general north and south direction, traverses the entire region, and is a very important element in the determination of the topography. In the Sevier country the faults and volcanic outflows have created all the geographical features. At the south, where the system of terraces is intersected at nearly right angles by that of faults, it results that the country is divided into a great number of minor tables. The lines of cliffs, determined by the occurrence of harder and more massive strata, are modified not only by the intersecting faults, which have great local effect upon the rate and manner of denudation, but by changes in the constitution of the beds which give rise to them. Beginning with the uppermost, the principal lines are as follows:

First, the fresh-water limestones, referred to the Tertiary, form a series of pink and white cliffs, culminating southward in two principal points, terminating the two tables, for which Professor Powell proposes to use the Indian titles, Pownsagunt and Markagunt.

The next cliff consists of the calcareous sandstone at the top of the Cretaceous System, and has a pale greenish-yellow color. On the headwaters of the Kanab and Virgen it is inconspicuous, as compared with those adjacent to it, but derives great interest from the coal it bears.

The third escarpment is made up principally of massive, ochreous and cream-colored sandstone, referable to the Triassic system, but is capped by a few feet of limestone, in which are Jurassic fossils. At Steamboat Mountain it unites with the red cliff below it, but on the Upper Virgen forms a distinct line, through which the East Fork passes in the cañon below the town of Mount Carmel. The great fault of Long Valley, to which further allusion will be made below, here interrupts it, and it re-appears as a bluff overlooking Long Valley from the east. Turning abruptly near Mount Carmel, it resumes its westerly course a few miles north of its former line of direction, and, crossing Kanab Creek ten or twelve miles above Kanab, continues a bold bluff in the rear of, and parallel to, the Vermilion Cliffs, as far, at least, as Paria Creek.

The Vermilion Cliff, which comes next in order, has been further traced, and is a conspicuous feature of the topography of the country. The rocks which compose it are massive, cross-stratified sandstones, banded in buff and red, but ordinarily stained superficially to a bright vermilion. From Steamboat Mountain, near Little Zion, this cliff was traced north of Rockville and Shunesburg, at which latter place it is cut by a cañon of the east fork of the Virgin, and thence, southeast to Pipe Spring. At this point it is intersected by the same fault which deflected the Gray Cliff at Long Valley, and is itself carried northward a distance of three or four miles, when it resumes its easterly course, past the town of Kanab and Johnson's Settlement, to Paria Creek, four miles above the town of Paria. Here it turns abruptly southward, and follows for forty miles the most easterly fault of the Kaibab Plateau. In the southern part of this course it is the east wall of House Rock Valley, and it terminates that valley by turning sharply to the east. At Jacob's Pool, it swings to the northeast, and soon reaches the mouth of the Paria, where it crosses the Colorado, and once more assumes a southerly course. Beyond this point our explorations did not follow it, but it was seen by Mr. Marvine upon the eastern bank of the Colorado Chiquito, and there can be little uncertainty as to its general course in the interval.

The next bench, named by Professor Powell the Shinarump Mesa, is of minor importance, and for the most part projects but a short distance from the base of the Vermilion Cliff. It is most strongly marked between Virgin City and Kanab, where it forms a chocolate-colored escarpment from 200 to 500 feet in height. From Virgin City it was traced by Mr. Howell to a point on the Virgin River, twenty miles below the town of Saint George. East of Kanab it was seen, with diminishing propor tions, as far as Navajo Wells, and it must extend nearly to the Paria in that direction. From House Rock Spring to Jacob's Pool the conglomerate which caps it is absent, and the cliff is lost, but it re-appears in the neighborhood of Rocker Creek. Thence it holds its place to the mouth of the Paria, and is continued as far as our view commanded south of the Colorado. It was noted by Mr. Marvine on the east bank of the Colorado Chiquito.

Below this is the most important bench of all, capped by the upper limestone of the Carboniferous. Its extreme breadth, measured from the mouth of Paria Creek southwest to Aubrey Valley, is one hundred and thirty miles, and its length in a right line is more than three hundred miles. Through it the Colorado has cut Marble Cañon, and the greater part of Grand Cañon. Upon it stand the peaks of San Francisco, Bill Williams, Floyd, Sitgreaves, and Kendrick, and the Mogollon, the Uinkaret, the Sheavwits, and other volcanic mountains. South of San Francisco Mountain the names "Black Mesa" and "Mogollon Mesa" have been indefinitely applied, and north of the Colorado, portions definitely limited have been designated by Professor Powell, the Sheavwits, Kanab, and Kaibab Plateaus. For the portion south of the Colorado, bordering on that river from Diamond Creek to Paria Creek, and limited at the east by the Shinarump Cliff, I shall employ the title, *Colorado Plateau;* and for the cliffs which limit it at the south, I propose the title of *Aubrey*, since the Aubrey sandstone is their most conspicuous stratigraphic member. From the vicinity of Camp Apache to the Colorado at Diamond Creek, two hundred and forty miles, their line is continuous, and wonderfully direct in its general course, though, in places, deeply sinuate in detail. Beyond the river it holds its northwesterly course to the mouth of the Grand Cañon, and then turns north, becoming the upper member of the double cliff caused by the Grand Wash fault.

Finally, the Red Wall limestone, southwest of Aubrey Valley, forms a series of low escarpments, of which the Music Mountain, of Lieutenant Ives's map, is a promontory.* They are seen, at intervals, to Camp Apache, but are so interrupted by the disturbances of the adja-

* A regular alternation of hard and soft strata, producing parallel and equidistant lines across the face of the headland, suggested a musical staff, and led Lieutenant Ives to distinguish it with a name. As it is not distinguished by its size, it has been overlooked by frontiersmen, and the name caught from his map has been applied to a conspicuous crest ten miles further west. This later usage has been followed by Lieutenant Wheeler.

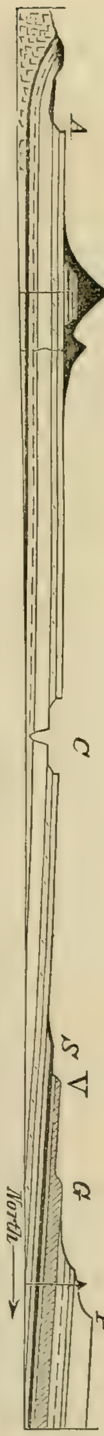


Fig. 22.—Section from the Aubrey Cliff to the Pink Cliff. Vertical scale exaggerated. Base-line = sea-level. *A.* Aubrey Cliff. *F.* San Francisco Mountain. *C.* Grand Cañon of the Colorado. *S.* Shinarump Cliff. *V.* Vermilion Cliff. *G.* Gray Cliff. *P.* Pink Cliff.

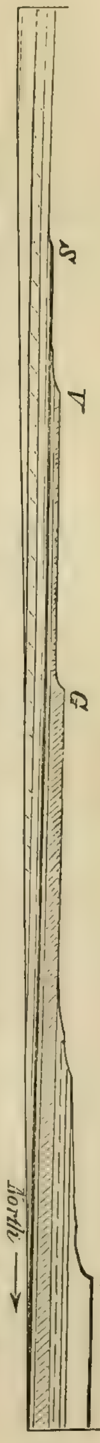


Fig. 23.—Portion of section 35 drawn with the same vertical and horizontal scale, viz: 1-340000. Letters the same as in Fig. 22.

cent Basin Range System, and modified by variations in the lithological succession on which they depend, that they have no topographical continuity.

The relations of all these mesas, except the lowest, are illustrated by the upper diagram, Fig. 22, which gives a profile and section from the Pink Cliffs at the head of Kanab Creek, Utah, one hundred and seventy miles, to the Black Hills, near Prescott, Arizona. The vertical scale is of necessity greatly exaggerated. In the lower sketch a portion of the same is given with the same vertical and horizontal scale. Two great watersheds are intersected by the line of the diagram. The Pink Cliff separates the Sevier River of the Great Basin from Kanab and Paria Creeks, tributaries of the Colorado. The Aubrey Cliff divides the waters of the Colorado Chiquito from those of the Gila.

Faults.—The term "fault," as it has been used in preceding paragraphs has a somewhat more extended meaning than the one usually given to it, and must be understood to include all cases in which rock-masses, once adjacent, have been separated by vertical movement without great disturbance otherwise, whether the movement produced a fracture, simple or compound, or merely a flexure. In the field under consideration there are numerous instances in which the same fault affords, in different places, examples of fracture and of flexure. The accompanying diagrams, as well as those given below to illustrate the Sevier Valley fault, will serve to indicate the range of variation.

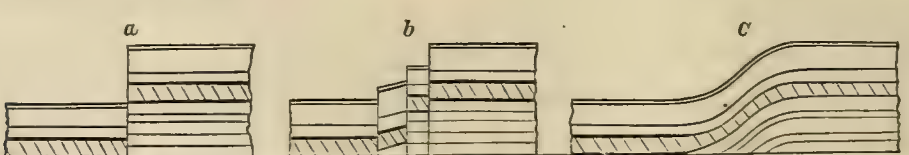


FIG. 24.—Ideal sections of faults. *a* and *b*, fractured faults; *c*, a folded fault or monoclinal fold.

In their distribution the faults are in two ways systematic. First, they exhibit parallelism, not universal, but widely extended. Throughout the basin of the Upper Sevier, their direction ranges from north 10° east to north 30° east, and the faults, recurring with subequal intervals, have given rise to the series of parallel ridges which constitute the main features of the topography. Farther south, on the borders of Utah and Arizona, their trend is more nearly north and south.* The second element of uniformity is in the direction of motion along the vertical plane. With few exceptions, throughout the region of the Upper Sevier, the eastern wall has been lifted, (or the western dropped,) and, as a concomitant feature, the strata have received an easterly dip. Wherever, between Salina and Panquitch, the mantle of lava permits the inspection of the underlying strata, their escarpments are found facing the west, and their inclinations directed to the east.

The average amount of vertical displacement in this region along the lines of fault is not less than 2,000 feet. Farther south it diminishes somewhat, and at the extreme southern edge of the plateau, in the neighborhood of the San Francisco and Mogollon Mountains, the disturbances have been slight.

There is reason to believe that the several faults can be traced for great distances. One of them, the Sevier Valley fault, it was our fortune to examine at so many points as to be able to define its course for a distance of two hundred and twenty-five miles, without including either end. The most northerly point at which a cross-section was obtained is the north end of Sam Pitch Valley. Its profile there exhibits, first a simple bluff, and then a duplex flexure involving several minor faults. With great variation of detail, these continue along the eastern margin of Sam Pitch Valley to Manti and Salina.† From the latter place to Glencove the convex fold is partly removed, so that its front consists of a bluff escarpment overlooking a narrow ridge of highly inclined rock at its base, while the reverse fold is concealed beneath the detritus of the valley. From this point to Panquitch, a distance of sixty-five miles, the ridge, to which the fault gives rise, continues unbroken, but is so completely covered with volcanic rocks that the presence of the sedimentary cannot be predicated from direct observation. At Panquitch the dislocation is by a simple fracture, and this character maintains as far as the divide between the Sevier and Virgen, where it

* Exceptional to the general parallelism are some instances in which faults have forked, and their branches have become quite divergent.

† Since this chapter was written, Mr. Howell has made some examinations near the town of Salina, which lead him to conclude that the Sevier fault terminates there, and that the fault which walls the Sam Pitch Valley is the prolongation of one which, southward, bears more to the east. His investigations, however, although fuller than mine, do not entirely explain the structure at Salina, and for this reason I let my description stand, save as qualified by this note.

changes to a flexure, and so continues to the town of Glendale, at the head of Long Valley. East of Long Valley, from Glendale to Mount Carmel, it consists in part of a simple, and in part of a complex fracture, and beyond

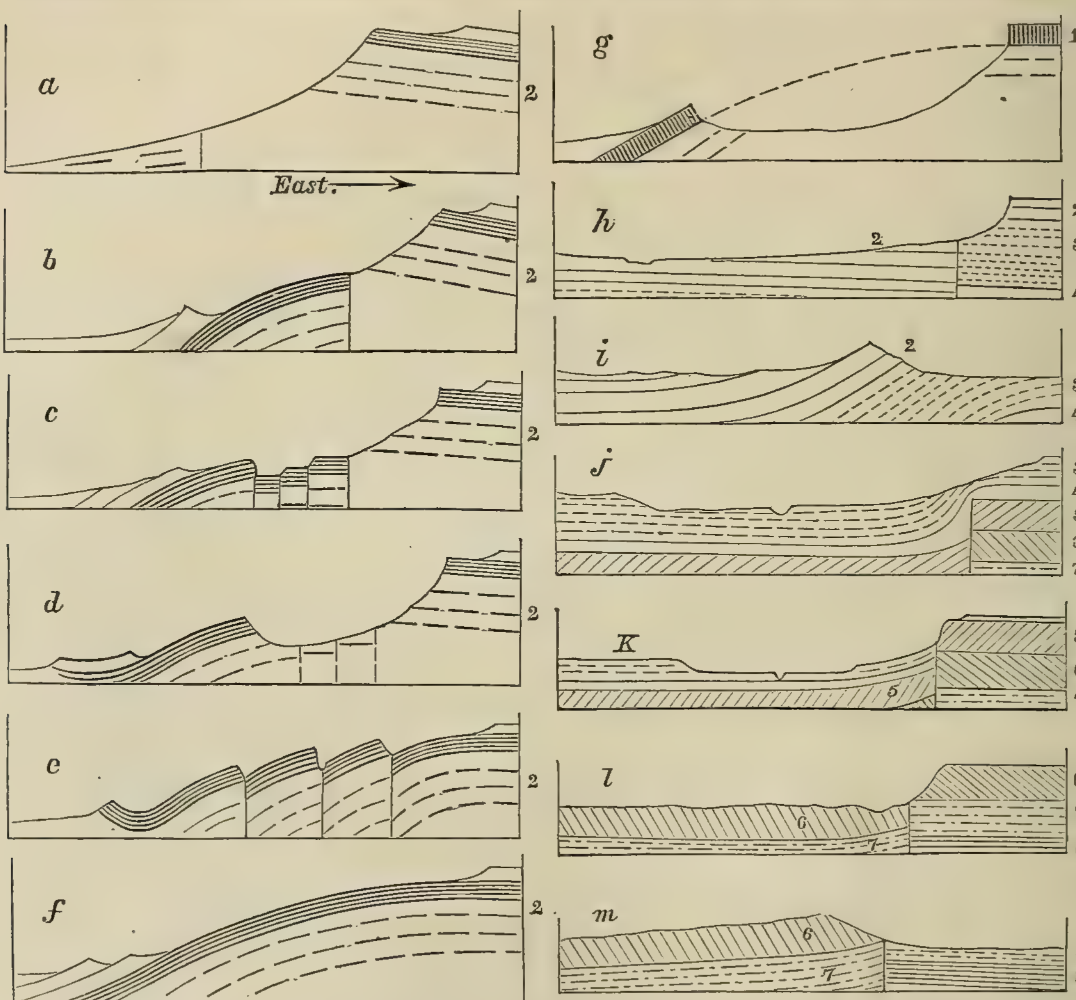


FIG. 25.—Thirteen sections of the Sevier fault, in order from north to south. The localities are: *a*, north of Springtown, Sam Pitch Valley; *b*, Springtown; *c*, Ephraim City; *d*, Manti; *e*, south of Manti; *f*, north of Salina, Sevier Valley; *g*, Glencove; *h*, twenty miles south of Panquitch; *i*, Upper Kanab; *j*. Glendale, Long Valley; *k*, Mount Carmel; *l*, near Moccasin Settlement; *m*, Pipe Spring, Arizona; 1. Trachyte; 2, Tertiary; 3, Cretaceous; 4, Jurassic; 5, 6, and 7, Triassic; 8, Carboniferous.

the latter place, owing to the yielding nature of the material which here constitutes its margins, its structure is not evident, but its existence was traced continuously to Pipe Spring, Arizona. It is this fault which occasions the deflections in the cliff lines to which reference has already been made.

It is to be observed, that while the several escarpments at the east of the dislocation are carried further north than at the west, this is not due to any horizontal displacement along the line of fault, but merely to the fact that the eastern portions, being lifted higher than the western, became subject to different conditions of denudation.

Another phase of the system involved in the arrangement of the faults is exhibited in their symmetry with reference to the Kaibab Plateau. That table has been uplifted bodily between parallel meridional faults, and all faults west of it have a westward throw, while the only one at the east that our exploration intersected has an eastward throw.* This is well shown in the accompanying section, Fig. 26, which crosses the system, in an easterly direction, from the Virgin range, near the mouth of the Grand Cañon of the Colorado, past the mouth of Paria Creek, a distance of one hundred and sixty miles. The dislocations west of the Kaibab Plateau are the southward prolongation of the system manifested in the Sevier Basin.

There are some special considerations that will warrant a brief individual mention of the several details of this section, with fuller illustration.

The Paria fold was visited at but one point—that where Paria Creek enters the Colorado. The Colorado here has a southwesterly course, and, at its intersection with the fold, passes from Triassic to Carboniferous rocks. On both sides of the river the fold produces conspicuous topographical features. At the

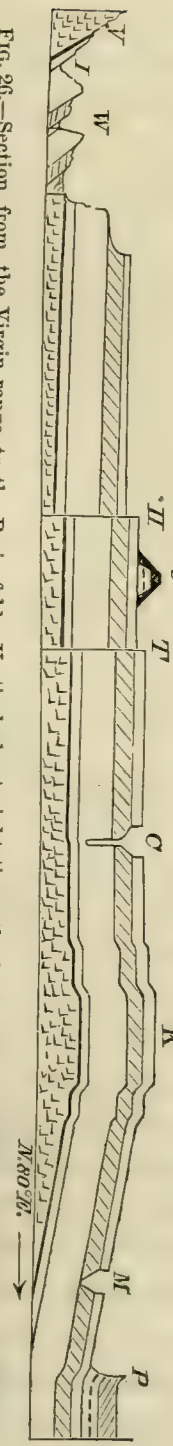


Fig. 26.—Section from the Virgin range to the Paria fold. Vertical about eight times the horizontal. Base-line = sea-level. *V*, Virgin range; *I*, Colorado River in Iceberg Cañon; *W*, Colorado at Grand Wash; *H*, Hurricane fault; *U*, Uinkaret Mountains; *T*, Toroweap fault; *C*, Kanab Creek; *K*, Kaibab Plateau; *M*, Colorado in Marble Cañon; *P*, Paria fold.

*In the Geology of the Colorado Expedition, (p. 95,) Dr. Newberry describes a partially flexed dislocation, near Fort Wingate, N. Mex., with a throw of 2,000 feet to the *west*. This, and his account (p. 93,) of an anticlinal at Old Fort Defiance, constitute the earliest notices of any members of the system of disturbances within the Plateau area.

north, Paria Creek, for some miles, at least, has opened a cañon along the line of fault, and removed the greater portion of the inclined strata down to near the base of the Trias. It is especially noteworthy that what of the flexed sandstone remains belongs to the lower or synclinal side of the fold, (see Fig. 27,) indicating that the line of erosion, if determined by the

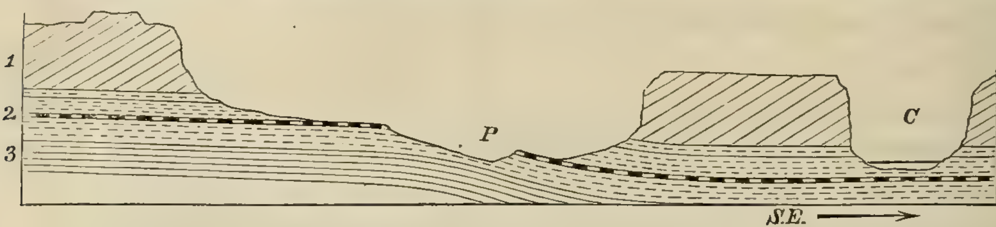


FIG. 27.—Section of Paria fold above the junction of the Paria with the Colorado.

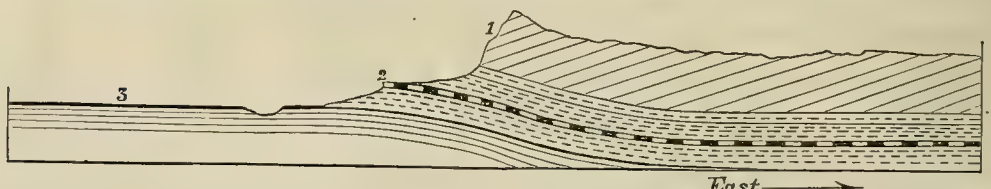


FIG. 28.—Section of Paria fold south of the Colorado River. Scale, 1-40000. *P*, Paria Creek; *C*, Colorado River; 1, Trias sandstone; 2, Shinarump conglomerate; 3, Aubrey limestone.

fault, was due to the fracture of the sandstone along the anticlinal flexure, and not to the channel afforded by the synclinal trough adjacent to it. South of the river the survival of the synclinal flexure is even more remarkable, for it marks the limit of the denudation of the Trias for many miles, (see Figs. 26 and 28.) The upturned sandstone beds rise higher than their horizontal prolongation, and constitute a persistent rim or parapet along the edge of the Triassic Plateau. It will be observed that the strata for some distance west of the fold are inclined to the east, and at the east are nearly horizontal, so that they include a gentle synclinal. An equally gentle and broad synclinal was noted by Dr. Newberry on the Colorado Chiquito, about one hundred miles distant, (Geology of Ives's Expedition, p. 77,) and in the line of direction, south 15° east, given by the Paria fold, and the presumption is strong that the two coincide.

The Kaibab Plateau was seen continuously from the Colorado River north to the neighborhood of Paria settlement, where its easterly fold intersects Paria Creek. At that point the fold is quite abrupt, and denudation has left the inclined Triassic sandstone in an acute ridge, precisely similar to the one which marks the Paria fold south of the Colorado. The section (Fig. 29 *a*) cuts a few miles north of this, and shows the relation of the drainage lines to the flexed strata. The western fold is either absent or very slight at this point, and the plateau is an unsymmetric anticlinal. Twenty miles further south, where the next section of the plateau was obtained, it has its typical profile. The cherty limestone at the top of the Carboniferous is its floor, and descends in unruptured folds to the plains on either side, (Fig. 29*b*.) At the east the marls and sandstones of the Trias overlie it, and House Rock Valley lies in the monoclinal between them. Further south the valley grows slowly broader, and finally opens into a broad plain, floored by the Carboniferous, and stretching to the Colorado. Ten miles south of the cross-line represented in Fig. 29*b*, the line of fault, on the eastern side of the plateau, forks, producing the general structure shown in Fig. 29 *c*. The total displacement at the same time increases, and the folds are finally replaced by fractures near the Colorado.

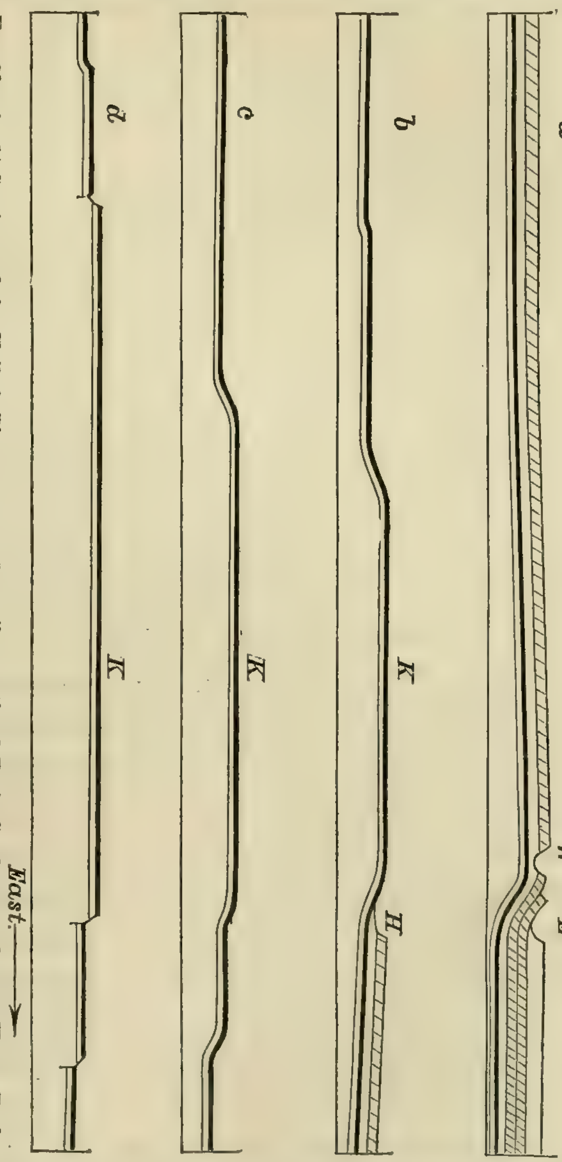


FIG. 29.—(*a–d*.) Sections of the Kaibab Plateau: *a*, a few miles north of Paria Settlement; *b*, near House Rock Spring; *c*, ten miles south of House Rock Spring; *d*, fifteen miles south of House Rock Spring; Scale 1-300000; *K*, Kaibab Plateau; *H*, House Rock Valley; *W*, west fork of the Paria; *E*, east fork of the Paria.

Along Kanab Cañon, apparently the cause of its general rectilinear course, is a simple folded fault, of about 200 feet drop.

The two faults next in order I did not visit, but they have been laid down on our map by Mr. Thompson, of the topographical corps. On the direct line between the Hurricane fault and the mouth of the Grand Cañon we made no survey, but, from the absence of faults along the Grand Cañon in that neighborhood, it is to be presumed that no considerable dislocations are omitted from the section.

FIG. 30.—Section of the Grand Wash fault as exhibited by the gorges of the Colorado. Scale, 1-150000. Upper horizontal line=river level. Base line=sea level. *V*, Virgin range; *I*, Iceberg cañon; *W*, Grand Wash; *A*, Aubrey Cliff; 1, Aubrey group; 2, Red Wall group; 3, Tonto group; 4, Archæan.

At the mouth of the Grand Cañon occurs the most profound dislocation of all. The lower wall of the separated rocks is beyond the possibility of examination; but from an inspection of the dip, as given in the accompanying section, it will be seen that the vertical displacement cannot be less than 5,000 feet, and is probably twice as great. Another fault succeeds this in close order, and beyond it the Paleozoic strata rest against the uplifted crystalline rocks of the Virgin range, which terminate in this direction the Plateau System.

A number of scattered observations of faults, whose precise relation to the system was not established, need not be recorded; but I will describe in this place a single one, to which I shall have future occasion to refer. It was observed at the mouth of Diamond Creek, and may possibly be found identical or confluent with the Hurricane fault. It trends north 25° east, and coincides with the course of the Colorado immediately above the southward bend at which Diamond Creek enters, as well as with the valley through which the Colorado is here approached from the south. The observed sections all exhibit dislocation of about 600 feet, by fracture, (Fig. 31.)

The direction given to planes of fracture in the sketches of faults presented in the preceding pages are, for the most part, hypothetical. Lines of fracture are apt to be covered by *débris*, so that they cannot readily be noted with precision, but in a number of instances, especially along the cañons of the Colorado, I was enabled to see them perfectly revealed, and in every such case I found their planes vertical. In the case of the folds the vertical movement was possibly, or even probably, accompanied by some

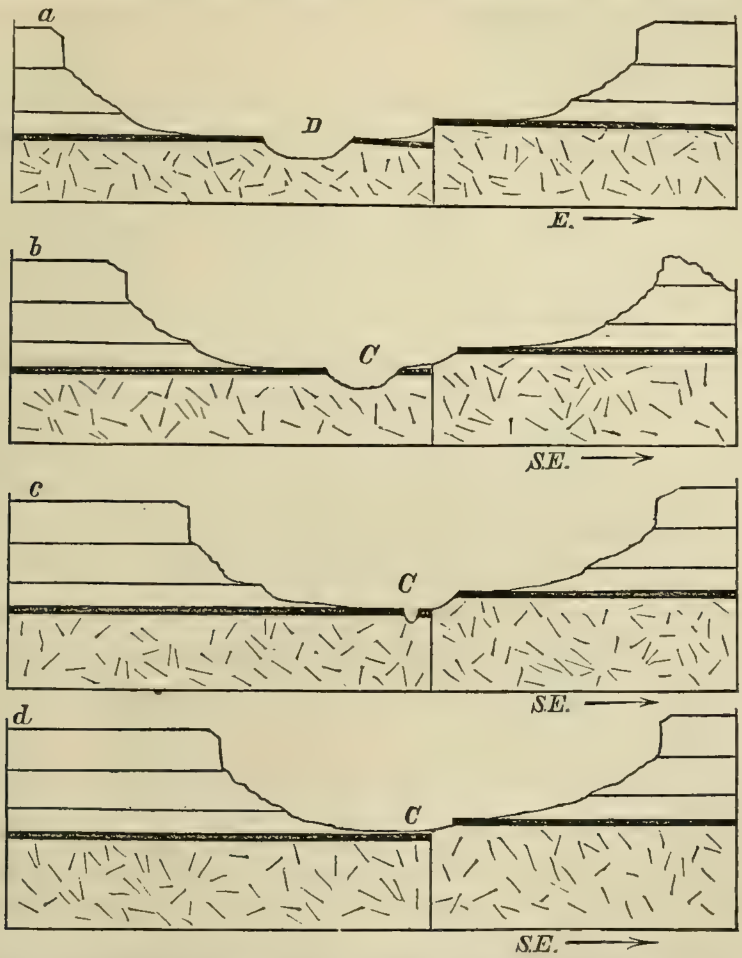


FIG. 31.—(*a–d.*) Sections of Diamond Creek fault: *a*, at the mouth of Diamond Creek; *b*, *c*, and *d*, at points on the Dry Cañon which join that of Diamond Creek near its mouth. Scale, 1-72000. Base line=sea level. *D*, Diamond Creek; *C*, Dry Cañon.

horizontal movement of the strata, resulting in a slight diminution of the transverse diameter of the faulted region, but it is impossible, in the light of the convertibility of folded and fractured faults, to suppose that the vertical movements have been caused by lateral pressure applied to the strata in which they are manifested. Whatever the place and mode of the remote cause, the immediate acts vertically and from some position beneath the strata we are able to examine.

The flexures of strata in the folded faults are not accompanied by metamorphism; no lithological differences were detected between the disturbed and undisturbed portions of the strata.

The amount of flexure sustained without fracture at any point we might assume, *a priori*, to depend on the nature of the rocks and the rate of movement. As a matter of fact, the most perfect arches are found in limestones and very calcareous sandstones, but they are not abruptly bent without partial rupture. Along the margins of the Kaibab Plateau, which afford the best examples, the Upper Carboniferous limestone has a convex curvature of from two to three miles' radius. In the massive sandstones (freestones) of the Trias, I saw but a single instance of anticlinal curvature—at the north end of the Kaibab Plateau—and in that the convexity, though sufficient to demonstrate their flexibility, is very slight. In the synclinal curves of the Paria and East Kaibab folds, the sandstone is seamed throughout, as though it had been crushed and re-united, like the bars of ice in Professor Tyndall's celebrated experiments on regelation. In the Sevier Valley fault, the rigidity of the Triassic sandstones appears to have determined the fracture along Long Valley, while the overlying Cretaceous shales were bent. In Figure 25, I have drawn what I imagine to be the relation of the two beds, although it is impossible to prove it by ocular demonstration. I see no reason why, regarding the phenomena as the results of a slow-acting force, we may not suppose that in depth, as well as longitudinally, the relation and alternation of fractures and flexures will depend on the nature and condition of the beds affected. That we must regard the phenomena as of slow production, no one can doubt, who considers that they include the curvature, through an arc of fifteen or twenty degrees, of a massive sandstone 1,000 feet thick.

RECAPITULATION OF FACTS IN REGARD TO THE COLORADO PLATEAU SYSTEM.

The Colorado Plateau is subdivided in the area examined by a system of transverse—east and west—cliffs, marking limits of successive strata.

It is further subdivided by longitudinal—north and south—cliffs, produced by faults.

These faults are of great longitudinal extent, and of vertical, or nearly vertical, throw. They are manifested indifferently by fractures and by flexures of the visible strata.

They exhibit system:

By general parallelism with subequal intervals;

By uniformity in direction of throw through broad areas;

By symmetrical disposition about the Kaibab Plateau.

The force or forces that have produced them are hence believed to be deep-seated, and uniform in kind and phase over large areas.

SECTION III.

THE BORDER LAND BETWEEN THE RANGES AND THE PLATEAUS.

Broad as is the distinction between the two provinces we have described, it is no easy task to define their common boundary, for here, as everywhere in nature, there is an interlocking of characteristics along the borders, and features regarded at first as crucial lose their significance with the extension of observation. If we begin our examination in the latitude of Provo, Utah, we find in the Wahsatch Mountains a perfect boundary. The country at the east is tabular, and composed of little disturbed strata of Cretaceous and Tertiary deposition, beneath which are buried disturbed strata of greater age, and at the west are narrow mountain ridges of greatly disturbed Pre-cretaceous strata, alternating with desert valleys. The sea in which were accumulated the Cretaceous sediments was limited by this Great Range. The topographical distinction of plateau and ridge, that arrests the attention of every observer, is thus coupled with a great fact of geological history, and it is easy to conceive that in mapping the plateau, we shall map the shore of the Cretaceous sea—that the presence or absence of Cretaceous rocks will guide us in assigning limits to the plateau at other points. If, however, we next examine the margin in the vicinity of Prescott, Arizona, a new element is introduced. The distinction of table and ridge is equally pronounced; but the boundary, instead of a mountain range, is the valley

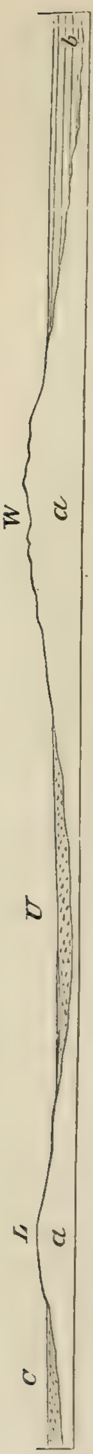


FIG. 32.—Generalized section of the Cretaceous shore, near Provo, Utah. Scale, 1–405600. Base line = sea-level. East → aa, Pre-cretaceous rocks; b, Post-jurassic rocks; C, Cedar Valley; L, Lake range; U, Utah Valley; W, Wahsatch range.

of the Rio Verde, and the same Carboniferous strata that constitute the table at the northeast, re-appear, with some inclination, in the first mountain ridge. The limit of the plateau now coincides with the limit of a great Post-carboniferous disturbance, that may or may not have preceded the Cretaceous period, and has no ascertainable relation to the Cretaceous sea.

The consideration of the phenomena presented in these and other localities, leads to the conclusion that the Plateau is not a unit in history and origin, and that the only criterion by which it can be distinguished from the Range country, is the original superficial one of table and ridge. The plateau area has in part been longer and later submerged than adjacent regions, and in part exempted from the action of forces that threw up mountain ridges along its borders. It has not, however, been entirely exempt, and, differing from the Basin Range region only in the *degree* of disturbance, has not an absolute boundary. With this preliminary understanding, we will pass in rapid review the border land between the two provinces.

In the statement above, that the Wahsatch marks locally the shore of the Cretaceous sea, the story is but half told. The Cretaceous and Tertiary deposits, which rest against its eastern flank, and which have no counterpart in Utah Valley, are many thousand feet higher than that valley. In explanation of this, we cannot suppose for a moment that the mountain was an impassable barrier to the ancient sea. Not only is the local drainage of the plateau now directly across the range—via the deep gorges of Provo River and Spanish Fork—to Utah Valley, but the ancient Wahsatch ridge terminates abruptly southward in Mount Nebo, and leaves open communication between Utah Valley and the Tertiary basin. The plain meaning of the absence of the later strata in that valley and the great area west of it, is that these regions were above water at the time of their deposition. The Wahsatch and the country immediately east of it have been elevated, relatively to the adjacent portion of the Great Basin, not less than 4,000 feet since the drainage of the great Tertiary lake.

Concurrent with this general elevation, the plateau has been ridged by the formation of the system of faults described in the last section, and the lines of these later disturbances not merely run parallel to those of the Jurassic upheaval, but in places actually coincide with them. The Wahsatch range affords a case in point. South of Mount Nebo it is prolonged, with reduced proportions, as far as Gunnison; but the constituent strata are Tertiary instead of Paleozoic. The first elevation of the main range has been ascertained by King to have occurred at the close of the Jurassic period,* and we here find evidence that it was again lifted after the deposition of the lacustrine strata of the Eocene. Another example is afforded by the Pahvan range, which may, perhaps, be considered a southward extension of the Oquirrh. South of the great bend of the Sevier River it begins to show Tertiary (and perhaps Mesozoic) strata on its eastern flank, and near Holden, Fillmore, and Corn Creek they form the entire range, except the western foot-hills, resting unconformably upon Paleozoic rocks that were greatly tilted and eroded before their deposition. From Fillmore south their dip is uniformly eastward, correspondent to that exhibited in the successive parallel ridges at the east, until, a little beyond Corn Creek, they are lost to view beneath the great lava-field of the Sevier. The range is at this point the most westerly of the ridges bearing Tertiary deposits, but in the vicinity of Cedar City, where it re-appears from under the lava, the Tertiary passes beyond it to the Iron Mountain and Pine Valley Ranges. Throughout this region, from Mount Nebo to the Arizona line, there is a graduated mingling of characters, completely bridging over the interval from the plateaus on one side to the ranges on the other.

FIG. 33.—Section of Pahvan range, near Fillmore, Utah. Scale, 1-144000. Base line=level of Great Salt Lake. *a*, Tertiary; *b*, Cretaceous?; *c*, Paleozoic.

*Geology of the Fortieth Parallel, vol. iii, p. 3.

In Arizona the change is more abrupt. The plateau edge is a mesa of Carboniferous limestone, (chiefly the Aubrey limestone, but in part the Red Wall,) and the nearest Basin Range bears on its flanks these beds (or the Tonto sandstone) inclined toward the plateau. The valleys between are for the most part monoclinals, floored by the Tonto group, and contain the headwaters of Bill Williams Fork of the Colorado, and of the Verde and Tonto Creek, tributaries of the Salt River. The Grand Wash and the prolongation of the same valley south of the Colorado occupy a pseudo-monoclinal formed by one of the great north and south faults, (Fig. 30.) About Camp Apache is an exceptional tract, drained by the upper tributaries of the Salt River—the White Mountains, Carrizo, and Cibicu—belonging properly to the plateau, but deeply scored in every direction by cañons, resulting from local conditions of denudation, wrought by lava-flows, an account of which is given in the report of Mr. Marvine.

In brief, we may say that, as the Basin Ranges and Plateaus defy absolute definition, their common boundary must be left indefinite, and that the Jurassic and Tertiary systems of upheaval, coinciding in character and trend, can be locally discriminated only in the presence of intervening deposits.

SECTION IV.

GENERAL CONSIDERATIONS.

It remains to colligate the phenomena of the two provinces, and consider their relation to the general study of orology.

We have already been led to conclude that the forces which have produced the Basin Ranges were uniform in character over large areas, and in horizontal direction over minor, but still considerable, areas; that they have produced parallel ranges by nearly vertical upheaval; and that they were deep-seated. We have reached the same conclusions in regard to the forces which have produced the conjoint system of faults and ridges in the Colorado Plateau. We have also seen that the *loci* of the latter forces are in part coincident with those of the former. And a single short step brings us to the important conclusion that the forces were identical, (except in time and distribution;) that the whole phenomena belong to one great system of mountain formation, of which the ranges exemplify advanced, and the plateau faults the initial, stages. If this be granted, as I think it must, then it is impossible to overestimate the advantages of this field for the study of what may be called the embryology of mountain building. In it can be found differentiated the simplest initiatory phenomena, not obscured, but rather exposed, by denudation, and the process can be followed from step to step, until the complicated results of successive dislocations and erosions baffle analysis. The field is a broad one and its study has but begun; but with its progress I conceive there will accrue to the science of orographic geology a more valuable body of geological data than has been added since the Messrs. Rogers developed the structure of the Appalachians. Of late years the most important contributions have come from the physicists, and in their scales have been weighed the old theories of geologists. Here will be an opportunity to compare the speculations of the physicists with new geological data.

The Appalachian mountain system, as the best studied great system—at least of those which exhibit unity of structure—has formed the geological basis of many theoretical structures, although, as Professor Whitney has pointed out, it is rather exceptional than typical in its character. The system we have described resembles it in the absence of any great central axis and in the general tendency to uniformity throughout, but differs widely in other respects. In the Appalachians corrugation has been produced commonly by folding, exceptionally by faulting; in the Basin Ranges, commonly by faulting, exceptionally by flexure. The regular alternation of curved synclinals and anticlinals is contrasted with rigid bodies of inclined strata, bounded by parallel faults. The former demand the assumption of great horizontal diminution of the space covered by the disturbed strata, and suggest lateral pressure as the immediate force concerned; the latter involve little horizontal diminution, and suggest the application of vertical pressure from below. Almost no eruptive rocks occur with the former; massive eruptions and volcanoes abound among the latter, and are intimately associated with them.

To attempt the reconciliation of these antithetical phenomena is premature, before the characters of the Basin Ranges shall have received more thorough study than has been possible for us; and I do not desire to undertake here a discussion of theoretical orology, but I cannot forbear a brief suggestion before leaving the subject. It is, that in the case of the Appalachians the primary phenomena are superficial; and in that of the Basin Ranges they are deep-seated, the superficial being secondary; that such a force as has crowded together the strata of the Appalachians—whatever may have been its source—has acted in the Ranges on some portion of the earth's crust beneath the immediate surface; and the upper strata, by continually adapting themselves, under gravity, to the inequalities of the lower, have assumed the forms we see. Such a hypothesis, assigning to subterranean determination the position and direction of lines of uplift in the Range System, and leaving the character of the superficial phenomena to depend on the character and condition of the superficial materials, accords well with many of the observed facts, and especially with the persistence of ridges where structures are changed. It supposes that a ridge, created below, and slowly upheaving the superposed strata, would find them at one point coherent and flexible, and there produce an anticlinal; at another hard and rigid, and there uplift a fractured monoclinal; at a third seamed and incoherent, and there produce a pseudo-anticlinal, like that of the Amargosa Range.

CHAPTER II.

VALLEYS. CAÑONS. EROSION.

In the region of the Basin Ranges the valleys are residual; the mountains were uplifted in parallel lines, and the intervening troughs remained as valleys. In the typical Plateau country the reverse holds good; the valleys have been formed by erosion, and the tables are residual. Transporting agencies are still deepening the latter valleys, but have for a long time been engaged in filling the former. Their general classification thus corresponds very nearly with that of the mountains, and it will be convenient to describe them in the same order.

There is no evidence that the Range country has been beneath the ocean since the close of the Jurassic period, though it is impossible to say that the sea has not had access to some of its valleys since that time. Then began such of its ranges as had not earlier appeared, and since then they have been subjected to the unceasing play of atmospheric erosive agents, wearing away their summits, furrowing their flanks, and conveying their substance to the intervening valleys. A part of the eroded material—possibly the larger part—has been transported beyond the limits of the Range System, and contributed to the Cretaceous and Tertiary sediments at the east and west. Of the detritus that remained in the valleys, a portion may have been spread by the waters of estuaries connected with the Cretaceous sea, a portion was received by local bodies of fresh water, and the remainder has received such subaerial distribution as is now prevalent over the major part of the area. What may have been the original altitude of the ranges we have no means of knowing, but there is evidence, along the margin of the system, that their elevation was not all accomplished at once, and it is not impossible that progressive elevation and denudation, as they have opposed, have also measurably counterbalanced each other. Volcanic rocks have made important contributions to the filling of the valleys, both directly by floods of lava, and indirectly by their detritus; and they have been thrown as barriers across valleys, partitioning them off into minor basins. In this way the valleys have become floored by detritus of great and unprobed depth as universally as they are walled by mountain ridges.

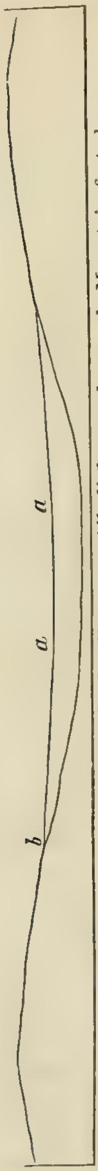


FIG. 34.—General section of an undrained valley. *aa.* Alkali flat or *playa.* *ab.* Mountain foot-slope.

FIG. 35.—General section of a drained valley. *ab.* Foot-slope. *a.* Arroyo.

Under the existing climate, many valleys and groups of valleys are undrained. In the most arid the meager rain-fall sinks into the porous soil, from which it is slowly evaporated by permeating air. On rare occasions a surplus of water accumulates in the lowest depression, and there evaporates on the surface, depositing its fine sediment and dissolved minerals, and producing a level, lake-like plain, the familiar "alkali flat," smooth and hard, if mechanical sediments prevail, but often pulverulent or pasty from the presence of efflorescent or hygroscopic salts. In more humid basins permanent streams are maintained, and the evaporation plain is replaced by a lake, beneath which the fine sediments are deposited, and in which the soluble salts are concentrated. The best watered regions send rivers to the ocean.

Of the undrained valleys the cross-profile is broadly U-shaped. From the base of the mountain on either side stretches a long talus, or foot-slope, comparatively steep at first, but gradually losing its inclination, and finally merging in the evaporation plain. From the drained valleys the plain is absent and the foot-slopes meet in V-form. The *débris* of the mountain is brought to its margin in gorges or cañons, from the mouths of which it is spread in broad, low talus-cones, which make up the foot-slope. The stream that flows from the cañon, whether transient or perennial, distributes the detritus over the cone by shifting its bed from time to time as the sediments clog it. As the cañon wears deeper at its mouth, and the stream discharges at a lower level, the upper portion of the cone is excavated and a new one modeled with lower apex and lower grade. In a general way, the coarsest material remains nearest the mountain, and the finer is farther removed, but the sorting is very imperfect, and heterogeneity is a characteristic of the gravels. Where limestone abounds in the constituent pebbles, they are commonly cemented, a little below the surface, into a firm conglomerate.

The principal deserts of the province are relatively depressed regions, marked by excessive accumulations of detritus, which have so filled the valleys as to connect them in a continuous plain, beneath which the minor ranges are completely buried, and through which the peaks of the more lofty jut as islands. In the Colorado desert, Mr. Blake and Dr. Newberry found abundant evidence of the agency of lacustrine waters in the formation of the plain,* and the Gila Desert, which communicates with it, is floored by a nearly level plain of gravel and sand, from which the insular ridges—"lost mountains"—spring with an abruptness that testifies to wave action along their bases. No persistent mountain chain divides the latter plain from the ocean, and it rises but little above the sea level. There can be little doubt that it has been covered at some time since the creation of the mountain system by the waters of an estuary, and that the ocean level has been the efficient barrier to the further transportation of the detritus here accumulated; but of its chronology nothing definite is at present known.

The Great Salt Lake desert occupies a depressed portion of the Range area, due to broad, general undulations, that have no discernible relation to the orographic corrugation of the surface, except that they co-exist, as do a long ground swell and the wavelets of a rising breeze. East and west of the desert the ascents culminate in the Wahsatch and Humboldt Mountains. Northward a general elevation of the ranges and intervening valleys along parallels 43° and 43° 30′ separates the plain of the Upper Snake River. One hundred and fifty miles farther south a similar line of uplands, including the Onaqui, Thomas, House, and other ranges, divides the Salt Lake from the Sevier desert. The lowest part of the included depression has been filled with a sea of detritus, until some of its ranges are completely submerged and others protrude only insular buttes to mark where they are

* Pac. R. R. Repts., vol. v, Geol. Rept., by W. P. Blake, p. 235. Colorado Expedition, Geol. Rept., by J. S. Newberry, p. 17.

sunk. If these hidden mountains rise as high above their bases as do their neighbors on the rim of the basin, we may, by comparing summits with summits, learn something of the relative depression of the rocky bottom of the basin below its margin; and it would appear, judged in this manner, to be not less than 4,000 feet. And, on the same supposition, the desert sediments, which, before burying the mountain ridges, have filled the intermediate valleys, may have a maximum thickness of 5,000 or 6,000 feet. Their upper surface, water-laid and smooth, is the broad floor of the desert, from which arms stretch north and south, between the fringing mountains. In longitude the plain measures a little over a hundred miles, and in latitude a little less. Its general level is about 4,200 feet above the ocean, and Great Salt Lake probably occupies its greatest depression, though lying close to its eastern border. Its surface material is a fine, adhesive, absolutely sterile clay, charged with chloride of sodium and other soluble salts, the deposit from the last expansion of the waters of the lake, an expansion so recent that the beach-lines formed at its culmination and during its slow subsidence are perfectly preserved on the shores of the desert. In another chapter these phenomena will receive fuller description, and attention will be called to their relation to the glacial epoch.

The eccentric position of the lake is evidence of the novelty of the present relation of altitudes of different portions of the plain, which is far from an equilibrium. Nearly the whole present increment to the desert floor comes from beyond the Wahsatch Mountains, and is deposited in the deltas of the Jordan, Weber, and Bear rivers, on the eastern margin of the lake. Since the lake has no outlet, but parts with its surplus by evaporation, its area rather than its level tends to constancy; and, as the eastern shore increases, the water will rise, *pari passu*, and encroach on the western. The continuation of this process, if there is no counter influence, such as a secular depression of the lake basin, will push the water, in a few thousand years, to the western side of the desert.

The Sevier Desert is of comparatively small extent, and is less sterile and arid. The Sevier River runs completely across it from northeast to southwest, and carries enough water to maintain a lake with one-tenth the evaporation surface of Great Salt Lake. The eastern portion of the plain is floored with basalt, in the hollows of which are a number of fresh and brackish lakes. The altitude of its general surface above the ocean is 5,000 feet, and of Sevier Lake, which occupies its greatest depression, 4,600 feet. The water of the lake is charged with salt, but in less degree than that of Great Salt Lake. No living thing was seen in it save *Artemia*, but the larva cases of dipterous insects floated on the surface and lay heaped upon the beach. Along the storm line, too, are dead fishes and fluviatile shells, and beaver-gnawed willows, all of which have floated from the river. The odor of these decaying organisms, though very like the "perfume of the sea," is over strong, and renders the shore as repulsive as it is desolate.

A portion of the valleys of the Plateau country, and especially those of the upper Sevier, are, like the troughs of the Range region, structural, and lie between the monoclinal ridges produced by the system of faults described in the last chapter; the remainder are valleys of erosion, and include the cañons for which the region is renowned.

The cañons of the Colorado and of its tributaries, and the country which they intersect, are unsurpassed as a field for the study of river denudation. Not merely do they exhibit the grandest and most impressive results, but they show the agent by which they have been wrought, still in vigorous activity; and the conditions that have guided denudation and determined the resultant forms, are there so little complicated that they may be differentiated and analyzed.

At the mouth of Paria Creek, the Colorado leaves the sandstones of the Trias, through which it has meandered for many miles in a narrow cañon, emerges for a short space into full sunlight, while it crosses the marls at the base of that formation, and then begins its descent into the Carboniferous and underlying rocks, which wall it in through Marble and Grand Cañons. In these gorges the river has no flood-plain. It is a well recognized fact in the natural history of rivers that their first work of erosion, where they have rapid fall, is upon their beds, and that it is only when they have so far reduced their grades as to greatly diminish their transporting and cutting power, that they begin wearing their banks and widening their channels, so as to render flood-plains possible. The Colorado is here devoted to the deepening of its valley, and occupies its whole width from wall to wall so completely that where the shore is of massive rock it is often difficult to find foot-hold at the water's edge. Were the entire wall from top to base of durable rock the chasm would indeed be as gloomily abysmal as it has been sometimes represented,* but there is an alternation of hard and soft strata, that serves to terrace the cliffs on a grand scale. In every profile of the cañon the positions of the hard, massive beds are marked by precipices, and of the soft by slopes. With infinite slowness the latter are disintegrated by the action of the weather, the former are undermined, and the upper cliffs are caused to recede from the margin of the river. The stream in descending through the strata is walled at its edge alternately by cliffs and slopes, and each cliff begins its recession when the river, in deepening its channel, cuts below it into the softer strata. Where the cañons are deepest and oldest, there they are broadest at top; and the recession of the uppermost terrace measures the same interval of time as does the depth of the cutting at the same place.

In each of the accompanying sections of the cañon the widths and depths are given in the same scale, so as to present, as nearly as possible, the true proportions of the chasms. In Figure 36 the cañon proper is contained by the Aubrey limestone, and is a simple sluice, seven or eight hundred feet deep, with vertical walls. While the river has been cutting this narrow slot in the hard limestone, atmospheric denudation, working on the Trias marls, and undermining the Trias sandstone, (1,) has driven back the escarpment of the latter four miles from one brink, and still farther from the other. So soon as the limestone is passed, and the gypsiferous sandstone of the Aubrey reached, the undermining process begins at a lower level and the gorge opens to the form represented in Figure 37 and Plate II. At Kanab Creek, Figure 38, the Aubrey limestone has receded so far as to be visible from the water only at angles of the cañon, and the immediate

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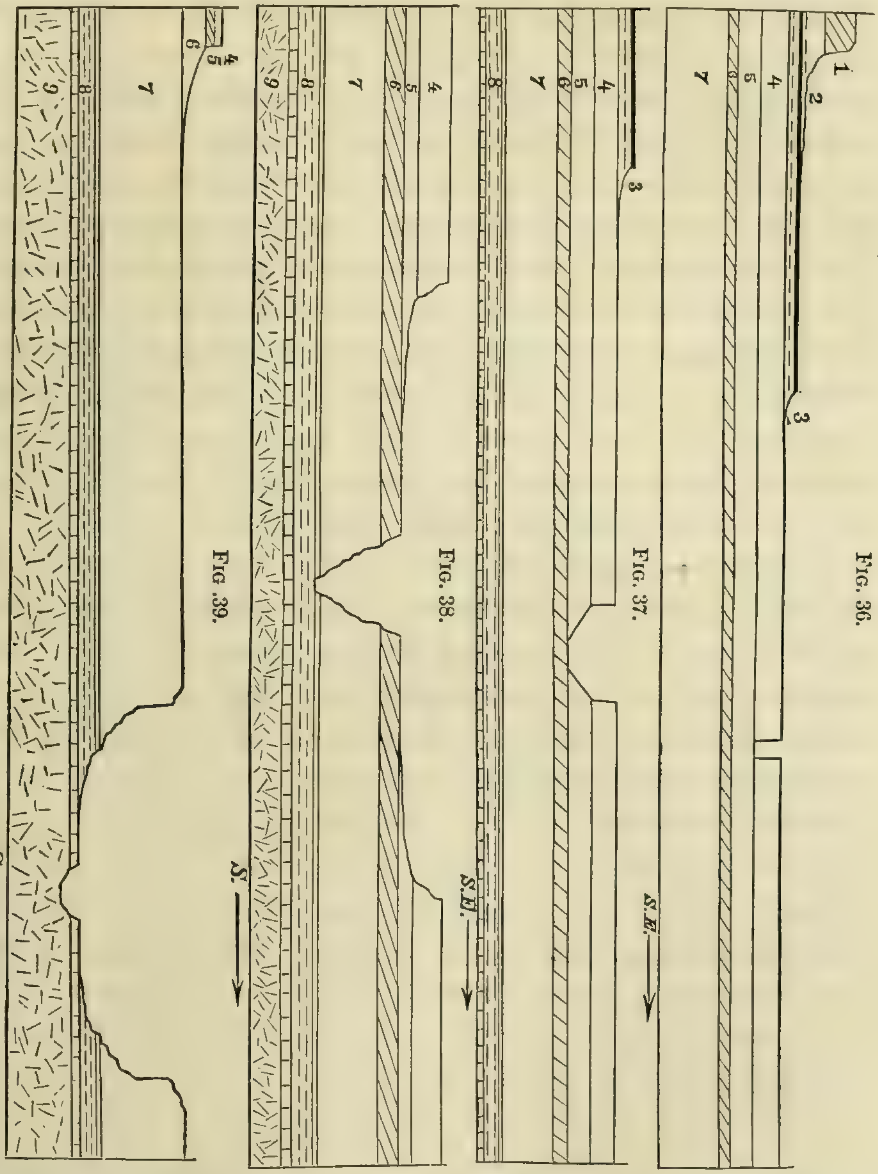
*The difficulty of presenting in a sketch the proper relation of vertical and horizontal spaces, in illustration of which Humboldt's drawings of volcanic cones have been so often quoted, is conspicuously exhibited in the representations of the Grand Cañon, given in Plates VI and IX of Lieutenant Ives' Colorado report. The inexorable camera has since been brought to bear on the scene depicted in Plate VI, and demonstrates that the cliff of granite, there adjacent to the water, and which presents in the engraving an acclivity of about 80°, has in nature an inclination of no more than 40°. A somewhat similar allowance is needed in the interpretation of the representation of the Black Cañon in the same volume. (Plate V.)

wall is of Red-wall limestone.* At Diamond Creek, Figure 39, the terrace at the base of the Aubrey has expanded to a width of three or four miles, the Red-wall limestone is in turn undermined by the soft Tonto shale, and



FIGS. 36–39. Sections of Marble and Grand Cañons. Scale, 1-72000. Base line = sea level. Fig. 36, Marble Cañon, near the mouth of Paria Creek; Fig. 37, Marble Cañon, ten miles lower; Fig. 38, Grand Cañon, at mouth of Kanab Creek; Fig. 39, Grand Cañon, at mouth of Diamond Creek.

1, Trias sandstone; 2, Upper Trias marls; 3, Shinarump conglomerate and lower marls; 4, Aubrey limestone; 5 and 6, Aubrey sandstones; 7, Red-wall limestone; 8, Tonto group; 9, granite and schists.

the river flows in Archæan rock—at this point granite. It chances that the sections which I am able to give from my own observations form an orderly

* The definition of this and other terms pertaining to the stratigraphy will be found in Chapter VI.

suite, in which the depth and magnitude of the erosion has an apparent relation to the descent of the river, being least in its upper course, and successively greater at lower points. The relation, however, is not constant, but is modified by the system of faults. If the reader will refer to Figure 26, which gives a section parallel in the main to this portion of the river, he will readily perceive the cause of the modification. The descent of the water is from right to left, and the line of section crosses the river at *M*, *W*, and *I*. The cañon sections may be referred to this one as follows: Figure 36, above *M;* Figure 37, at *M;* Figure 38, at *C;* and Figure 39, below *H*. Between *M* and *C* the plateau attains its greatest height, and the cañon its profoundest depth, cutting farther into the Archæan rocks than at Diamond Creek, and giving a maximum of erosion in the middle, instead of the lower end of the gorge. In the vicinity of the eastern fault of the Kaibab Plateau (*K*) Professor Powell found the gorge so broadly opened at bottom, as to lead him to distinguish the narrows above and below by the separate titles of Marble Cañon and Grand Cañon.

At Kanab Creek, the highest point at which I entered the Grand Cañon, the river runs in the upper part of the Tonto shale, here of firm texture. In Plate VII, which pictures it there, the walls at right and left are of limestone, including the Red Wall and Marbled, and they are capped by the lower Aubrey sandstone, which appears in the middle distance, while the most distant mesa shows the escarpment of the Aubrey limestone.

From the mouth of Diamond Creek to the end of the Grand Cañon, a distance of forty miles, the river washes only Archæan granites and schists, and the overlying Tonto sandstone; and to this portion of the cañon my own observations of its river-action were chiefly confined. With the boat party, headed by Lieutenant Wheeler, I ascended this portion of the gorge, and had my attention especially drawn to the rapids and other phenomena of erosion and transportation.*

The river in this part of its course has two functions—of transportation

* Besides the opportunities afforded by this boat-excursion, I entered the Grand Cañon at Kanab Creek, and examined Marble Cañon from above, near the Paria. Mr. Gilbert Thompson, of our topographical corps, kindly made some observations for me in the vicinity of the Uinkaret Mountains and Kaibab Plateau; and Mr. Bell's photographs from the former locality have afforded geological information.

and erosion—which it will be convenient to distinguish, though they are intimately interdependent.

The transported material is derived from several sources. That abraded from the bottom of the cañon is too insignificant in amount to demand more than mention.

What reaches the bottom from the immediate sides is of greater volume, but is chiefly noteworthy because it includes large masses which locally obstruct the channel and produce some of the most violent rapids.

Far more important and, in the work it entails on the stream, of the greatest importance is the detritus introduced through tributary cañons. Many of these are of very rapid fall, and are occasionally traversed by powerful torrents, which sweep down bowlders of great size—in some instances 10 or 15 feet in diameter—and heap them in the main cañon in dams, that must often be of great depth. Over each of these the water finds passage at the edge opposite the tributary, and descends the lower slope with swift current and broken surface; and thus arise the great majority of the rapids. To roll, jostle, break, and finally grind up and remove these bowlders is the task—perhaps the chief task—of the river, and until it removes them it can perform no work on the solid rock which underlies. In the V-form of the cañon, and in the fact, shortly to be considered, that the river does in places cross a bottom of bed-rock, there is evidence that downward erosion has not ceased; and we must suppose that, in the current cycle of events within the gorge, there are times when each of these dams in turn is removed. The torrents that bring and the torrents that destroy them depend on the rains of regions widely separated, and the former at least are notoriously variable; so that, while the dams will recur at the same localities and with the same characters, they cannot be regarded as strictly permanent.*

Yet another agent brings into Marble and Grand Cañons an amount of detritus even greater than do those that have been enumerated; namely, the

*No observations have been made on their fluctuations in the Grand Cañon; but in Black Cañon, where rapids bear the same relation to side washes, we have evidence of a change. Lieutenant Ives, ascending in 1858, encountered a rapid of such violence that he dignified it with a name, and mentioned it in his hydrographic report as the most serious obstruction to navigation in the cañon; but in 1871, with the same stage of water, I was unable, even with the aid of his map, to distinguish the "Roaring Rapid," so nearly equal in importance were several rifts in that vicinity.

river itself. From its thousand sources to the ocean the Colorado has no still reservoir to accumulate its sediment, and all that its upper waters detach must find its way, soon or late, through these cañons. The greater part of this material is reduced to the form of fine sand and mud before it enters, but some pebbles of tough crystalline rocks from remote volcanic regions are included. At no season is the water free from the red mud whence the stream derives its name, and the amount of detritus conveyed in time of freshet must be enormous.

This brings us to the consideration of the erosion performed by the river; for the tool by which it is accomplished is this very sand and mud, together with that produced by the trituration of rocks within the cañon. Hurried on by the swift water, it gnaws away whatever it touches. Nothing can resist the incessant impact of the fine siliceous particles, and the whole river-bottom, including both solid rock and bowlders, bears indisputable testimony to the mightiness of their work. Every exposed surface is polished at least, and the most salient faces are deeply and beautifully carved. Plate X gives an example of this sculpture, in which the material wrought is a homogeneous, fine-grained limestone—the Marbled limestone of the stratigraphic series—and the carved face lay nearly horizontal, the current crossing it from left to right, as indicated by the arrow. The specimen represented was broken from a slab three or four feet in diameter, that lay on top of one of the bowlder dams, and is a fair type of the carving in homogeneous material. The concave facets, of which the surface is composed, appear to be of the nature of paraboloids of revolution, the apices of which are turned up stream. In rocks of less even texture the surfaces are correspondingly irregular, and the greatest variety of pattern is developed on rocks of irregular form, which present faces at all angles to the current.

The rapid erosion to which these gouged surfaces testify I am disposed to regard as exclusively—or almost exclusively—the work of the fine detritus, propelled by the water just as the sand of the sand-blast is propelled by air, and accomplishing its result on precisely the same principle. The most rapid cutting is doubtless executed by the coarser sand carried by freshets; and the fine mud borne by quieter water, working in the same manner, but more delicately, produces the perfect polish that everywhere prevails. It is to be doubted whether pure water, or water with no mineral matter in mechanical suspension, has any appreciable erosive power. In the beds of streams of clear water, disintegration, if not due entirely to solution, at least depends so largely upon it that the surfaces of calcareous pebbles are covered by spongy films marking the depth to which the removal of the most soluble matter has extended. Under the muddy Colorado, however, erosion is so much more rapid than solution, that no traces of the latter are to be seen upon the rock surfaces. We may assign to the direct action of the water the transportation of detritus, and the solution of calcite and other minerals, after trituration, but the actual rock excavation is accomplished by means of the transported material.

Besides the evidences of erosion already described, there are numerous pot-holes drilled in the bed-rock of the river. They occur in a variety of materials, but are best developed in granite and cognate massive rocks. They are not of great size, averaging only 12 or 15 inches in diameter, but in some places are so thickly disposed that they fairly adjoin over considerable areas, to cross which one must step from crest to crest of the rocky partitions that divide them. In them are to be found the characteristic worn pebbles that have helped to bore them. On the steep river-walls were seen numerous natural sections of pot-holes, in places where the same vertical seam in the granite that at first determined their position, had finally cleaved away their outer walls, and left the inner fully exposed to view. In these sections are exhibted two type forms. The simplest is that of the chemists' test-tube, a cylinder slightly flaring at top, and terminated at base by a hemispherical cup. In the other form a round boss or knob rises in the center of the basal cup, and gives an emarginate outline to the vertical section, as shown in the diagram. The explanation of this peculiarity is not difficult. The pebbles and sand that bore the pot-hole are controlled by two forces; the gyratory motion of the water revolves them, and gives roundness to the

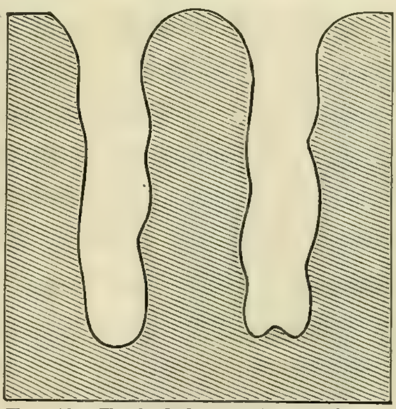


FIG. 40.—Typical forms of pot-holes in the granite of the Grand Cañon.

hole, and gravity keeps them at the bottom, and determines the vertical descent of the excavation. When the motion of the water is simply rotatory, centrifugal force will keep the grinding particles at the periphery of the base, and produce the emarginate form. Where, from the surging of the current above, much vertical movement of the water is combined with the rotation, the simpler form of bottom results.*

In addition to the rapids caused by bowlder heaps at the mouths of side gorges, and those produced by rock masses fallen from the immediate walls of the cañon, are others due to prominences of the solid bed, and upon them are displayed the finest river sculpture. At these points, certainly, the deepening of the cañon is still in progress, and, though they make up but a small proportion of the entire cañon bottom, they suffice to show that the torrent phase of the river is here not yet completed. There have been distinguished in rivers the torrent portion, in which the descent is comparatively rapid, and the bed is sinking by erosion into the subjacent rock; the river proper, in which the bed holds a constant mean level, and erosion is diverted to the increase of the width of the valley; and the delta, in which the bed is rising by deposition. The river phase is distinguished from the torrent by the presence of a flood plain, which commonly merges below with the delta plain. In the ordinary sequence of events, the delta slowly encroaches upon the river portion, and that upon the torrent. In the Lower Colorado there is an alternation of river and torrent conditions. The canals the river is cutting through the Virgin and Black ranges are far from complete, but they progress so slowly that the stream in the intermediate valleys, where it encounters nothing more obdurate than gravel, assumes the true river phase. Below the Black Cañon there is the same alternation, but less pronounced, and an equilibrium has nearly been reached.

* It is worthy of mention, in this connection, that the great ancient pot-holes near Cohoes Falls, New York, are all, so far as examined, spheroidal at bottom. They are grouped on a *moutonnée* surface, and are referred by Prof. L. Agassiz (quoted by Prof. J. Hall in the twenty-first report of the New York Regents, p. 105) to cascades falling through crevasses in a glacier. The views here advanced as to the origins of the different forms tend to confirm Professor Agassiz's hypothesis. Moreover, the excavations produced by the Colorado, with its high-water depth of 50 to 100 feet, and descent of 5 to 20 feet to the mile, are, after making all allowance for the difference of rock, of the most insignificant size, as compared with the mighty cisterns of the Cohoes Plain.

As the work of denudation in the Grand and Marble Cañons progresses, and the river sinks deeper below the plateau, there will accompany a gradual diminution of the inclination of its bed, of the velocity of its current, and, in consequence, of its erosive power, until finally it can no longer clear its bottom of introduced detritus, and, its downward progress being arrested, the widening of its channel will begin. Of the time that will elapse before this consummation we can form little conception, but it can hardly be less than that consumed in the excavation already accomplished, so slowly will the work proceed as it approaches completion. Of the time already consumed we may some time have an approximate estimate in years, for so rapidly does the sand carve away the rock, that I believe it perfectly feasible to ascertain its rate by observation, and, by considering what part of the rock-bed is exposed and what protected, to assign, within reasonable limits, the present rate of degradation of the cañon. To pass from this to the average past rate would require the consideration of somewhat involved conditions, and the result would not be so satisfactory as that obtained from the secession of Niagara Falls, but it would be of great interest to obtain even a crude estimate in centuries of a period of time commencing, as I believe, before the close of the Tertiary age.

Throughout the cañons there are no cataracts; that is to say, at no place does the river fall from a ledge of rock into a pool below. Professor Hall has shown that in the future of Niagara there will come a time when the fall can no longer be maintained by the undermining of the limestone from which it leaps and will be replaced by a rapid. In the Grand and Marble Cañons this stage has been reached, and the whole descent of 1,600 feet accomplished entirely by rapids. The stratigraphic conditions to the formation of a cataract are indeed not wanting. The Cherty limestone near the mouth of Paria Creek is as massive as the Niagara limestone at Niagara; the underlying Aubrey beds are as soft as the Niagara shales, and their dip is up stream. So, too, with the great Red Wall limestone and the Tonto shales below. But the river passes the hard beds and the soft with almost equal pace.

Of the tributaries of the Colorado, Paria Creek, Kanab Creek, and the principal forks of the Rio Virgen rise in the Tertiary and Cretaceous escarpments, and descend southward through Jurassic and Triassic and (except Paria Creek) through Carboniferous strata. Kanab Creek alone has its geological descent uninterrupted; the others are intersected by folds, which cause them in portions of their courses to rise in the strata. The data are not at hand for a full description of either stream, but a few points will be noted especially pertaining to the phenomena of denudation.

Paria Creek.—It has already been remarked, in speaking, in the last chapter, of the great flexed faults, that Paria Creek, near its mouth, follows the anticlinal portion of one of these double flexures. While my observations were not sufficiently extended to place the matter beyond doubt, they tend to show that the flexure determined the course of the creek, and must itself have been of earlier origin. At its mouth the creek runs in the variegated shales at the base of the Trias, and has so far washed them away as to give space for a few acres of arable alluvium. By the undermining of the shale the cliffs of the superior sandstone are carried back so as to open between them a valley half a mile in width. Ascending the stream-bed, however, Lieutenant Marshall rose above the shale, and found himself walled in by vertical precipices of sandstone, of great height, between which the entire interval was frequently occupied by the stream. Thirty miles above, where the west fork of the creek crosses the same sandstone, (lifted by the East Kaibab fault,) a broader opening has been produced, and the cañon walls are separated by a bottom several hundred feet in width.

Kanab Creek traverses box cañons in two portions of its course, the first where it intersects the Gray and Vermilion Cliffs, (Trias;) the second, where it descends through the Carboniferous series to the Colorado. In the interval it crosses a broad plain, floored by the variegated marls. At ordinary stages the stream is in part subterranean, sinking in the sand of its bed, to re-appear when a ledge of rock rises to bar its way. Its general direction is remarkably straight, and is, in one part at least, determined by a fault, the throw of which is to the west, and does not exceed 200 feet. Traversing the same rocks, and intersecting the fault at a wide angle, are a system of parallel vertical joints, and the combined influence of these on the erosion of the Creek Cañon has produced a curious and very interesting result. The fault is of the flexed order, and runs close to the east wall of the cañon, the erosion appearing to have begun along its western or synclinal edge. In descending from the table, the stream encountered first a massive limestone, nearly 300 feet in thickness, then 150 feet of softer calcareous and gypsiferous beds, and then a second heavy bed of limestone. Through the upper limestone the cañon is about 500 yards broad, and of remarkably rectilinear course, the result apparently of its direct dependence on the straight fault; but, in wearing through the lower limestone, the stream has been greatly influenced by the joints, and follows them from side to side of the main valley, producing a narrow, serpentine cañon within a broad, straight one. The photograph, reproduced in Plate VI, was made for the purpose of exhibiting these features. The camera was placed near the base of the upper limestone, on the western side of the cañon, and directed southward, or down stream. The fault, which would otherwise appear at the extreme left of the view, is concealed by the haze. Further south, the creek cuts down into the Aubrey shales, the limestone walls diverge, and the cañon acquires the form represented in the view, Plate II, of Marble Cañon. Still further, it descends through the Lower Aubrey sandstone and Red-Wall limestone to the Colorado, meandering in the latter bed through a defile so deep and narrow, that our photographer hardly found light enough to picture it. Its majestic gray walls, rising almost vertically to a height of more than 2,000 feet, impressed us more with their grandeur than their beauty, and we gladly exchanged them for a more open country, with a broader arch of sky.

In its upper course, the east fork of the Virgin River follows the line of the great Sevier fault, and, though overhung at the east by a wall of Upper Trias sandstone, has opened its channel in the coal-measures of the Cretaceous system. Restrained by the resistance of the sandstones through which it has cut its progress southward, it has found time to excavate, in the soft Cretaceous shales, a narrow, fertile valley, in which repose the secluded Mormon towns of Mount Carmel and Glendale, (see Fig. 25 *k*.)

The north fork has, in a similar manner, opened a valley in the Cretaceous, but too narrow for cultivation. From the foot of this valley to the hamlet of Little Zion, the stream traverses, in the most wonderful defile it has been my fortune to behold, the massive sandstones of the Gray and

Vermilion Cliffs, here combined in a single undistinguishable body, certainly not less than 2,000 feet in depth. At the head of "The Narrows" the top of this bed is at the water's edge; and, as the strata rise, and the stream descends southward, the height of the cañon-walls gradually increases, until it includes the entire mass of sandstone. At the water's edge the walls are perpendicular, but in the deeper parts they open out toward the top. As we entered and found our outlook of sky contracted—as we had never before seen it between cañon cliffs—I measured the aperture above, and found it 35°. We had thought this a minimum, but soon discovered our error. Nearer and nearer the walls approached, and our strip of blue narrowed down to 20°, then 10°, and at last was even intercepted by the overhanging rocks. There was, perhaps, no point from which, neither forward nor backward, could we discover a patch of sky, but many times our upward view was completely cut off by the interlocking of the walls, which, remaining nearly parallel to each other, warped in and out as they ascended. For a number of miles the bottom of the cleft averages 30 feet in width, contracting frequently to 20, and in many places is entirely occupied by the stream, even at its low stage. Near the head of the cañon it is covered by sand and bowlders of sandstone, worn and fallen from the walls, and these continue throughout; but at a certain point a tributary gorge from the west brings in basaltic bowlders from some extinct volcano on the mesa above, and they abound to the end of the gorge. The superior toughness of the basalt enables it to withstand the shocks that rapidly crush the sandstone, and, though its supply must be far less, its rounded bowlders almost exclusively pave the river-bed for many miles. The course of the gorge is exceedingly tortuous, and, though our general direction in traversing it was southward, we yet journeyed toward all points

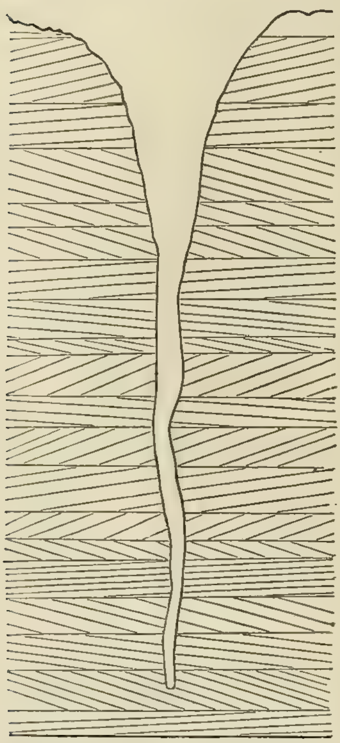


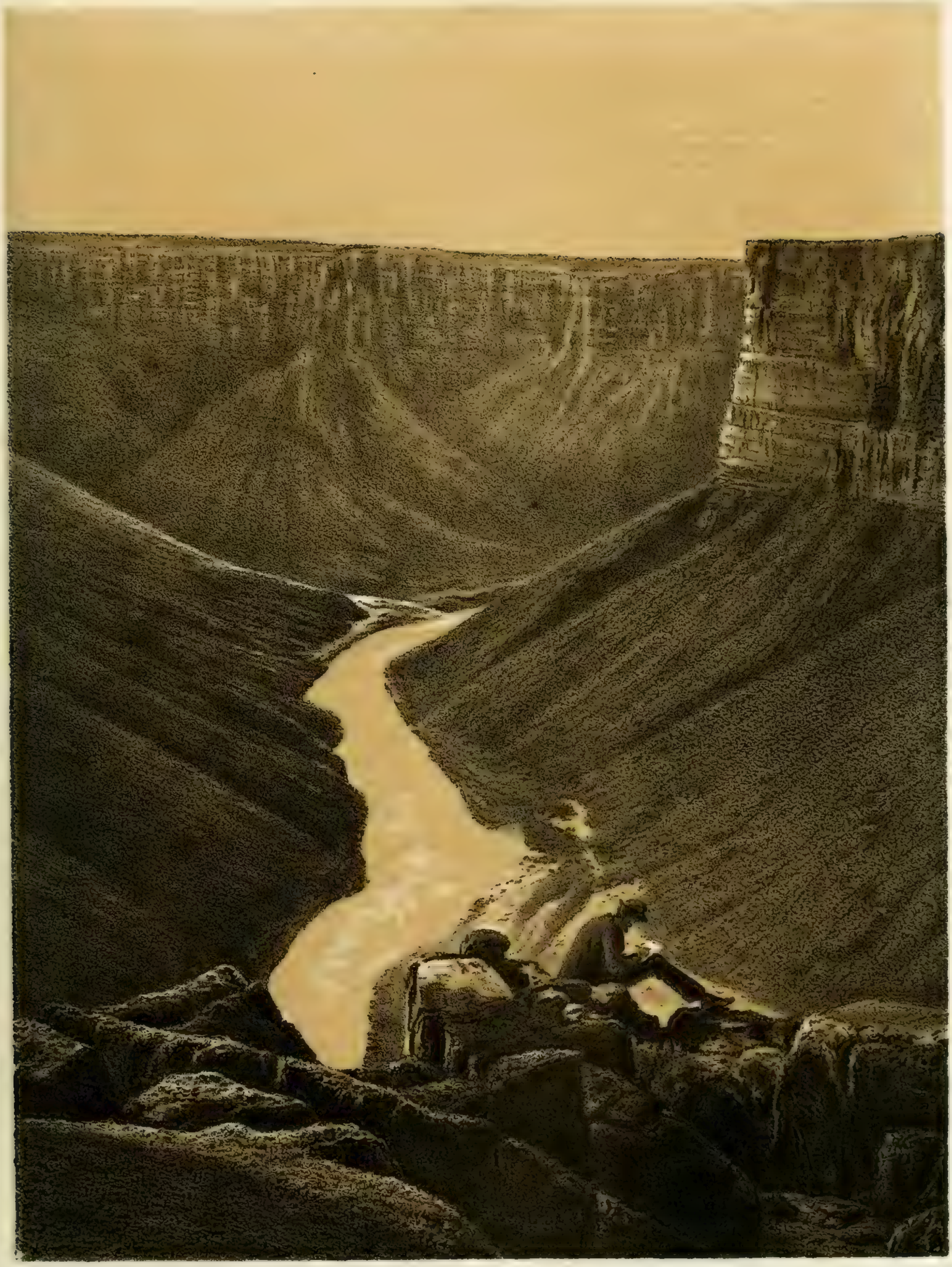
Fig. 41.—Section of the cañon of the North Fork of the Virgin River. Scale, 1-7200.

of the compass in turn, our view in advance being usually limited at a few rods' distance by an angle. The side cañons all partake of the character of the main, but, being worn by smaller streams, are narrower, and their bottoms are of steeper grade. Many of them at their mouths are not cut so deep as the one we followed, and discharge at various heights above the river. These illustrate the perfect continuity and integrity, beneath the cañon beds, of the sandstone that forms their walls—a continuity that cannot be seen in the main cañon, since its bed is everywhere covered by detritus. As a monument of denudation this chasm is an example—and a peculiarly differentiated example—of downward erosion by sand-bearing water. The principle on which the cutting depends is almost identical with that of the marble-saw, but the sand grains, instead of being imbedded in rigid iron, are carried by a flexible stream of water. By gravity they have been held against the bottom of the cut, so that they should make it vertical, but the current has carried them, in places, against one side or the other, and so far modified the influence of gravity, that the cut undulates somewhat in its vertical section, as well as in its horizontal. The diagram represents an extreme but not exaggerated case of this departure from verticality, and, at the same time, shows the relation of the depth to the width of the cañon, where it is narrowest. The form at top is necessarily hypothetical; from our subterranean position we could form little idea of it.

Upon this line of section, the transition from the massive sandstone to the variegated marls below is gradual, leading to a slow opening out of the cañon at its mouth; and the river in Little Zion Valley still flows between its beetling walls before passing finally beyond the limits of the sandstones.

Diamond Creek.—At the mouth of Diamond Creek center four valleys of denudation, whose relation to the structure of the Plateau is very interesting. Two of these valleys are occupied by the Colorado and are portions of the Grand Cañon; that is to say, the river turns here abruptly at a right angle, and its two courses appear to have been determined by distinct causes. The third valley is the cañon cut by Diamond Creek, and is a prolongation eastward of the lower course of the Colorado. The fourth is that of Peach Spring wash, and prolongs southward the upper course of the Colorado. No perennial stream follows it to the river, and it is but twenty miles in length; yet it affords an easy descent to the bottom of the Grand Cañon, and is entirely exempt from the precipices that render Diamond Creek and other cañons impassable. It is, indeed, the only valley tributary to the Grand Cañon, through which a wagon road can readily be made. This character, and its remarkable straightness—I refer to its general course, and not to its details—are due to the fact that it was primarily determined by a fault. On a preceding page may be found diagrams (Fig. 31) of this fault; its throw is to the west, and the amount of dislocation near the river is about six hundred feet. Its strike is north 25° east. For a few miles at least it is included in the upper course of the Grand Cañon, and, as I looked down Peach Spring wash, and commanded with my eye a long vista of the cañon beyond, I was strongly impressed with the idea that the dislocation which determined the one, had also marked out the other for a great distance. Later geographical determinations show that from the neighborhood of the Uinkaret Mountains to the mouth of Diamond Creek, a distance of thirty miles, the general direction of the cañon is straight and coincident with the observed trend of the fault. If what now appears probable shall hereafter be demonstrated—that the cañon for a long distance follows closely the line of faulting—the necessary deduction that the fault antedates the beginning of the cañon will be an interesting addition to the chronology of the river.

The identity in direction of Diamond Creek with the lower course of the Grand Cañon is not a mere coincidence, but depends on their common relation to the Plateau structure. The Aubrey Cliff, which crosses Arizona in a northwest direction, here intersects the Colorado. Since the general dip of the strata is to the north, and the escarpment is due merely to their unequal denudation, there lie, at the foot of the escarpment, a series of monoclinal valleys, of which the Tonto Basin, the Upper Verde Valley, and Aubrey Valley are examples. Diamond Creek runs, in like manner, parallel to the cliff, and differs from the others only in having excavated a deep gorge, which the low level of its discharge enabled it to do. The same Aubrey Cliff that follows its northern or northeastern margin re-appears beyond the Colorado, and, for forty miles, bears the same relation to the lower course of the Grand Cañon, leading to the belief that the stream was here



MARBLE CAÑON

COLORADO RIVER.

guided, at the first, by the monoclinal valley, and that the Aubrey Cliff, as a topographical feature, is more ancient than the Grand Cañon. The cliff now rises from three to five miles back from the brink of the cañon, and may be supposed to have retired to that position by slow waste during the excavation of the cañon.

Of the immensity of the denudation that has reduced the Plateaus to their present condition, we have unmistakable, and at the same time unexpected evidence, in the existence of insular masses of strata, remote from the mesas of which they once formed part. The most important of these are found between the Shinarump and Aubrey Cliffs, and consist of limited tables of Triassic rocks, resting on the broad Carboniferous floor, and surviving the general destruction in virtue of protective mantles of lava.

Mr. Marvine observed a number of outliers of the variegated marls southwest of the Colorado Chiquito, near Sunset Tanks, and there is reason to believe that San Francisco Mountain, distant forty miles from the Triassic mesa, contains an outlier of its sandstone. The evidence in this latter case is not very full, but, taken in connection with the other facts enumerated, can hardly be mistaken. On the northern and eastern flanks of the peak I observed outcrops of cross-bedded orange sandstone, resembling, lithologically, portions both of the Upper Aubrey sandstone, and of the Triassic sandstone series, but occurring 1,000 to 1,200 feet higher than the nearest compared exposures gave reason to anticipate the discovery of the Aubrey sandstone; the outcrops are completely circumscribed by volcanic materials, on one side the peak itself, and on the other the chain of later lava and cinder cones that surround its base. The nearest exposure of determined strata is ten miles distant,

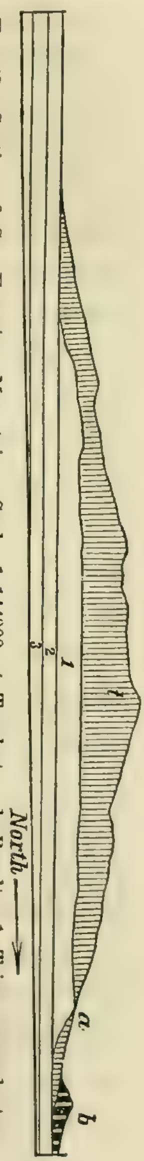


Fig. 42.—Section of San Francisco Mountain. Scale, 1–144000. *t*, Trachyte; *b*, Basalt; 1, Trias exposed at *a*; 2, Aubrey limestone; 3, Aubrey sandstone.

at Antelope spring, close to the southern base of the mountain, and consists of the upper portion of the Aubrey limestone, undisturbed, and dipping gently to the north. Dating from this point and making due allowance for dip, the thickness of Triassic strata included in the mountain appears to be 700 feet, with the top undetermined.

If a line be drawn to connect these several islands, and be compared with the line of the present Triassic outcrop, the included area will be found to approximate 10,000 square miles; and from all this the Lower Trias has been denuded since the eruption of the older lavas of the Uinkaret and San Francisco groups. The geological date of these eruptions we have no means of knowing, further than may be surmised from the fact that in the Upper Sevier country great floods of very similar lava have risen through and overrun lower Tertiary deposits. How much further the Triassic strata extended, we cannot conjecture.

The Cretaceous and Tertiary series, which were deposited conformably above an even floor of Jurassic strata, cannot be supposed to have thinned rapidly southward, yet they have been so far excavated, that their escarpments aggregate no less than 5,000 feet.

Natural sand-blast.—In the discussion, above, of the erosion of the Grand Cañon, the idea has been advocated that the transported detritus is the efficient tool, wielded by running water, in excavating its bed. To the same general purport are a variety of phenomena, illustrative of the efficiency of dry sand as an erosive agent, when borne by the wind. The subject is by no means a novel one, and has been touched by numerous writers, especially since the invention of the sand-blast. Some of the phenomena at the West have been described by Newberry, Blake, and Antisell, in the Pacific Railway Reports. My own observations have included so many additional data of the same character, that I am disposed to attach considerable importance to this agent of terrestrial denudation. In humid regions the traces of its action are seldom seen; partly because dry, volatile sands are of infrequent occurrence, and partly because their traces upon rock surfaces are obliterated by the more rapid wasting accomplished by decomposition and solution. But in arid climates, where the power of frost is greatly lessened, and vegetation does not suffice to protect the soil from the wind, sand and dust are in almost continual motion, and the cumulative effect of their incessant impact is not merely appreciable, but even important. In passes and contracting valleys, where the wind is focused, and its velocity augmented, the most conspicuous results are to be seen; but no inconsiderable work is accomplished on broad plains, where its normal force only is felt. Blake and Newberry observed that in the Colorado desert the pebbles were etched by drifting sand, and our examinations have detected the same phenomena in the Gila and Amargosa deserts, and other broad valleys. The most perfect work of this character that has fallen under my observation, is on a broad gravel mesa sloping gently toward the Colorado River, just below the mouth of the Virgin. The surface of compacted sand and gravel is hard, smooth, and even, and upon it are thickly strewn loose pebbles, shaped by the drifting sand. Hard, homogeneous stones, as quartzite and chalcedony, are rounded and highly polished, as though by collision in running water; crystalline rocks, as basalt and trachyte, are unevenly worn, the harder crystals maintaining prominences; and limestones are carved, with a net-work of vermicular grooves, into the most beautiful arabesque designs, (Plate IX.) The dust that results from this attrition flies off with the wind, and ultimately finds its way to the playa of some desert, or to some water-course, that carries it to the ocean. Slow as is this process, there can be no question that it is wearing away the mesa; the pebbles that now strew its surface, will, in time, be completely dissipated, and others will be dug from the valley below to take their places. Such wearing cuts no cañons, and leaves no grand monuments of the magnitude of its results, but it is nevertheless a true denudation, applied to broad areas, and, where water is deficient, is no inconsiderable factor in the sculpture of the land. The broad belts of cross-bedded sandstone that are exposed where the Lower Aubrey bed caps the second terrace of the Grand Cañon, and the still greater areas on the Vermilion mesa, are traversed by drifting sand, and probably owe much of their sculpturing to this agency; though it is not easy to distinguish, there, its work from that of frost. As a rule, their denudation has progressed with the most conspicuous irregularity, and their numerous prominences are carved in fanciful and grotesque forms.

At the head of Black and Bowlder Cañons, and at the foot of Monument Cañon, the configuration of the surface so modifies the winds as to give them especial violence, and their achievements are correspondently conspicuous. In the first locality, on an exposed spur of the hill to which Lieutenant Ives gave the name "Fortification Rock," are examples of sand sculpture, little, if any, inferior to those displayed on the bed of the Colorado. Bowlders of basalt and trachyte, gradually weathering from the gravel of which the hill consists, are here subjected to a natural sand-blast of great power. The wind, confined by the hills, has locally but two directions—directions exactly opposed to each other—and these are conspicuously portrayed by the carving. In the larger of the basalt bowlders represented in the illustration, (Plate VIII,) a point near the left margin faces the prevalent wind, and from it eroded grooves radiate over the convex surface; and the course of the blast, as it whirls around its edge, is finely shown on the stone at the right.

Just below the mouth of Paria Creek, and thence along the bases of the Shinarump and Vermilion cliffs, nearly to House Rock spring, similar carving may occasionally be seen, but it is poorly preserved by the friable sandstone, upon which it is executed. From Paria Creek to Rocker Creek, a large share of the excavation of the lower cliff is performed by wind and sand. Wherever a fragment of the Shinarump conglomerate, which caps the cliff, falls to the base, it is at once attacked. The wind, deflected by it, has exceptional force at its margin, and scoops away the underlying shale about its base. Moreover a greater amount of sand is drifted close to the ground than higher up, and the base of the block is eroded more rapidly than the top. It results, in time, that the block, now smaller below than above, becomes perched on a pillar of shale, and, as this gradually grows more slender, is finally completely undermined, and tumbles over, only to renew the process at a lower level, (Plate XI.) Where the wind is least restricted, the base of the cliff is swept almost entirely clean of bowlders, and the shale moulded in smooth graceful curves: as, for example, on the south side of Chocolate Butte, (Frontispiece,) an outlier of the Shinarump mesa.

Rain-sculpture.—In Plate I is represented a very peculiar style of sculpture, executed by rain in half-consolidated sands and conglomerates, and in the softest water-rhyolites. The material, in this instance, is a local sand and gravel deposit, at the eastern base of Mount Nebo, Utah. Similar fluted escarpments are to be seen at numerous localities in Nevada and Arizona, as well as in Utah; but in more humid regions I am acquainted with none of purely natural origin. Steep earth-slopes, laid bare in railroad cuttings, are sometimes carved, by the rain, in similar fashion; but the frost soon destroys its work. In the dry air of our desert States and Territories, however, a steep escarpment rarely remains saturated with water long enough to be disintegrated by freezing.

It is in the presentation of such subjects as this that the camera affords the greatest aid to the geologist. Only with infinite pains could the draughtsman give expression to the systematic heterogeneity of the material, and at the same time embody in his sketch the wonderfully convoluted surface—so suggestive of the folds of heavy drapery. But to photography the complicated is as easy as the simple; the novel, as the familiar. The negative once secured, the observer may at any time, and at his leisure, restudy the view, of which a hurried visit has given him but a first impression; and, more than this, he is enabled to publish its lesson, or its story, with the vividness that pertains to all graphic illustration, and with a guaranty of accuracy afforded only by the work of the sun.

CHAPTER III.

THE GLACIAL EPOCH.

We have seen in the last chapter that the valleys of the Basin Range system are filled to a great depth by detritus from the adjacent mountains. Our knowledge of these deposits is eminently superficial, no thorough section having been discovered. Some of the coarser gravels, resting against mountain-flanks, have been excavated and exposed to the depth of a few hundred feet, where the streams that spread them have so far deepened their mountain channels as to discharge at lower levels, and begin the destruction of their own deltas; and the Colorado River, between Bowlder and Iceberg Cañons—near Callville, Nevada—has cut the valley beds to a depth of five or six hundred feet; but none of these partial sections reveal anything else than half-sorted gravels and saline clays and sands, such as are now gathering along the margins and in the *playas* of other arid valleys. The beds have afforded no fossils, and we can say of their antiquity only that their deposition commenced before the Colorado had carved its cañons.

The unruffled repose of all such unconsolidated beds in Nevada and adjacent Utah, is proof positive that no general glaciation has prevailed. It is impossible that ice-floods should have invaded their domain, without molding them into the most impressive and conspicuous glacial monuments; but all their forms and conditions point to their quiet distribution by running water, aided locally and occasionally, as we shall see, by the agency of lakes. Adding to this the merely negative fact that no glacial striae, nor other trace of glaciers in the Basin Range troughs, have been found, though experienced eyes have looked for them, we may conclude, without reservation, that the great ice-field of Eastern North America had no counterpart in the same latitude at the West.

The climate of the West was not, however, unaffected in the Glacial epoch, and there is abundant evidence of a change similar in kind to that which occurred at the East. To this evidence our explorations have made some contributions, and to present these, and point out their general relations, is the purpose of the present chapter.

Local Glaciers.—Although the valleys which separate the mountains of Nevada and contiguous territory were not flooded with ice, yet glaciers formed about the crests of the highest ranges, and their traces have been discovered even farther south than they are known on the eastern coast. The ancient glaciers of the Sierra Nevada, described by Prof. J. D. Whitney, in the Geology of California, extended nearly to Walker's Pass, in north latitude 36°.

They occupied large areas on the loftier portions of that range, and stretched long arms toward its base, but were strictly local in character. Northward, on the Cascade Mountains, Dr. J. S. Newberry noted glacial striæ at so low an altitude as 4,450 feet,* and at Puget Sound begins the system of fiords, which, along the coast of British Columbia and Alaska, mark the extension of the ice to the ocean—or at least to regions that are now washed by it. On the Rocky Mountains the southern limit has not been ascertained, but moraines of considerable magnitude were observed in the South Park, by a party led by Prof. J. D. Whitney, in 1869.† Upon the Wahsatch range, near Salt Lake City, glacial phenomena have been noted by Mr. E. P. Austin and others, but I am not aware that any description of them has been published. We may look to the forthcoming volumes of the report of the Fortieth parallel survey for a full account, not only of these but of similar phenomena on the Humboldt and Uintah ranges. In the third volume of that report Mr. Emmons announces the discovery of glacial striæ on the Toyabe range, Nevada, (latitude 39°,) but mentions no associated phenomena. South of these mountains our explorations in 1872 led to the discovery of a number of localities which there is reason to believe are the most southerly in the longitudes in which they occur.

* Pacific Railroad Reports, vol. vi, p. 42.

† Prof. J. J. Stevenson, geologist of the Colorado division of this exploration in 1873, found moraines as far south as north latitude 38°, on the eastern flank of the Sangre del Cristo Mountains.

The Schell Creek range, Nevada, has an altitude at White's Peak, (latitude 39° 15′,) and for six or eight miles southward, of 10,500 to 11,200 feet. The crest is remarkably acute, and is buttressed by lateral spurs, between which are close, hopper-shaped valleys, that once contained very small glaciers. The ice could have moved at most only two or three miles, and the moraines, which are its only observed record, were pushed no lower than 8,000 feet. A little farther south, (latitude 39°,) and in the next range to the east, Wheeler's peak rises to a height of 12,000 feet, and bears upon its eastern flank a moraine of the same character and at the same altitude as those of the Schell Creek range, but of greater magnitude, and retaining Alpine lakes. I did not myself visit the lakes, and indeed saw only the lower side of the moraine, but, by the descriptions of Lieutenant Wheeler and Mr. W. M. Ord, who ascended the peak in 1869 and viewed them from above, I am persuaded that the waters are dammed, either by the moraine I saw or by later formed moraines of the same glacier. No opportunity was afforded to look for glacial phenomena on other sides of the peak, and it is not improbable that they shall be discovered a few miles farther south on the same range.

Belknap Peak, near Beaver, Utah, overlooks two moraines, lying in sheltered valleys on opposite flanks, and the western contains the waters of a lakelet at an altitude of 9,000 feet. Its latitude is 38° 25′.

Sixty miles farther east, in latitude 38° 30′, Mr. Howell observed upon a high ridge of the Sevier plateau a series of terminal moraines, inclosing a chain of small lakes and swamps, (Chapter IX of this volume.)

In all of these instances the glaciers were of insignificant magnitude, and confined to the neighborhood of the loftiest summits.

Lake Bonneville.—From considerations that will appear in the sequel, I have come to regard as phenomena of the Glacial epoch a series of lakes, of which the beaches and sediments are to be found at many points in the Great Basin. The greatest of these with which I am acquainted, covered a large area in Western Utah, including the valleys now occupied by Sevier, Utah, and Great Salt Lakes, and its limits and history have been so far indicated by our examination, that I venture to propose for it the name of Bonneville, in honor of Capt. B. L. E. Bonneville, who first afforded an authentic account of Great Salt Lake.* The lacustrine deposits which form part of the record of this lake, I shall designate the Bonneville group.

The most conspicuous traces of Lake Bonneville are its shore-lines. At their greatest expanse the waters rose nearly 1,000 feet above the present level of Great Salt Lake, and at this and numerous other stages, marked their lingerings by elaborate beaches and terraces. These are very conspicuously displayed on the slopes of the Wahsatch range near Great Salt Lake, and on the rocky islands of the lake, and have attracted the attention of every observant traveler from the time of the explorations of Frémont and Beckwith. All the varied products of wave-work, as we know them on modern shores, are represented and beautifully preserved. Rocky promontories are cut in notches of greater or less depth, as the water lingered a longer or shorter time, the upper face of the notch being a bluff escarpment,

FIG. 43.—Diagram of beach carved in rock.

undermined by the waves, and the lower a shingle, consisting of parts of the excavated rock. The water level, as we know from the study of modern shores, was at or a little below the angle of the notch. On promontories of softer materials, such as salient curves of the gravel foot-slopes of the mountains, the phenomena are precisely similar save that the inclines are less steep, (Fig. 44.) Along re-entrant curves, and across the mouths of

FIG. 44.—Diagram of beach carved in soft earth.

deep indentations of the contour, beach ridges, or bars, were thrown, having for their material a portion of the sand and gravel excavated from the

* Captain Bonneville saw Great Salt Lake in 1833. His account of it was published by Washington Irving ten years later, in "The Adventures of Captain Bonneville, U. S. A., in the Rocky Mountains and the far West."

promontories, (Fig. 45.) Where considerable streams entered, tabular deltas were built of their sediments, and gravel bars of great magnitude were thrown across straits. Of this latter feature conspicuous examples are to be

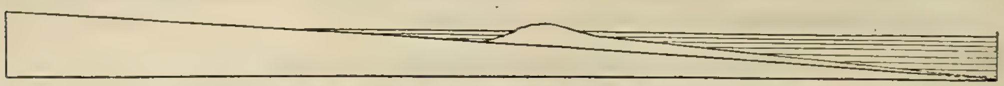


FIG. 45.—Diagram of beach ridge thrown up on a shelving shore.

seen at Dry Pass in the House range, at the pass between Tooele and Rush Valleys, at the pass between Juab and Utah Valleys, and at that between Utah and Salt Lake Valleys. The last mentioned is especially interesting, from the fact that the Jordan River has cut across it and revealed the constitution of the bar to a depth of 500 or 600 feet. The cuttings of the Utah Southern Railway have likewise afforded fine sections at the same locality, exhibiting clean, well-sorted, beach-rolled gravel.

No number can be assigned to the successive shore-lines from the highest to the modern. Upon gentle slopes many more can be detected than on steep, and they are of all grades of distinctness. It is doubtless true that some, which are at certain stations conspicuous, as compared to others, are elsewhere, from local causes, inconspicuous, but there are two lines that can, at nearly every point, be recognized as far more strongly traced than any others. One of these is the highest of all, the Bonneville beach. The other occurs about 300 feet lower, and this we have found it convenient to entitle the Provo beach, drawing the name from the town of Provo, on the shore of Utah Lake, near which it is especially well exhibited. These tell us that, during the progressive subsidence recorded by the entire series, there have been two marked epochs, perhaps many thousands of years in duration, through each of which a constant water level was maintained. The level of Great Salt Lake, like that of other lakes without overflow, is notoriously inconstant, for the obvious reason that it depends on the ratio between precipitation and evaporation over a limited area—factors which diverge, and change their conditions of equilibrium, with every fluctuation of annual mean temperature or humidity. It is difficult to imagine that so unstable a climatal equilibrium was maintained for the time that was consumed in the production of either the Bonneville or the Provo beach, and, before we accept such explanation of their origin, we are led to inquire whether at these levels the stage of water was not regulated by an overflow. The coincidence of one of the constant levels with the highest water stage of all, renders the presumption of an outflow at that stage especially strong. With these considerations in view, we endeavored, in tracing the outline of the lake, to discover its point of discharge, but without success. Our examination was almost exclusively confined to the southern half of the lake, and points to the conclusion that no outlet existed toward the Colorado River. At one low point of the southern rim, near Hebron, Utah, the observation was not so complete as was to be desired, and the question may be considered as not definitely settled. Prof. O. C. Marsh informs me that he has discovered, on the northern shore of the lake, an outlet leading to the Snake River, but I am not aware at what point, nor at what altitude. The northern portion of the lake area falls within the field of study of the corps of Mr. King, and when their observations and those of Professor Marsh shall have been published, the relation of the beaches to the outlet, or outlets, will doubtless be known.* Meantime I anticipate that the Provo beach, as well as the Bonneville, will be found to have been determined by an overflow.

In the map of Lake Bonneville,† the southern half, and the eastern shore to Ogden, is based on the surveys of our parties in 1872. Wherever the shore-line was crossed by Mr. Howell or myself, its position was noted, and in this way about forty-five points were fixed. These were connected by lines, in part sketched in the field from views more or less distant, and in part assumed from the general relations of the orography to the determined altitudes of topographical stations. The northern and northwestern contours are merely provisional, and are based on some scattering altitudes furnished by the Pacific Railroad explorations, and Dr. F. V. Hayden's reports. A bay is assigned to Cache Valley on the authority of Dr. Hayden, (Annual Report, 1871, p. 19.) The southern and eastern portions of the lake were studded with rocky islands, and fringed with ragged, "iron-bound" promontories. The largest open body lay over the Great Salt Lake Desert, and had a depth of about 900 feet. The average depth of the

*Prof. Frank H. Bradley mentions four points of possible outflow from the northeast margin.—(U. S. Geol. Surv. of the Territories, 1872, p. 202.)

†At the time of writing, this map has not been executed, but it is hoped to publish it together with others, constituting a geological atlas, either with or soon after the appearance of this volume.

whole was not far from 400 feet, and the extreme depth 1,000 feet. Its area was not far from eighteen thousand square miles, being a trifle less than that of Lake Huron, and eight times as great as Great Salt, Utah, and Sevier Lakes combined. Its extreme length, from north to south, was about three hundred and fifty miles, and its width one hundred and twenty-five miles.

The altitude of the Bonneville beach was accurately determined, at a point where it is distinctly marked, near Camp Douglas. A system of levels, carefully run by Mr. Gilbert Thompson, establish the relation of this point to the shore of Great Salt Lake, to several "benches" convenient for reference, and to the track of the Central Pacific Railroad, at Corinne, Utah; and the combination of the railroad and local levels affords the following:

	Feet.
Water-surface of Great Salt Lake (May 16, 1873) above the sea..	4,210.4
Instrument pier, Salt Lake Observatory, above the sea...........	4,330.4
Bonneville beach, near Camp Douglass, above the sea...........	5,178.1
Bonneville beach above Great Salt Lake	967.7*

The fluctuations of the present lake have been observed for so short a period, and with so little care, that we do not know its mean stage, (if, indeed, we can assume it to have one,) but such meager data as are available indicate that, at the date of our comparison, its level was some feet higher than it averaged for the past twenty years.†

No other determination of the Bonneville beach was made by spirit-level. Aneroid barometers were carried, by Mr. Howell and myself, to numerous and widely-distributed portions of it, as well as to a number of stations on the Provo beach; but, owing in part to the loss of a note-book containing collateral data, the discussion of these observations does not give satisfactory results. To the most important question that we would ask of

* Professor Bradley places the altitude near Ogden, in 1872, at 966 feet, a most remarkable coincidence, if, as I suppose, his measurement was made by barometer.

† Capt. H. Stansbury, describing Antelope Island, in 1850, (p. 158 of his report,) says: "The southern part of the island is connected with the main shore of an extensive sand flat, which, in the summer, is for the most part dry, but is frequently flooded to the depth of 18 inches, the water of the lake being driven over it by every gale from the north." Mr. Joseph H. Barfoot, of the Salt Lake City Museum, writes me of this same sand-flat, in 1874, that "it is crossed at times by the steamer," and that "there are now 11 or 12 feet of water at that place."

them, they afford but a qualified answer. They render it probable only that the Bonneville beach, on the western foot of the Pah-van range, south of Fillmore, Utah, has a greater altitude than at Camp Douglas, &c.; and that the portion which outlines the southern arm of the extinct lake in Escalantes Valley is nearly 300 feet higher than that about the Great Salt Lake Desert. These facts—if future investigation shall prove them so to be—will have especial interest as the record, in the middle of the continent, of undulations of the solid earth, produced at so late a geological date that we may presume them identical with changes now transpiring. In the present state of the science we are able to detect and measure the slow writhing of the earth's crust, only where a broad water-surface affords a datum-plane; and, for this reason, our data are almost confined to the margins of continents, where, as Professor Shaler has shown,* there is reason to suppose that the amount of motion is least. There are, however, a few interior lake systems, broad enough to tell us something of the warping of their shores, and our continent contains two, at least, that are of value—that of the Laurentian lakes, and the one we are considering. The fact that the basin of Lake Bonneville is now nearly dry is rather advantageous than otherwise, since its slow desiccation has left intact, for our study, a series of contour lines, that record, by their flexures, or by their horizontality, the relative motion, or the stability of the parts of a large area, subsequent to the successive times of their production. Since the geologist has ceased to look upon the present order of things as an ultimate result, and has come to perceive that the epoch in which he lives is a geological epoch, that geological history as well as human history is enacting, and that the earth has a future no less than a past, a peculiar interest attaches to every evidence of recent or actual progress. Inquiry is directed to all that seems most permanent, in the firm faith that the discovery of its instability can only be postponed, not averted; and, actuated by this spirit, the geologist has even prophesied that the growth of mountain-ridges—"the everlasting hills"—will some time be seen. For evidence of their recent progress no better field could be studied than the region of this ancient lake, which bathed the feet of a dozen ranges of the Basin system.

* Proc. Bost. Soc. of Nat. Hist., vol. xii, Oct. 7, 1868.

Bonneville Beds.—Intimately associated with the Bonneville and lower beaches are a series of lacustrine deposits, whose history is very clearly defined by their constitution and relations. They are largely composed of fine, friable, white, calcareous marl, and this passes, on the one hand, into a cream-colored, partly oolitic sand, of calcareous and siliceous grains, feebly cemented by calcite, and, on the other, into an impalpable clay, charged with chloride of sodium and other soluble salts. All of these beds, excepting the most saline of the clays, are fossiliferous, affording, in great abundance, a few species of lacustrine gasteropoda.

The clay is distributed through the lowest portions of the Sevier and Salt Lake deserts and their arms, and, lying for the most part below the reach of modern denudation, is rarely to be seen in section. The marl is best exposed, and probably best developed, on gentle declivities. Its greatest measured thickness, noted on the southern margin of the Great Salt Lake desert, is 30 feet. Usually it is so friable as to crush readily between the fingers; but near Fillmore, Utah, it is consolidated into a chalk, and has furnished the name—Chalk Creek—of the stream upon which that town is built. The sand beds lie also upon the margins of the basin, but are less widely distributed. In most instances, their association with some one of the beaches can be definitely seen, and in all observed instances of superposition, they overlie the marl. On the western flank of the House range, opposite Fish Spring, they are greatly developed, but admit of no section. Near the River Bed station of the old overland stage road they exhibit a depth of 50 feet

The area covered by the Bonneville group is completely circumscribed by the Bonneville beach, and comprises, with an exception presently to be noted, whatever of the surface of the basin lies below the level of the beach. The waves which carved and molded the Bonneville beach, excavated only indurated rocks and subaerial gravels derived from them. The escarpments excavated at all lower water stages exhibit sections, more or less complete, of the Bonneville beds. In fine, the Bonneville beds are the sediments of the lake whose successive margins are recorded by the series of beaches we have described, and their deposition has been continuous, over a gradually restricted area, from the date of the Bonneville beach to the present time.

In some places the lacustrine deposits have in turn been covered by fresh, rill-borne gravels. The waste from the mountains that, during the existence of Lake Bonneville, was sorted and distributed by its waters, received, after they retired, only the partial sorting and limited distribution that the mountain streams accomplished. Upon easy slopes, these subaerial gravels sometimes cover and conceal the Bonneville beach, but oftener the modern streams intersect the higher beaches in channels eroded below the general surface, and spread their detritus over the lacustrine strata and the lower beaches.

The general section about the margins of the Bonneville basin may, then, be stated as follows:

a. Subaerial, unsorted gravels; deposited by running water; distributed in unconnected patches; still accumulating.

b. Subaqueous sands, marls, and clays; thoroughly sorted; deposited by still water; limited by the Bonneville beach. The greatest measured section shows 75 feet; the maximum depth may be greater.

c. Subaerial, unsorted gravels; deposited by running water; not limited by the Bonneville beach; found under the Bonneville beds wherever their base is visible. Maximum depth unknown; a partial section shows 200 feet.

The gravels *a* and *c* are identical in character, and above the beaches are inseparable. They are, in fact, a continuous formation, interrupted locally by the intercalation of the lake beds. So, too, if we pass from the margin of the basin to its lowest points, where are now salt lakes, we find now depositing a saline clay, identical in point of time with the upper gravel, (*a*,) but in point of condition identical with the Bonneville clays, (*b*,) and connected with them by unbroken continuity of deposition. That is to say, on the borders of the basin the accumulation of subaerial gravel has been continuous, and in the lowest parts the deposition of subaqueous, while a broad middle ground has received the two deposits in alternation. The circle of beach which has always separated the two areas of deposition, has dilated and contracted, so as to enable each, in turn, to overlap the other.

Of the history of the beach, or what is the same thing, of the history of the lake, we know only the last few pages. We know that the present low tide has been preceded by a high tide, the duration of which, though extended, was not unlimited, and we know that for a comparatively long antecedent period there had been no similar flood; but we do not know that there were or were not earlier floods; nor can we tell how low was the stage from which the water rose to its last maximum.

Our chief present interest in these phenomena lies in the fact that they are the secular meteorological record of Utah. The water stage of Great Salt Lake depends on the relation of precipitation to evaporation—and these upon atmospheric humidity and temperature—within the area from which it receives drainage. If the air-currents that cross the basin absorb more water than they yield, the lake surface contracts, until the consequent diminution of evaporation restores the equilibrium; if they absorb less, it expands, and the effect is, and has been, the measure of the cause, up to the limit marked by Lake Bonneville, when, an overflow being reached, the water could rise no higher.

We may, then, translate our stratigraphical data into climatic, and say that during a period, represented by the lower gravel, (*c*,) Utah was arid; that its humidity increased to a maximum, and again began to diminish, during the deposition of the Bonneville beds, (*b*,) and that its present aridity has been reached and maintained during the time marked by the upper gravel, (*a*.) Some idea of the relative lengths of these periods may be derived from the comparative magnitude of the deposits, though our data upon that point are not so full as is desirable. The general impression, derived from a month's travel in the region, is that, if the gravel *a* be taken as unity, the lacustrine deposits might be represented by ten, and the known portion of the gravel *c* by fifty. In passing from depth to time, it should be borne in mind that the lacustrine deposits accumulated faster than the gravels. They were formed during an epoch of greater humidity, when denudation was more rapid, and they received material from wave erosion, as well as from atmospheric. After making this allowance, it still remains probable that the Bonneville Lake occupied more time than has transpired since its subsidence, and that the anterior epoch of aridity was many times longer than what time has elapsed since its close. The humidity marked by the Bonneville beds thus appears to have been an *episode*, occurring in the later part of a long era of aridity, and it was the consideration of this fact that led to the introduction of these data in the chapter devoted to glacial phenomena.

The Bonneville epoch and the Glacial epoch were alike climatal episodes, and they occurred in the same general division of geological time, namely, the division of which modern time is the immediate sequel. If it can be shown that the climatic changes were of the same kind, there need be no hesitation in assuming the identity of the epochs. The glacial climate we commonly regard as merely cold, and a low temperature was doubtless its chief characteristic; but it admits, nevertheless, of another view. The climatic condition essential to the formation of glaciers is, that the summer's heat shall be inadequate to dissipate the winter's snow, and this may be brought about, either by a lowering of temperature, or by an increase of winter precipitation. The profuse precipitation of our northwestern coast would maintain great glaciers, if the climate were cold enough; rivers of ice would follow the higher valleys of the Rocky Mountains if the snow-fall were heavy.

To account for the origin of Bonneville Lake, we need to assume a climatal change, that would increase precipitation, or diminish evaporation; and both of these effects would follow, in accordance with familiar meteorological laws, if the humidity of the air were increased, or if the temperature were lowered. There can be no doubt, then, that the great climatal revolution, which covered our northeastern States with ice, was competent to flood the dry basin of Utah; and that it actually did so is at least highly probable.

Before quitting the subject of this ancient lake, a few special features should be recorded.

Calcareous Tufa.—Along many of the beaches, and especially at points where they are carved in solid rock, the bench or terrace below the waterline is composed of calcareous tufa, usually full of small gasteropod shells, and often involving so many fragments of the contiguous rock as to constitute a breccia. In the localities where I found it best exhibited, the beach was carved in limestone, but the deposit is probably independent of the character of the adjacent formation. Mr. Howell observed it upon Granite

Mountain, coating granite, and remote from limestone exposures; and a similar association was seen by Prof. W. P. Blake on the Colorado Desert. Down some steep slopes it stretches, as an apron, for several rods, and, where it rests on soft materials, the waves of the retiring lake have undermined it and formed caves. Several of these are to be seen on the north end of the Oquirrh range, and the largest, which is popularly reputed to have been excavated by Spaniards years ago as a mine, is remarkable as a specimen of "Purgatorial" wave-work. The Carboniferous strata have a local northward dip of eighty degrees, and trend parallel to the face of the acclivity. Two beds of limestone, which constitute the walls of the cavern, are separated 12 feet at the entrance, and evenly converge to the rear end, where they are 4 feet apart. At the end, a shale, in place, fills the interval, but I was unable to determine whether this had once occupied the entire excavated space. The roof is built entirely of recent calcareous breccia, and the floor is evenly spread with earthy *débris*. The height of the gallery is uneven, ranging from 2 to 25 feet, and the length is 275 feet. The breccia of the roof pertains to one beach of the great series, and the floor is near the level of another. The wonderful depth of the excavation, in a direction nearly parallel to the shore, is explained by the convergence of the straight walls, between which the waves gained, in their progress, on the principle of the hydraulic ram, enough velocity to compensate for the loss by friction.

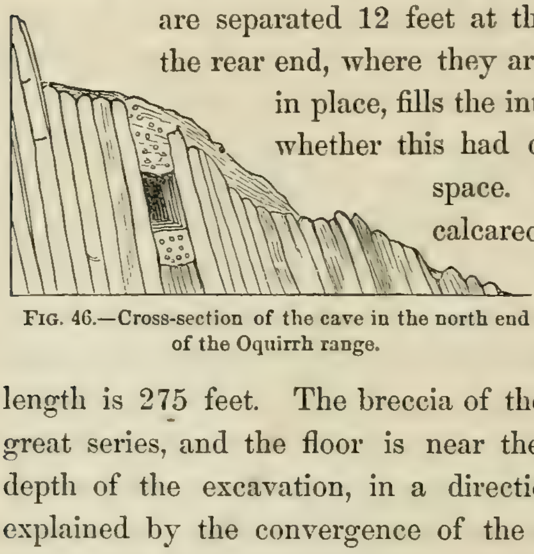


FIG. 46.—Cross-section of the cave in the north end of the Oquirrh range.

Great Salt Lake and Sevier Lake are separated by a divide, which, in its lowest part, is not many feet above the level of the latter. When, in the progress of the great desiccation, this divide was uncovered, and the two basins were separated, evaporation proceeded less rapidly on one side than on the other, and for a time there was an outflow across the barrier. The channel opened by this connecting stream is of such magnitude, and so perfectly preserved, that it has been appropriately designated by frontiersmen "the Old River Bed." "River Bed station," of the old overland stage road, is upon its margin. Our lines of survey intersected it at two points, seven miles apart, but neither end was examined. In its narrowest part, where it traverses mountain gravels, its floor is from 200 to 300 yards across. It has here absolutely ceased to be a drainage line, and deltas of *débris* from the adjacent hills stretch completely across it, dividing it into a series of small *playas*. Observations upon its altitude at different points were, unfortunately, not so connected as to determine the direction of its descent, and we cannot be certain which of the two lakes was tributary to the other. It is to be presumed, however, from the fact that Sevier Lake is now by far the less saline,* that it was the upper of the system, and by its overflow gave what salt it had then accumulated to Great Salt Lake.

Fossils of the Bonneville group.—The shells found by us in the Bonneville beds are all of modern species, either fresh water or terrestrial. The specimens in our collections were submitted to Mr. Geo. W. Tryon, jr., for identification, and the following list is from his notes:

Limnæa desidiosa, Say.
Pomatiopsis lustrica, Say.
Amnicola cincinnatiensis, Anth.
Succinea lineata, Binn.
Cypris?

In all the localities we examined, the specific forms were few—one or two—but individuals were usually abundant. The form most widely distributed is *Limnæa desidiosa*, and it ranges through the entire series of marls, from those which rest directly on the older gravel, to those thrown down at the latest stages of the receding water. The greater portion of the fossiliferous beds are calcareous, and not appreciably saline; but at a few of the more recent localities examined salt was visible as an efflorescence, and perceptible by taste. In these saline muds were found a few specimens of *L. desidiosa* and *Pomatiopsis lustrica*. At the time of their collection, the only explanation of their occurrence in such association appeared to be that, by slow acclimation, they had survived the change from fresh to salt

* Dr. L. D. Gale found in Great Salt Lake water 22.42 per cent. of mineral matter; Dr. O. Loew, in Sevier Lake water 8.64 per cent. The difference, however, is not so great as these figures would indicate, for the reason that the two tests were separated by an interval of twenty-two years, in which time the lakes underwent a change. That there is a difference is proved, independently, by a rude observation on their comparative specific gravity. A bather floats so much higher in Great Salt Lake as to indicate that its brine is nearly twice as strong.

water; but some observations, soon after, on the shore of Sevier lake, led to a different conclusion.

The only tributary to Sevier Lake is the Sevier River, and it has no outlet. Its water contains 8⅗ per cent. of saline matter. No trees stand on its shore, nor is it fringed by aquatic plants. Frequent careful examination of the water along its shore discovered no life, save *Artemia*, characteristic of all briny lakes, a few larvæ of insects, and small floating *Algæ*. Along the highest line reached by the waves were accumulated, just as upon the shores of Great Salt Lake, the dry *exuviæ* of the larvæ, and, mingled with them, we found *Algæ*, numerous dead and univalve shells, small dead fishes, and beaver-gnawed sticks of willow. There is no reason to suppose that any of these remains, except the larvæ, and perhaps the *Algæ*, belong to lake. The willows could have come only from the Sevier River. The fishes appeared to be the young of fresh-water species. And some, at least, of the shells are known to live in the fresh waters of Utah. It is fair to assume that the shells, along with the willows and fishes, were floated by the waters of the lake from the mouth of the river to their present position, ten or even twenty miles away. Any of these shells that should become filled with water and sink, in their transit across the lake, would be imbedded in the saline sediments now accumulating, and offer to some future generation the same anomaly that we have encountered. The drifted shells include, (here, too, we are able to give the names on the eminent authority of Mr. Tryon:)

Limnæa desidiosa, Say.
Limnæa palustris, Müll.
Physa heterostropha, Say; and
Carnifex newberryi, Lea.

It is noteworthy that *Anodonta oregonensis*, abundant in the river, and too conspicuous to be readily overlooked, was not found on the beach.

In view of these facts, we may safely affirm that the mere presence in lacustrine deposits of such fluviatile shells as will readily float after the death of the animal does not prove that such deposits are from fresh water; and we are led to review carefully our opinion, expressed in the preliminary report for 1872, that the water of Lake Bonneville was fresh.

The water of Lake Bonneville.—Considering first the fossils, we note that one of the species is terrestrial, and must have been introduced from the shore. Of the remaining eight species, seven are light fresh-water or amphibious gasteropoda, the dead shells of which would readily float to great distances, and may have been introduced by streams. The eighth species is a minute ostracoid crustacean, so extremely light that it might be carried along by even a feeble current. Our data are not sufficiently full to give great value to merely negative evidence, but we may still note the apparent absence of so conspicuous a family as the *Unionidæ.* In the examination of localities scattered widely through the basin of the lake, and including every variety of station, as regards depth of water and slope of bottom, myriads of gasteropoda were found, but not a single conchifer—and this, although *Anodons* are abundant in the fresh water of the region, and the sediments of other ancient lakes of the great basin are characterized by bivalves. Dr. J. S. Newberry found in a deposit from the ancient expanse of Klamath Lake numerous specimens of *Unio;* Dr. Jas. Blake reports *Anodonta* from ancient lake-deposits in the Queen River Valley, and the same genus was found by the writer to abound upon the old beach-line of Owens Lake. While none of these facts in regard to the fossils demand salinity for their explanation, their bearing is certainly favorable to the idea that the waters of the lake were not entirely fresh.

The evidence derived from the character of the deposits is, perhaps, even more vague. The salt which is so prominent a characteristic of the present Sevier and Great Salt Lakes, and abounds in all the later sediments of the shrunken ancient lake, is nearly absent from the beds most clearly associated with the upper beach; and its distribution indicates that Lake Bonneville, if not perfectly fresh, was at least far less saline than either Great Salt or Sevier Lake. The deposits which can be definitely associated with the greatest expanse of water are calcareous, consisting, along the immediate shore-line, of the tufa already described, and in deeper water of marls almost entirely made up of crystalline particles. These particles do not cohere, as we might expect them to do if the crystallization took place at the bottom of the lake, but are loosely aggregated, as if they had been formed in the body of the water, and sank to their present position. We cannot avoid the inference that, whatever may have been its percentage of salt, the water was saturated with carbonate of lime.

As we have already remarked, the strong delineation of the upper beach can hardly be accounted for, save upon the supposition that at that level there was an outflow which preserved a constant stage of water. The observations of Professor Marsh and Professor Bradley on the "divide" between Great Salt Lake basin and the valley of the Snake River, confirm this view. But, if it be proved that this was so, it by no means follows that the water of the lake was sufficiently free from saline ingredients to be denominated fresh. So long as the inflow was greatly in excess of the outflow, the water of the lake would retain a great portion of its dissolved salts. A comparatively slight difference of this sort would suffice to saturate the water with calcite, and, if the overflow were comparatively very small, even a high degree of salinity might be maintained. If we suppose, for example, that the inflowing streams contained .0001 of carbonate of lime, and .001 of common salt, and that their volume was fifty times as great as that of the outlet, the remaining water being removed by evaporation, then the outflowing water, to maintain an equilibrium by carrying off both lime and salt, must contain .005 of the former and .05 of the latter, and the water of the lake would be charged in the same degree. But, while this would be perfectly possible for the salt, the water could not hold so great a portion of protocarbonate of lime, and all in excess of saturation would be precipitated in the lake as evaporation progressed. Upon such an hypothesis the profuse precipitation of calcite would consist with the maintenance of a constant level of overflow.

In this connection the inquiry is pertinent whether the basin contains the amount of salt which would have sufficed to render the great lake briny. The ancient volume was no less than three hundred times greater than that of Great Salt Lake, (when surveyed by Captain Stansbury,) and the brine of the latter, so greatly diluted, would give only one-thirteenth of one per cent. of salt. But, if we add to the salt of Great Salt Lake that of Sevier Lake, and the far greater but indeterminate quantity accumulated in the sediments of the lower parts of the two deserts, we shall probably have enough to give Lake Bonneville, if it were undrained, the salinity of the ocean.

In fine, we are led to believe that, while Lake Bonneville certainly held less salt than do its modern representatives, its recorded phenomena comprise no fact that places it definitely among either fresh or salt lakes.

The lake we have studied was but one of a group. Vestiges of a similar flood have been found, by various observers, in many of the valleys of the Great Basin, and it is probable that all of the minor basins of which it is composed were partially, or wholly, filled with water. In the list of those which overflowed, may probably be included all of the northern tier, bordering on the present drainage system of the Columbia River, and those which, lying at the feet of the Wahsatch range and the Sierra Nevada, received the streams from those mountains. What we know of the Death Valley and other southwesterly basins, tends to show that they were not entirely filled.

Of the interesting group of lakes that along the base of the Sierra Nevada survive the general desiccation, our route touched but one, and that the most southerly. Owens Lake lies in a trough between the Sierra Nevada at the west, and the Inyo and Coso ranges at the east, and receives its water from Owens River, which, rising seventy miles at the north, follows the trough, and accumulates the streams from the adjacent mountains. It now contains a strong brine, and is without outlet, but it is surrounded by ancient beaches, and in the sands of the most elevated of these are abundant specimens of *Anodæ*, testifying to its former freshness. Its ancient area did not exceed its modern by more than one or two times, and the channel through which its surplus discharged is distinctly marked. Following the channel southward for forty miles, past Hawee Meadow and Little Owens Lake, we found it ending in a broad desert valley, that stretches eastward from Walker's Pass and Indian Wells. From this the water probably had no escape. Our line of march compassed the southern margin of the desert, without the discovery of a channel through which it had found outlet.

Résumé.—The following are my principal conclusions:

I. The general glaciation of the Eastern United States had no counterpart, in the same latitudes, over the region extending from the Rocky Mountains to the Sierra Nevada, inclusive.

II. There were in that region local glaciers high upon the flanks of the mountains, the most southerly of which did not extend lower than an altitude of 8,000 feet above the sea.

III. There was a general accession of water to the valleys of the Great Basin. Lakes were formed where now are only deserts, and valleys, now nearly empty, were filled to overflowing.

The flooding of the valleys is correlated in time with the formation of glaciers upon the mountain summits, on the same principle on which the different local floods are correlated with each other, the local glaciers with each other, the glaciers of the East with those of the West, and those of America with those of Europe, namely, that the phenomena were of the same class and occurred in the same division of geological time. Each took place during the Post-tertiary, and each marked a climatal change of polar tendency.

IV. The phenomena of the Glacial epoch at the West differed from the synchronous phenomena in the same latitudes at the East, for the reason that then, as now, the former region was comparatively arid, and material was lacking for a great ice-field. The configuration of continents was not so far different from the present, but that the principal climatal districts were marked out, and the great flexures of the lines limiting zones of climate were arranged very much as we now know them.

CHAPTER IV.

WATER SUPPLY.

SPRINGS—STREAMS—LAKES—ARTESIAN WELLS.

We have here collocated a few groups of facts, connected by the common element of water, but otherwise so little associated that, but for the meagerness of our data, they would be deemed worthy of separate chapters.

The dependence of the agriculture of the Great Basin and adjacent regions upon irrigation, gives great interest to the subject of water supply. There has been a great deal of speculation upon possible changes of climate to transpire, or now transpiring, through the influence of irrigation, and upon the possible increase of water supply by means of artesian wells. Of the latter we shall have occasion to speak further on.

The rise of water of Great Salt Lake ever since, or nearly ever since, the occupancy of the neighboring country by Mormon settlers, has suggested to many people the possibility that the change of level is produced by irrigation and agriculture. The working of large tracts, which had formerly been dry and heated, might, it was surmised, be inducing a permanent change toward humidity, and the wish has been father to the thought, that this might extend so far as to enable the reclamation to agriculture of a large portion of our desert territory. There can be no question that the rise of the lake has occurred, nor can it be questioned that this rise indicates an increase of rain-fall as compared to evaporation; indeed, the lake tide is a most delicate indicator of the fluctuation of the annual climatal means. But I am disposed to doubt the possibility of connecting the change with the synchronous cultivation of the soil. While it may be true that large areas of land brought under cultivation are cooler than desert surfaces, and hence better able to induce rain-fall from currents of moist air, it is equally true that the coolness is due entirely to the increase of evaporation, brought about by the wide distribution of water in irrigation, and there seems no reason to believe that the result in precipitation shall exceed, if indeed it can equal, the expenditure in evaporation.

Recent discussions of our meteorological record at the East, have shown the popular belief in the influence of the cultivation of the soil upon the annual rain-fall to be unfounded, and in Utah—at least until we shall be able to reason from a broader basis of facts—it will be easier to suppose that the rise of the lake is due to a fluctuation of climate, within limits that our observation does not comprehend, rather than to a permanent change, induced by the comparatively slight modifications that agriculture has made on the face of the country. Taking the broadest view, the humidity of the Great Basin depends on air currents that completely traverse it; and nothing will augment it, that does not either increase the moisture of the incoming air currents, or decrease that of the outgoing.

Streams.—The water that comes from the clouds as rain, or flows from melting snow, gives rise to a double circulation. One part descends over the surface of the ground, in the form of rill, brook, and river, to whatever depression is its bourne, and another part, sinking in the earth, descends, by slow percolation, through soil and porous rock, until it reaches the same goal, or until, by some impenetrable barrier, it is crowded once more to the surface. Every bed of sand and gravel, and every porous stratum, while it is a reservoir in so far as it retards the stream, is a water-course in that it lets it pass. The phenomena of springs and wells have everywhere familiarized us with this underground circulation, but its manifestations are peculiarly impressive in the arid West, where precipitation is so small, and evaporation so great, that the superficial circulation is rarely conspicuous, and often is not perennial. It is a peculiarity of the streams of desert countries, that they do not flow constantly over the surface, but alternately rise and sink, appear and disappear.

In a varied valley, which is alternately broad and narrow, deep and shallow, of rapid and of slow descent, the flood of gravelly detritus that is slowly carried forward by the agency of the stream, behaves, in many respects, in the same manner as the stream. It acquires width and depth and a surface of slow descent, where the valley is open, and contracts and thins where the valley is narrow. The associated stream of water at its flood-stage fills a channel upon the surface of the detritus, and is its moving agent, but at its low, or usual state is in part absorbed, and, where the gravelly deposits are broad and deep, sinks entirely below the surface, and creeping along the rock bed of the valley, re-appears only in narrow and shallow places, where the mass of gravel is not sufficient to contain it. As a rule, the minor water-courses of the Great Basin contain a perennial stream only where their channels pass through narrow cañons, and are dry in broad, open valleys. Streams which rise in mountain gorges are perennial so far as they flow upon rock in place, but so soon as they reach the detrital foot-slope of the mountain, sink* out of sight, sometimes to re-appear, where some ledge interrupts their progress at a lower level, but more often to evaporate, without ever returning, as running water, to the surface. As there are subterranean rivers, so, under the *playas* of deserts, there are subterranean lakes, whose surfaces, though spread beneath the ground, are, nevertheless, reached by permeating air, and serve as areas for evaporation, just as do the surfaces of superficial lakes. The evaporating surfaces of such an underground lake must be multiplied, by capillary action, to many times its horizontal area, and the rapidity of its evaporation can depend only on the freedom of the interstitial circulation of air, and the air's capacity for moisture. That such evaporation is sufficiently rapid to constitute an important element in the meteorological history of the country, is sufficiently evinced by the fact that numerous shut valleys are relieved of their entire ordinary supply of moisture in this way.

Some cognate features of littoral evaporation are both curious and instructive. The sandy margins of some rivers and lakes in the arid region—bars and beaches accumulated by the adjacent water—are far more saline than the water. The water of the Colorado River, for example, carries so little salt that it is perfectly palatable. But, while camping in the Black

* The word "sink," as applied to streams, has two colloquial uses on the desert. Its ordinary and legitimate use, as a verb, refers to the disappearance of a stream from the surface by *absorption*, but its familiar use as a noun, arose from a fallacy, fortunately far less prevalent now than the use of the term. The lake, pond, or marsh, in which a stream ends, and from which its water is *evaporated*, is viciously entitled the "sink" of the stream. "The Sink of the Humboldt," "The Sink of the Sevier," "The Sink of Chalk Creek," are misnomers of this class.

Cañon, and in the lower part of the Grand Cañon, it was our custom, in order to avoid the fine mud with which the running water was charged, to dig shallow wells in the sand, close to the water's edge, and the water obtained from these wells—and which was merely the river water filtered through the sand—we found always saline, often in such degree as to prevent its use. I conceive that the sand, kept moist below by the percolation from the river, and rapidly dried from above, had stored up the saline constituents of the water which evaporated within its body, so as to produce the results we observed.

Very similar facts were noted on the shore of Sevier Lake. The brine of that lake, though three times as strong as that of the ocean, is far from saturation, and, in the laboratory, must be reduced to one-third or one-fourth of its volume before precipitation of common salt will begin. Nevertheless the sand of its beach is highly saline, a deposition having commenced long before the attainment of a condition of saturation. I am persuaded that in this case, as in the other, there is, within the porous earth of the shore, a slow circulation *shoreward*, by reason of which the salt of the lake is conveyed into the sand, just as the salt of the river is conveyed into the lake. In humid regions, where the rain-fall keeps the soil saturated nearly to the surface, the subterranean circulation would be directed lakeward, instead of shoreward, and lakes would gain, rather than lose, water by percolation. That this is the fact is shown wherever fresh water is obtained by wells sunk near the ocean and below its level.

Springs.—The name of spring is often given to the issuing or re-issuing of a stream that has been following its valley through the alluvial deposits, but is more properly applied to the outflow of water that has previously run or percolated only through the crevices or pores of rocks in place.

In plateau regions, the springs, in common with all the other physical features, depend on the succession and dip of the strata. Porous beds overlying imporous are water-bearing, and they discharge from the line of contact at its lowest exposure. In the case of a mesa composed of strata with a gentle dip, one side being mural and the other gently inclined, springs appear most commonly in embayments of the mural side, and, as this is the prevailing structure of the plateaus, the majority of springs in such regions are found under escarpments. Nevertheless they are not entirely wanting on the dip sides of inclined tables, and the streams of these slopes are, during rains, more copious than those of the steeper and narrower sides.

The rain which falls on such tables is divided into portions, that flow in opposite directions, and often to far distant goals. What penetrates, descends to some retaining stratum, and thus finds egress on the face of the escarpment, while the remainder follows the inclination of the upper strata to the opposite edge of the table. In this way the water which runs off from the plateau edge of the Sevier Basin, finds its way into the Sevier River, and is evaporated in the Great Basin, while that which sinks into the ground near the edge of the plateau, re-appears, along the escarpments facing to the south and east, in springs tributary to the Virgin, Paria, Dirty Devil, and other branches of the Colorado of the West. The surface drainage of the San Francisco Plateau is northward to the Colorado and Colorado Chiquito; but a share of its subterranean drainage goes southward, and gives rise to the Verde and other tributaries of the Gila.

In the region of the Basin Ranges, the conditions which control the distribution of springs are complex. The universal shattering of the rocks prevents the distribution of subterranean water according merely to the arrangement of pervious and impervious strata, and springs more commonly issue through crevices, from sources whose direction and distance cannot be determined. The phenomena, in both regions, are complicated by the presence of volcanic rocks, the stratification of which, when it exists, is less regular than that of detrital rocks. In some instances, the whole drainage-system has been turned aside by lava streams, while, in others, the lava floods have covered water-courses without damming them, so that copious streams issue from beneath their edges.

Virgin Salt Well.—Near the confluence of the Rio Virgen with the Colorado, is a curious natural well. Lieutenant Wheeler first visited it in 1869, and mentions it in his report of that year's reconnaissance. Two years later, I was enabled to examine it with him. In a smooth, gravelly plain, sloping gently to the Colorado River, is a round, funnel-shaped, or crater-like opening, nearly 300 feet across at top. None of the shallow arroyos of the plain lead to it or from it. The sides are of unconsolidated detritus, horizontally bedded, the upper 35 feet being of half sorted gravel and sand, and the lower 15 of saline sand showing a slight efflorescence. At 50 feet below the plain, is a water surface about 120 feet across, and beneath

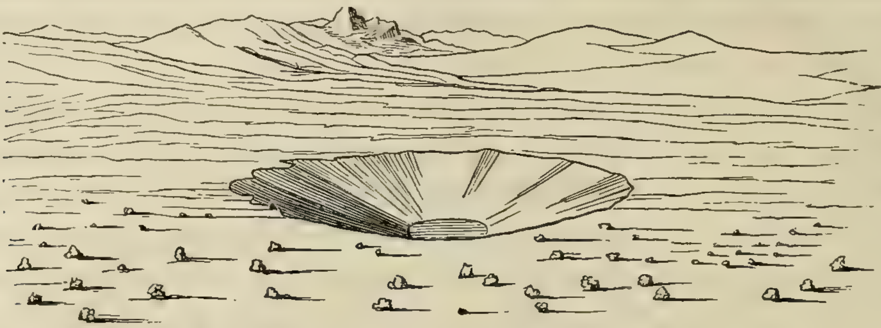


FIG. 47.—Salt well at the mouth of the Virgin River.

this the slope of the bottom could be seen, continuous with that of the bank, for 15 or 20 feet. The water is too saline for drinking, and I detected no motion in it. A few hundred yards away, the plain terminates in a bluff facing the river, and under the bluff, at the contact of the sand and underlying rock—a lava—is a line of springs, the altitude of which cannot be far different from that of the water in the well.

FIG. 48.—Section of salt well at the mouth of the Virgin River.

The Devil's Hole is near the eastern base of the House Range, Utah, and about ten miles south of Fish Spring. Like the Virgin well, it interrupts a smooth plain, and is circular. Its depth, to the water, is 15 feet, and the width of water is 15 feet. Above the water, the earth rises with a steep slope, and beneath, is vertical for a few feet, and then overhanging, (see Fig. 49.) The bottom was not visible. The water was brackish, and a

FIG. 49.—Section Devil's Hole.

yeast-like scum partly covered the surface.

There is no evidence that either of these wells ever overflowed. The water-ways that would mark outflow are not to be found. The waters are not thermal, nor are there any marks of geyser action. The openings appear to be due to the undermining action of subterranean currents, flowing in channels sufficiently open to permit the removal of even coarse detritus, and the salinity of the water suggests that these channels may have been opened by the solution of deposits of salt.

In the reports of Drs. Loew and Hoffman will be found notice of hot and mineral springs, and in treating of volcanic phenomena we shall have occasion to mention, besides hot springs, some supposed geysers of Southern Utah.

Lakes.—The lakes that were examined by our parties gave little occasion for doubt as to their origin. The most important of them may be called lakes of corrugation. The disturbances which give rise to mountains produce at the same time valleys, which are their antitheses; and as there are peaks higher than all their surroundings, so there are valleys completely inclosed by rocky rims. Where the erosion is sufficiently rapid, it may keep pace with the wrinkling of the surface, and either accomplish a complete drainage of these valleys, or so fill them with detritus from the surrounding ridges that no lakes shall be formed. In the Great Basin, partly by reason of the aridity of the climate that has characterized the region for a long period, there have resulted a great number of cups that have never been completely drained. The majority of these are now desert troughs, with *playas* in their lowest parts, and hold water only during a brief portion of the year; but others contain permanent lakes. The greatest of these, and one which may serve as a type, is Great Salt Lake. It occupies portions of three parallel troughs of the Range System, and is limited, north and south, by broad waves of the earth's crust, which intersect the meridional system of upheavals at right angles, (see Chapter on Orology.) Sevier Lake is in precisely the same case, save that it occupies but a single one of the trough-like valleys. Utah Lake lies in a portion of the most easterly of the Great Salt Lake troughs, and its valley is separated from that of the Lower Jordan by spurs from the adjacent ranges, which, while they do not meet, apporoach so near that their gravel slopes intersect and afford an effectual dam. Owens Lake, in Southern California, lies in the narrow valley between the Sierra Nevada and the Inyo range, and occupies a depression exceptional to the general slope, which is southward. It is not improbable that volcanic outflows have assisted in maintaining the southern barrier. Little Salt Lake in Southwestern Utah is similarly contained in a north and south trough. Stockton Lake in Rush Valley, and an unnamed pond in Cedar Valley, are to be assigned to the same cause, but cannot be called permanent lakes.

In some instances, the retaining dams are merely accumulations of gravel, poured out from the larger cañons of the adjacent mountains, and would quickly be cut through if the climate of the country were somewhat more humid. Rush Lake, in Southern Utah, Beaver Lake, a small expansion of Beaver Creek, near the North Star mining-district in Utah, and Pahranagat Lake, from which evaporate the waters of the Hyko Springs, are of this character. Little Owens Lake occupies a portion of the ancient channel by which Owens Lake overflowed to the south, and is held in check by a dam of gravel thrown across the channel by an intermittent stream from the Coso range.

Another group of lakes is directly connected with volcanic phenomena. "Mountain Lakelet," near the divide between the Sevier and Virgin Rivers, lies in a valley of erosion, between limestone walls, and is retained by fresh lava streams, which have filled the lower portion of the eroded valley. Panquitch Lake, in the same neighborhood, is believed by Lieutenant Wheeler, who visited it, to be a phenomenon of the same character. The "sink" of Chalk Creek, on the edge of the Sevier Desert, is a brackish pond, that appears to have been partitioned off by a fresh stream of basalt, and with it may probably be classed Spring Lake, which lies near the foot of Pah-van Butte, in the same desert. At the foot of San Francisco Mountain, Arizona, a small crater of basaltic scoria, with rim entire, contains a pond a few rods in diameter; and a water-pocket near Fillmore, Utah, is an accumulation of rain in the flue of an extinct crater. A description of the latter will be found in the Chapter on Volcanic Rocks.

A third class of lakes is of glacial origin, being retained by terminal moraines. Fish Lake, the most considerable of these, was examined by Mr. Howell, and a description of it will be found in his report. Of this character are the lakelets near Wheeler's Peak, Nevada, and that which lies at the foot of Belknap and Old Baldy Peaks, in Utah.

I have enumerated only those lakes which were examined by members of our expeditions in 1871 and 1872, and which now exist as such during all or the greater portion of the time. All through the region of the Basin Ranges are the vestiges of lakes, which have disappeared by evaporation, or by the cutting of their barriers. The greater number would fall within the first named group, but many belong to the volcanic and glacial classes.

The character of lake water, whether salt or fresh, depends chiefly, though not entirely, upon the question of outlet. Utah, Panquitch, and Beaver Lakes, and all of the glacial lakelets, overflow and are fresh. "Mountain Lakelet," which is nearly fresh, has no visible outlet, and its shores show that its level fluctuates. Its highest beach-line is so strongly marked as to suggest that, at that level, its water finds outlet through the shattered lava stream that constitutes its lower barrier. The pond in which Chalk Creek terminates is but slightly brackish, and may have a subterranean outlet. The ponds found in craters are fresh, by reason, perhaps, of the restricted areas from which they can derive soluble minerals. The Cedar Valley and Stockton ponds, although they receive the drainage from considerable areas, are said to contain drinkable water; but their conditions are exceptional. The former is chiefly supplied by a stream that is completely consumed during the summer by irrigation, and it is evaporated to dryness nearly every season. The latter has come into existence since the settlement of the country, and covers a tract that was at one time set apart by the Government as a hay reservation. It apparently owes its origin, or at least its resuscitation, to the same general change of climate which has caused the contemporaneous rise of Great Salt Lake.* The anomalous freshness of these waters is doubtless connected with their peculiar intermittence, but in what manner I am at a loss to conjecture.

With these exceptions, the undrained lakes of our list are saline. The waters of Great Salt, Sevier, Rush, and Owens Lakes are heavily charged with mineral matter. We are able to give analyses of but two of these brines. That of Great Salt Lake, obtained by Captain Howard Stansbury,

* The information presented in regard to the Cedar Valley pond was gathered by Mr. E. E. Howell; that in regard to Stockton Lake by Mr. Louis Nell, of the topographical corps.

in 1850, was analyzed by Dr. L. D. Gale.* The brine of Sevier Lake was collected by Lieut. R. L. Hoxie, in 1872, at a point on the west shore, remote from the inflow, and has been analyzed by Dr. O. Loew.

	Brine of Sevier Lake, (O. Loew.)	Brine of Great Salt Lake, (L. D. Gale.)
Chlorid of sodium	6.23	20.196
Sulphate of soda	1.34	1.834
Chlorid of magnesium	1.03	0.252
Sulphate of lime	0.04	....
Chlorid of calcium	....	Trace.
Total in 100 parts of water	8.64	22.282

The areas draining to these lakes are of very similar character, and it is not surprising that the brines should be qualitatively identical. The sulphate of lime in one case need not be distinguished from the chlorid of calcium in the other, as the difference is merely one of interpretation by the analysts. The brine of Great Salt Lake is economically superior to that of Sevier Lake, not merely in its greater strength, but in the less relative percentage of sulphate of soda and chlorid of magnesium. In comparing the two waters, some allowance must be made for the difference of date in the collection of the samples. The levels of the lakes and their volumes undergo fluctuations, which must affect the percentage of mineral matter in their waters. While the tributary streams are flooded by the melting snows, the waters rise, and during the remainder of the year subside; and besides this annual oscillation is the still greater one dependent upon slow moving changes of climate. If Sevier Lake has undergone the same fluctuations as Great Salt Lake, and, since the areas they drain are similar and contiguous, it is extremely probable, its volume must have been less and its brine stronger in 1850 than at the time it was sampled. The best data we have in regard to the rise of Great Salt Lake in the interval place it at 10 or 12 feet. The soundings made by Captain Stansbury in 1850 indicate a mean depth of about 13 feet, and the shores of the lake shelve so gradually that a

* Exploration and Survey of the Valley of the Great Salt Lake of Utah, p. 417.

rise of this amount would suffice to more than double its volume. In ignorance of the configuration of the bottom of Sevier Lake, we cannot tell what relation maintained between the increase of its surface and of its volume; but if it expanded in sympathy with Great Salt Lake, its brine must now be more dilute than formerly.*

In a general way, we must regard Great Salt Lake as saturated with chlorid of sodium; that is to say, whenever, in the irregular rise and fall of its level, depending upon the varying seasons, its volume reaches a minimum, there is a precipitation of salt. This was observed by Captain Frémont in 1845, and may take place, even at the present day, upon its western shoals, at times when the water is not sufficiently stirred by the wind to prevent local concentration by evaporation.

Artesian Wells.—The principle upon which artesian wells depend is a simple one, and the conditions essential to successful search for them are few. The well, and the stream which supplies it, are always equivalent to a bent tube, or inverted siphon, filled with water, in the longer leg, to a height greater than the top of the shorter. The well is the shorter leg; the natural conduit, tapped by the well, the longer. The natural conditions upon which the possibility of artesian supply depends are, firstly, that of a series of inclined strata, one, so porous as to permit the circulation of water, shall be contained between others comparatively or absolutely impervious; secondly, that these strata shall somewhere rise to a height greater than that of the point at which the discharge is sought; and, thirdly, that the free discharge of the subterranean water shall be checked in other directions. It is not essential that the reservoir shall be completely closed at all sides lower than the position of the well, but merely that the flow of water shall be so far impeded in such directions that the pressure from the head may suffice to raise it to the desired altitude.

In the region of our explorations, these conditions are best fulfilled within the limits of the Plateau system. The strata which compose the plateaus are unbroken over large areas, and they are more or less inclined, so as to expose their edges in elevated regions. All along the west side of

*According to Mr. H. S. Poole, the lake brine is found less productive of salt than formerly, in the ratio of 3 to 7. Article on "The Great American Desert," in Proc. Nova Scotia Inst. Nat. Sci., vol. iii.

the Sevier Valley, from Monroe nearly to Gunnison, it is probable that an artesian water-supply might be obtained. Throughout that line, the Tertiary strata are gently inclined toward the valley, and present, upon the summit and western face of the Pah-vant range, faces adequate for the accumulation of water from rain and snow. Farther south, in the same valley, at Panquitch, and thence twenty or twenty-five miles up the Sevier, the conditions are similar; and, in the next parallel valley at the east, it is probable that the same favorable relations can be found. To the south of the great Tertiary escarpment which limits the Sevier basin, the country is intersected by cañons, which drain the strata at so low a level that it is improbable that a free discharge could be obtained from deep wells; and, in the neighborhood of the deep cañons of the Colorado, the thorough under-drainage which they effect would be sure to negative any search for artesian water. The same under-drainage would affect, also, the entire San Francisco plateau to the south of the Grand Cañon of the Colorado.

In the region of the Basin ranges, the sedimentary rocks are too little continuous to warrant their exploration for artesian water. It is not impossible that it may be obtained in some localities; but too great uncertainty would attend the experiment to give it practical warrant. On the other hand, it is probable that water might be obtained from the *valley* deposits within the area of the ranges. We know too little of these deposits to be certain that they contain continuous and impervious beds; but if the alternations of climate that characterized the Glacial epoch was a repetition of anterior fluctuations, it would indeed be strange if they did not give rise in many places to alternations of gravels and clays in such way as to constitute reservoirs that might be economically tapped. The best localities to search for such reservoirs would be found in the broader valleys. In the narrower, we may expect that the deposits close to the flanks of the mountains have always been more or less open, and that clay beds, if they exist, are not sufficiently elevated at their margins to retain water at an adequate height. In shut valleys, such as those of Great Salt Lake Desert and Sevier Desert, a supply of water, if obtained, would be almost certain to contain too much mineral impurity to be fit for use; but in others, such as Ralston Desert and Amargosa Desert, which we may suppose to have subterranean drainage, it is by no means improbable that a supply of good water may sometimes be brought to the surface.

It is to be regretted that the localities which afford the best prospect of a supply are not those which stand in greatest need of it. The valleys of the Plateau region, for the most part, lie at such an altitude that they receive considerable rain-fall, and are better supplied with streams and springs than are the valleys, or even the mountains, of the Basin region. In the latter country, where agriculture can, at best, never become of great importance, and where the principal demand for water is in connection with the ore deposits along mountain ridges, it will be found difficult, and in most cases impossible, upon the mountains to increase the supply already afforded at the surface.

CHAPTER V.

VOLCANIC ROCKS AND MOUNTAINS.

LOCALITIES OF THERMAL SPRINGS IN THE UNITED STATES.

At the time of the preparation of this chapter, there is in progress the most active and wide-spread discussion of the whole subject of vulcanicity. Every month brings new contributions to its literature, and speculation and research are reacting with reciprocal stimulation. A chief center of interest is the problem of the source and cause of igneous eruptions, and with it are involved such other questions as the origin of mountain corrugation, and of the elevation and depression of continental areas; the mode and conditions of metamorphism; the relations in time and depth of the plutonic and volcanic rocks; the relations in time and space of the acidic and basic eruptive rocks. It is my purpose to make no theoretical contribution in this place to any of these topics, but merely to present such facts as have come under my observation, with occasionally a brief statement of their relation to the problems of the day.

Distribution of lavas.—No province of the mountain region west of the Plains has been exempt from volcanic eruption, and hardly a mountain-ridge is composed entirely without lavas. But while the distribution of volcanic rocks in general is thus well-nigh universal, there are distinctions worthy of note in the manner of arrangement in different districts, as well as in the comparative prevalence of the different species of lava. The physical provinces that we have characterized in a former chapter as the Basin Ranges and the Plateaus, as they are contrasted in all other characters, are measurably distinct also in their volcanic manifestations. In the former province, there is a linear arrangement of vents in trends coincident with, or parallel to, the axes of corrugation, and the acidic lavas predominate. In the latter, vents are grouped without evident linear system, and the basic lavas assume greater prominence.

The material gathered in the Basin region is most readily presented according to mountain ranges, and these will be taken up in such order that those of Southwestern Utah will be followed successively by those examined in Nevada, California, and Arizona.

There are no considerable extruded masses upon the Oquirrh range; but there were seen, at the head of Middle Cañon and upon Lion Hill, upon the crests, that is, of its two principal anticlinal folds, a number of trachytic dikes walled by Carboniferous limestone. The principal mass and the north end of the Lake range are without lavas; but Mr. Howell found a sheet of basalt covering the southern extremity. Lieutenant Marshall observed rhyolite in great force on the crest and eastern slope of the Tintic range. The Champlin Mountains were seen only along the Cherry Creek Pass, in which part the Paleozoic axis is almost completely buried by sheets of rhyolite and rhyolitic tuff; and the same belt of eruption appears to be prolonged to the southwest, interrupting the northern margin of the Sevier Desert with a series of lava hills. Volcanic rocks were seen in the Stansbury range at one place only. From Grantville southward to the head of Tooele Valley, Mr. Howell found a line of trachytic and doleritic eruptions along the eastern base of the ridge, under the escarpment of Paleozoic strata that there faces Tooele Valley, (see Fig. 97.) The same observer found basalt and trachyte in force at the south end of the Cedar range, in which vicinity the latter rock constitutes the highest peak; but farther north the lavas appeared in the foot-hills only. No volcanic rocks were seen about Granite Mountain; but the Thomas range, of which it is an outlier, is buried (except the eastern base) for several miles south of Dug Way Pass by a flood of trachyte. The principal mass of the eruption is of a light vesicular variety, which rapidly disintegrates, and it appears to have been greatly reduced by erosion; but one of its summits, a tabular peak, is still the loftiest point of the vicinity, and probably of the range. Immediately west of this part of the range, and parallel to it, are two short monoclinal limestone ridges, each of which is flanked at the west by a mass of basic lava. No lava was seen on the House range, although it was scanned from one side or the other for a distance of eighty miles. There has been a small outflow of rhyolite near its eastern base on the shore of Sevier Lake, and a line of basaltic hills trends parallel to the range just west of its northern member. In like manner, the Confusion range at the west of the House, and the Beaver Creek at the east, show no conspicuous eruptions. A small rhyolite flow was observed at the western base of the former, and a few basalt hills at the northern extremity of the latter. Small outflows of basalt and trachyte were seen in a valley of the Picacho range, two or three miles west of the town of Shenandoah. A great area in the southwestern portion of the Sevier Desert is floored, partly above and partly below the surface of the desert-sand, by basaltic sheets, and they are accompanied in the vicinity of Fillmore by an interesting group of tuff and cinder cones, of which further mention will be made. At the north, the excavation of the "old river-bed" has laid bare one edge of a similar basalt sheet, and it is not improbable that a large portion of the plain is similarly underlaid. At White Mountain Station of the Fillmore and Pioche stage-road, the basalt of the desert rests against a small island of trachyte, that is probably the crest of a range buried by the desert detritus. A little farther south, in the interval between the Beaver and Beaver Creek ranges, are massive eruptions of similar rock, overlapped to the south and southwest by the broad basalt flow, from the margin of which breaks Black Rock Spring. The Pah-vant range is, so far as I am aware, non-volcanic; but its immediate southward prolongation, the Beaver range, is, at surface, almost completely rhyolitic. A nucleus of sedimentary and plutonic rocks is exposed at a few points, and a few patches of basalt occur at the eastern and western bases; but the great mass of the range—and its top rises from five to six thousand feet above Beaver Valley—is of rhyolite. Between the Beaver and Mineral ranges, but nearer to the latter, there is, at the north end of the Upper Beaver Valley, a lava cone of considerable magnitude, from which streams of basalt have overrun the head of the valley. The Mineral range elsewhere has very little volcanic material; the only locality noted being at the south end, near Adamsville, where, at the foot of the mountain, are inconspicuous eruptions of trachyte and basalt. Mr. Howell, in passing the south ends of the Hawawah and Needle ranges, saw only volcanic rocks; rhyolite, with minor areas of basalt. The spur which stretches westward from the Beaver range, and separates Beaver and Parowan valleys, is reported trachytic by Mr. Howell, and the same character is continued for twenty miles southwestward in the mountains facing Escalante Valley. The Pine Valley mountains were found by him to be capped by trachyte of great depth, and flanked at the east, south, and west by streams and cones of basalt. In the Bull Valley Mountains and associated ridges at the northeast, he saw only trachyte and rhyolite, except at Iron City, where the underlying sedimentary beds are exposed. The Virgin range at the points examined by Messrs. Marvine and Howell is not volcanic; but Mr. Marvine observed basaltic outflows along its eastern base in the vicinity of the Grand Wash.

In Nevada, the eruptions have been even more profuse than in Western Utah, and over large areas have buried all other rock masses. Throughout the region traversed by the expedition north of the Central Pacific Railroad, from Carlin to the Bull Run mining-district, and thence to Battle Mountain, the high, rolling uplands are volcanic, and other rocks, although constituting the highest summits, are exceptional and insular. The prevalent lavas are acidic—rhyolite and trachyte—and basalt, where it occurs, has an outlying or fringing position. The region abounds in secluded valleys, partitioned by the irregular outburst and outflow of the lavas, and is so well watered that these have all been opened by erosion. The streams, in consequence, traverse a quick succession of cañons and open valleys.

The Shoshone range, where crossed by Reese River, is rhyolitic, and, although cut to its base, shows no sedimentary axis. The Toyabe range has been described by Mr. S. F. Emmons as flanked by lava at several points. The Toquima range, south of Jefferson Pass, is built of granite and Paleozoic strata, but to the north has been completely overrun by rhyolite. A little basalt was seen on Jefferson Creek. The Monitor range, as seen from Belmont, has the characteristic habit of the acidic lavas; and in twenty miles of its length, examined farther south, these rocks only were seen, save that a single spur of metamorphic rock, at its western margin, faces Ralston Valley. Where I crossed the Hot Creek range, the only point at which I touched it, it is identical in character with the Monitor, and the nearest point I could recognize as other than volcanic was Tybo Peak, ten miles to the north. The same characters seem to be continued southward, in its prolongation, the Kawich. Between the Hot Creek and Monitor ridges, a parallel line of low rhyolite hills divides the valley. The Pancake range derives its homely but expressive title from the low conoid profile due to its constitution. The profuse eruptions that have escaped along its axis, not sufficiently viscous to build—as in the Monitor and Kawich ranges—steep-sided ribs and bosses, have spread in every direction from the line of outburst, producing low, gently-curved forms, of which the only steep acclivities are produced by erosion. The Reveille range, which continues the same structure line southward, is chiefly built of massive rhyolite, flanked by rhyolite tuff and basalt, but exhibits, at the mining-camp of Reveille, a small island of Paleozoic rocks. We did not follow it south from that point; but the portion west from, and overlooked by, Timpahute Peak has all the features of the Pancake range, (see Fig. 50.) Still farther south, at what may be regarded as the end of the range, it is still volcanic, consisting of rhyolite and rhyolite tuff. The Quinn Cañon range consists of two parallel massive eruptions of rhyolite, six or seven miles apart, and inclosing a north and south valley, at the southern gate of which is Quinn Cañon. Mount Worthington is an insular mass of Paleozoic rocks, but has volcanic (rhyolitic?) foot-hills at the north and south and along part of its eastern base.

FIG. 50.—A portion of the Reveille range as seen from Timpahute Peak, Nevada.

The Snake range is nearly free from volcanic rocks. There was probably a small rhyolitic eruption at the north end near the Clifton mining-district, and, at the pass between Kern Mountain and Go-si-ute Mountain, a spur of trachyte from the Antelope range west of it was seen by Mr. Howell to touch the range. The west side of Deep Creek valley and the low ridge known as the Antelope range showed us only trachyte and associated tuffs. The Schell Creek range is in the same vicinity—the vicinity of Schellbourne—overrun by trachyte and rhyolite, but not so completely as to entirely conceal the axial rocks. Southward, to Ruby Hill, its proportion of eruptive rocks diminishes, and none were seen beyond. The Ely range, which continues the same line of uplift to the south, was examined from Pioche northward by Mr. Howell, and found to be chiefly sedimentary, but flanked on the east in one place by trachyte.

The Pahroc range, where intersected by the road from Hyko to Pioche, is of trachyte, and, so far as could be judged from distant views, is volcanic for a number of miles both to the north and to the south. The Hyko range is a low ridge of limestone, accompanied by a few small bodies of trachyte. The Pahranagat, constituted chiefly of limestone, has one large eruption of rhyolite at its north end, where its strata dip below the general plain, and another at Logan Pass, where, at a cross-fault, the structure of the mountain is radically changed. Timpahute Peak is the culminating point of a massive eruption, which occurs at a similar change of structure in the parallel Timpahute range, and the intervening valley is interrupted by a line of volcanic hills.

The Belted Mountain range shows near White Bluff spring, and for several miles southward, an axis of quartzite; but its principal mass is of rhyolite and trachyte. Along the eastern front, these are of inflated and tuffaceous varieties; and, just north of White Bluff spring, they stretch eastward to the Reveille range. Along the crest of the range, there is a heavy cap of more compact lava, and this, extending westward, with slight descent, for ten or twelve miles, terminates in a bold step, overlooking the broad rocky desert that surrounds Oasis springs, the head of the Amargosa "River." From these springs eastward thirty miles, to Belted Mountain, westward twenty-five miles, to the edge of Death Valley, and northward as far as we could see—twenty-five or thirty miles—the entire surface of the country is covered by lavas. The principal centers of eruption are marked by broad, low-angled cones, and the prevailing colors are those of the acidic lavas. A few groups of small, steep crater-cones could be seen marking the position of basaltic vents, but they seemed quite subsidiary. To the south, this area is limited by the detrital stretches of the Amargosa desert, flanked at the east by the Paleozoic escarpment of Bare Mountain, and at the west by the Amargosa range.

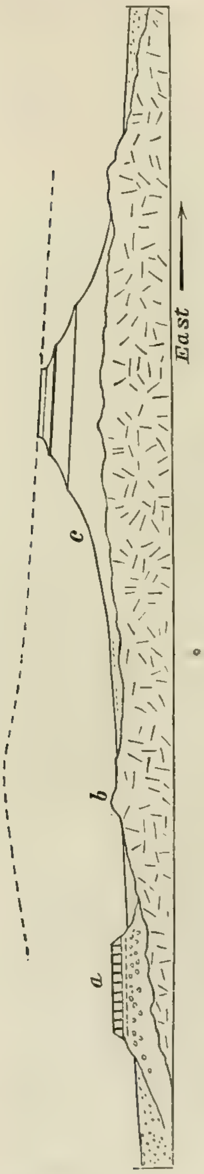


Fig. 31.—Section of Pilot Mountain, California. Scale, 1:150,000. *a*, basalt; *b*, granite; *c*, volcanic tuff.

The only locality at which lava was observed on the Spring Mountain range is near Good Spring, where there has been a small outflow of basalt. For thirty miles of its length, it has no considerable body of volcanic rock.

In California, our most westerly point was the eastern base of the Sierra Nevada; and the only volcanic eruptions seen there are some basaltic cones and *coulées*, a few miles north of Camp Independence,—utterly insignificant features in comparison with the granitoid body that overhangs them, and which constitutes, for so many miles, the eastern face of the great range. A little basalt was noted in crossing the Inyo range, but the mountain is not characterized by lavas. Its southward prolongation, the Coso, *is* so characterized, and south of Owens Lake appeared to us, as we skirted its western base, to be entirely eruptive. We noted, in its *débris*, rhyolite in great variety, trachyte, and basalt. The El Paso Mountains, southeast of Walker's Pass, are flanked at the south by basaltic and trachytic rocks, and connected at the east with a large mountain of acidic lavas, enclosing and nearly concealing a core of granite. East of this stands Pilot mountain, the monument of an accumulation and an erosion hard to conceive. Its summit is an inclined table of lava, capping and protecting about 2,000 feet of softer volcanic products, (probably tuffs,) and the whole stands alone on the highest swell of an uneven granitic surface that passes—except jutting peaks—beneath desert sands at the north and south. It appears to be an eccentric remnant of a great volcano, of which denudation has left no other conspicuous vestige. At its western base is a line of tabular basaltic hills of comparatively recent origin. Burnt Rock range is a monoclinal ridge of partially bedded volcanic products. It contains a series of trachytic and rhyolitic lavas, conglomerates, and tuffs, which present an escarpment to the east, and appear to have been uplifted *en masse.*

The mountains which flank Death Valley—the Panamint at the west and the Amargosa and Funeral at the east—are essentially mountains of upheaval; but, wherever we touched them, we found lavas present as subsidiary features.

The Colorado Mountains in Arizona, where intersected by the Colorado River in Black Cañon, are of massive trachyte, with a deep-buried axis of syenite, and are flanked by basaltic cones and *coulées.* In Boulder Cañon, there is shown an axis of metamorphic rocks, overlapped at the east by acidic and basic lavas in order.

The San Prieto mountains about Prescott show very little lava, but in the vicinity of Postal's Ranch, and thence to Granite Peak, are eruptive in character. Crossing the Black Hills near their northwestern extremity of the ridge, I found an inconspicuous fringe of basalt along each base. Farther south, Mr. Marvine found the axis nearly buried under lavas; and it is probable that the tabular crest lying between our routes is basaltic.

A most important feature of these eruptions is their association with the ridges of corrugation. The great majority of vents are along lines of upheaval, and of the remainder, the principal part are arranged in rows parallel to the structure lines. In the case of many lava fields, the points or lines of issue cannot be made out, and there are numerous eruptions that show no conformity to the general rule; but the law that the distribution of the lavas is in sympathy with the ridge structure, rests on too broad a basis of facts to be vitiated by its exceptions. More than this, there seems reason to believe that uplift and extrusion are, in a certain degree, mutually complementary, or equivalent. The highest ranges, as a rule, are (comparatively) non-volcanic, and those ranges, or portions of ranges, which exhibit the greatest eruptions are endowed with but low nuclei of other material. Where, in tracing a range, we find its crest exchanging non-volcanic rocks for volcanic, we do not find the latter heaped upon an undiminished ridge of the former, but rather replacing it, as it gradually or suddenly diminishes in height; and the case is strengthened by the consideration that, while the low, buried portion of the nucleus has been guarded by its mantle against the forces of denudation, the higher part has been exposed to a continuous waste.

That lavas in a disturbed region should find vent along existing lines of fracture might be assumed as probable upon any theory of mountain genesis; and it does not necessarily follow from the coincidence, in place, of uplift and eruption, that the subterranean *loci* of the action which has produced corrugation are identical with the volcanic sources. If, however, it be shown that along lines of disturbance there is an inverse quantitative relation between uplift and outflow, a strong argument is adduced, not merely for the identity in location, but for the absolute identity of the upheaving and volcanic forces; for, if the two modes of mountain building are complementary actions, they must be regarded as co-ordinate manifestations of the same agency.

It is by no means easy to demonstrate this interrelation of upheaval and eruption. My own confidence that it exists is derived from the comprehensive review of my notes, referring to about fifty of the Basin Ranges, and is a result of inspection rather than analysis. I know not how to present the material to the reader—without special pleading—so that it shall have the same force. The distribution of eruptions is, in detail, so capricious, and all estimates of the magnitude of mountain movements are so involved with considerations of erosion, that it would avail little, even were the material at hand, to attempt a full presentation of individual examples; while, in a more general statement, it is impossible to dissociate the observed facts from those personal impressions that are liable to be shaped more or less by preconceptions.

The universality of the lavas has already been mentioned. I have seen no range of the Basin system entirely free from volcanic rocks, and the reports of other explorers confirm the impression that such instances are rare exceptions.

The lavas of the Basin ranges are chiefly acidic. The basaltic rocks assume an exaggerated importance upon the map, from the fact that, having a later date, they overlie portions of the trachyte and rhyolite, and their thin-spread sheets have suffered less from erosion; but, when masses are considered, they shrink to insignificance. The more ancient basic lava, to which Mr. Richtofen has given the name of propylite, is perhaps of more importance; but its mode of occurrence is so similar to that of trachyte that no distinction could be made when it was not absolutely crossed. It is certainly far inferior in amount to the acidic.

The trachyte and rhyolite are characterized by what have been called massive eruptions; that is, by viscous eruptions of great volume, the lava of which, instead of flowing off in *coulées*, or building cones by slow accumulation of congealed streams, has, by single or few issues, formed bosses, often of great thickness, and divided by few or no surfaces of bedding. It is probable that these bosses lie usually immediately above the fissures from which the material has arisen; and they are often elongated into ridges parallel to the fissure system, as though there had been, in each case, a simultaneous issue along a considerable line of fracture. The material of these masses ranges from very compact lavas to those which are nearly as light as pumice, though lithoid in texture and only minutely vesicular. From the compact lavas, there is an easy gradation to the breccias, and the porous lavas are separated lithologically by no trenchant line from the tuffs; but the last, when well marked, always betray more or less bedding. Nearly all of the varieties found in massive eruptions are seen also in bedded sheets; and this mode of occurrence is as general as the other. Considering together the whole regions of the Basin ranges, the prevalence of rhyolite and trachyte tuffs is marked, though in many districts they are entirely wanting. Notwithstanding the rapid destruction to which their accumulations are subjected when they occupy elevated positions, they are yet retained in immense volume. Where best preserved, they are protected by caps of harder material, and exhibit bedding with notable inclination; but their denudation has usually progressed so far that only a hint is given of the magnitude of the volcanoes to which they pertained. Tuffs are less frequently associated with the basalts.

In volcanic phenomena, as in other features, the Plateaus are in some degree contrasted with the Ranges. Basalts assume a far greater prominence, rivaling the trachytes in abundance. Rhyolites are not in great force, and the chief trachyte masses are of basic varieties. The minor manifestations are almost invariably basaltic. Tuffs are nearly unknown. There is no observed arrangement of vents according to structure lines, and (this last, however, is not a contrasting feature) the distribution is unequal as well as irregular. The two principal fields traversed by our parties lie near the boundary of the Plateau system, and have their longer diameters parallel to that boundary. The more northerly is entirely within Utah, and is nearly included in the Sevier Basin. Northward it touches the parallel of 39°, near the town of Salina, and southward that of 37°30′. Westward it passes the plateau boundary, and coalesces with the eruptions of the Beaver and more westerly ranges; and eastward its crosses the rim of the Sevier Basin and encroaches on that of the Dirty Devil. Its boundary is irregular and includes a number of islands of sedimentary rock, but within it a straight line more than one hundred miles long (in a north-northeast direction) could be traced entirely on lava. The greatest dimension at right angles to this is about sixty-five miles, and the entire continuous area of lava comprises about five thousand square miles. The predominant rock in this field is a trachyte closely related to dolerite, and this gives place eastward to more acid trachyte and rhyolite, and southward to basalt. Except in the Beaver range the flow of the lavas has been in broad sheets, and these, accumulating in a deep series before the faulting of the Plateau rocks, have been thrown into cliffs and inclined tables, together with the underlying sedimentaries. Along the east side of the Sevier Valley, from Red Cañon, near Panquitch, to the neighborhood of Glencove, these cliffs, produced by the great Sevier fault, reveal a depth of bedded trachyte that must average 1,500 feet, and at its maximum exceeds 2,000 feet by an unknown amount, the base of the series being unseen. The principal basaltic tracts in this field lie east of Fish Lake and Otter Creek, about the headwaters of the Dirty Devil River, and southwest of Panquitch. A description of the former will be found in Mr. Howell's report. The latter is thickly studded with lava cones and cinder cones of no great magnitude, and is spread with a long succession of *coulées*, the latest of which are so recent that vegetation has as yet no hold on their black, blistered surfaces.

North of this great field Mr. Howell observed two isolated masses of lava, the first of trachyte, constituting the southward spur of the Wahsatch range, which separates the main forks of Sam Pitch Creek, and the second of rhyolite, lying along the western base of the Sam Pitch Mountains. South of the same field are a series of basaltic cones and streams, that may, perhaps, be regarded as outliers of the Panquitch basalt district. They occur upon and to the east of the head of Kanab Creek, about the head of the Virgin River, overlooking the valley of the Virgin from both sides a little below the union of its main branches, and within the valley in the vicinity of the towns of Toquerville and Washington. The Uinkaret Mountains, beginning fifty miles farther south, are a larger group of the same character, carrying the chain, if chain it may be called, to the Grand Cañon of the Colorado.

A few miles beyond the Colorado commences the second great lava field of the Plateaus, one far exceeding that of the Sevier Basin in magnitude, but only partially included in our region of exploration. Beginning in the neighborhood of Truxton Spring and the head of Diamond Creek, it stretches, in an uneven but continuous belt, east-southeast to Sierra Blanca, and, beyond, spreads several broad lobes over New Mexico, the most easterly of which reaches nearly to the Rio Grande. Its extreme limits, in longitudes 113° and 107° 15′, are three hundred and twenty-five miles apart. Northward it touches the parallel of 35° 40′, and southward that of 32° 50′. What share of the Arizonian portion we have here to consider has an area of about ten thousand square miles, and is perhaps one-half of the whole. It includes the San Francisco group, the Mogollon Mountains, and the Sierra Blanca, and these follow from west to east, in the order named, along the southern margin of the Plateau country.

The San Francisco group includes a series of large cones of trachyte, the product of massive eruptions, and a great multitude of small basaltic cones, associated with broad and, in part, thick sheets of basaltic lava. The trachyte has, perhaps, the greater mass, but the basalt covers by far the larger area. The larger cones, though they may justly be called a group, are separated by intervals of several miles. The largest, San Francisco and Bill Williams Mountains, were ascended, and the character of Mount Floyd was ascertained in crossing its northward spur. Mount Sitgreaves, in form, color, and size, connects itself with the trachytic class, and Mounts Kendrick and Picacho are doubtfully referred to the same class, although in form they rather resemble the smaller, crater-bearing, basaltic cones. While the number of vents of trachyte was small, at most not exceeding a half dozen, the basaltic vents were very many, probably some hundreds in number. As many as one hundred are marked by cinder cones, of which sixty-five with craters, partially or wholly preserved, were counted from the summit of San Francisco Mountain about its foot. In this vicinity the floor of the Plateau is the Aubrey limestone, (Upper Carboniferous,) and there is a gentle dip northward from the Aubrey cliffs to the Colorado and Colorado Chiquito. The cones stand near the upper (southern) edge of the table, and the flowing lavas have in part overrun the cliff, and poured into the valleys of the Verde and its tributaries. The principal roads connecting the upper and lower countries avoid the precipice that marks the outcrop of the upper Aubrey beds, by following the easy grades of these black congealed rivers.

The Sierra Blanca likewise presents peaks of massive trachyte flanked by basalt. The interval of one hundred and seventy miles between it and San Francisco Mountain is bridged by a chain of basaltic eruptions, merging with those that surround the trachyte masses. Through the greater part of its extent, this basalt flow is low and broad in cross-section, and it neither merits nor receives the title of mountain, save at one point, where a cluster of unusually large basalt cones, near the Sierra Blanca, has been given the name of Mogollon (hanger on) Mountains. Mr. Marvine's route intersected this field in two places, and its characteristics will be found described in his report.

It is well worthy of note that the majority of these eruptions among the Plateaus rest upon nearly level strata, and that where they are associated with inclined strata, such inclination is seen to pertain to a structure extending far beyond the volcanic outburst, and evidently not dependent on it as a cause. Among the Basin Ranges the strata are so greatly dislocated, independently, that it is impossible to determine that the eruptions have or have not disturbed them; but where the normal structure is so simple as it is in the Plateau country, a local structure imposed by the extrusion of lava could not escape detection, and we have direct evidence in its absence that the eruptive rocks, in passing through, have not uplifted the sedimentary. This remark applies not merely to the eruptions of basalt, which we know from the narrowness of its dikes and the easy slope of its currents to have been usually a tolerably thin fluid, but also to the most viscous trachyte, which, in the case of San Francisco Mountain, for example, has been built, not a scoriaceous mass, but a pyramid of compact lava, to a height of nearly 5,000 feet, with slopes of 10° to 20°. It is by no means impossible, it is probable, rather, that in upheaved ranges, uprising lavas sometimes force apart rock masses, already greatly dislocated, so as to open the broad fissures, in which their dikes are occasionally found. But the idea that ridges of corrugation are lifted by the eruptive rocks that are associated with them—an idea that finds frequent expression in the phrases "upheaved by trap," "upheaved by granite"—appears deserving to be laid on the shelf along with the cognate idea of "craters of upheaval."

Turning now from the distribution of the lavas, we will consider for a moment their petrography.

The proposal by F. Richtofen of a "Natural System of Volcanic Rocks" (Proc. Cal. Acad. Sci.) is of special interest to geologists, as a most able attempt to classify geologically a group of rocks that had been before considered almost exclusively from a chemical and lithological point of view; and we have endeavored, so far as we were able, to test his classification by examinations in the field. Our material does not warrant a discussion of his conclusions, failing as it does to comprise the results of any detailed study, but upon one point the very width of the field crossed in our rapid transit, permits us to speak. Richtofen's theorem is that volcanic rocks have a natural order of sequence, viz, propylite, andesite, trachyte, rhyolite, basalt. The first and second of these divisions we have rarely met, and we have no reason to question their inferior position. Of the succession of trachyte and rhyolite, we cannot speak definitely, although we have seen them more often than other species. Their constant association, their identity in habit, the parallelism of their multitudinous varieties, and their intergradation have prevented their ready discrimination in the field, and, at the same time, occasioned doubt as to the validity of their separation. The basalt group, on the other hand, was everywhere distinguished, and its relations made out. With a single exception, observed by Mr. Marvine, at Truxton Spring, Arizona, it was seen to overlie, wherever it touched, rhyolite and trachyte. Usually there was evidence by erosion of a great lapse of time between the trachytic and basaltic eruptions, and in this way a relation of sequence was established where there was no contact. Along the Sevier fault, near Glencove and Salina, for example, trachyte sheets, conforming to the Tertiary strata, and dipping with them, are shown to have been spread before the disturbance, while basalt, resting unconformably on the tilted and eroded strata, evinces its later advent. The trachyte of Pine Valley Mountain has resisted the erosion that has opened valleys around it, (see report of Mr. Howell,) and it stands a lofty "mountain of circumdenudation;" while in the valleys at its foot have sprung up a chain of basaltic cones. Since the eruption of the trachyte of San Francisco Mountain, no less than 700 feet of strata have been removed from about it; and the basalt of the immediate vicinity rests on the new floor of the plain. At this locality, however, the succession is also shown by actual contact and superposition. Superposition was also seen at Mount Bill Williams and Mount Floyd, at Piute Spring, at the head of the Black Cañon, at Postal's ranch, near Little Owens Lake, near Logan, Nev., at Quinn Cañon, at Reveille, near Copper Cañon, between Battle Mountain and Rock Creek, on Maggie's Creek, near Black Rock Spring, Utah, and by Mr. Howell, near Adamsville, Utah, and in Rabbit Valley, east of Fish Lake. Other cases, less strongly marked, point in the same way, and serve to establish the rule—truly a rule, notwithstanding its exceptions—that in the great volcanic region west of the Plains, the trachytic or acidic lavas have preceded the associated basaltic.*

* The term basalt, here and elsewhere in this report, is used with Mr. Richtofen to include, besides basalt proper, dolerite and anamesite.

The variety of the trachyte and rhyolite lavas is endless. Nearly every new locality shows a new phase. From a mass,composed of a rough lithoid paste, with imbedded crystals of orthoclase, oligoclase, hornblende, mica, quartz, &c., there is a perfect gradation, in one direction to varieties with a compact and even vitreous paste, and thence to obsidians and varicolored glasses, and to pumice; and in another to a phase in which the paste predominates, and, while lusterless as chalk, and nearly as soft, is much lighter in weight. No line can be drawn between this and a volcanic mud, nor between the latter and tuff. All varieties contain occasional imbedded fragments, generally of somewhat similar constitution; and, by the multiplication of these, pass into corresponding lava breccias and conglomerates. A curious imitative phase makes up the principal massof Baldy and Belknap peaks in the Beaver range. An even, finely granular paste, without crystals, laminated, dull, harsh to the touch, it is to be distinguished, in hand specimens, from the buff sandstones of massive, cross-bedded habit, only by the aid of a miscroscope. Its mode of occurrence leaves no doubt of its eruptive character, but it was hard to realize, even when viewing it in mass, that it was not of sedimentary origin. Associated with it are subvitreous, laminated to foliated, rhyolites, strongly suggestive, in small masses, of silicified wood. The latter are also, in part, spherulitic, and at the western foot of the mountain include siliceous concretions several feet in diameter. To this class of lavas belong the glasses that at Argenta, Nevada, and Beaver, Utah, have been mistaken for anthracite.

The basaltic group shows less variability, its prevalent forms being compact microcrystalline lava and scoria. Obsidian, pumice, and tuff are seldom seen. The crater-cones are built of a light, thin-partitioned scoria never glassy, which weathers, from an original black, to various shades of brown and red. The upper surfaces of lava streams are distended by coarse vesicles with thick partitions, and these, in the older streams, contain crystallizations of calcite and zeolites. Columnar structure is far more frequent than with the trachytes, but in no instance have we observed it with such regular prisms as are found in Ireland and upon the Columbia River. The prisms stand normal to the cooling surface, and closely resemble in form those with which we are familiar in the starch of commerce. In the starch, the structure is produced by progressive shrinkage, beginning on the exterior of a drying mass; in the lava, by progressive shrinkage of a cooling mass. In dikes, independent systems of prisms are formed from the two walls, and at their meeting in the middle the rock is unevenly cracked. In *coulées* also there are often two systems, the one from above and the other from below; and, in this case, the line of meeting is usually below the middle of the mass.

The Geological Age of the Lavas is not clearly determined by such evidence as we have gathered. The trachytic rest upon, and intersect in dikes, all the sedimentary rocks from the Archæan to the Tertiary, and they were seen to underlie none of these. Their relation to Cretaceous and Tertiary strata is shown only in the Plateau country, since the region of the Basin Ranges was continental during those periods, and contains their record, so far as we know, only in subaerial, non-fossiliferous beds, continuous with, and not distinguishable from, the Quaternary. At a number of points, trachytes are seen to be interstratified with these subaerial deposits, and near Sevier Lake a sheet of rhyolite is spread near the top of the series. At every point of contact the trachytes and rhyolites underlie the Bonneville beds.

These meager data from deposition are supplemented by some facts of denudation. With the beginning of the post-Jurassic uplift of the Basin Ranges, there began a wasting of the ridges that has continued ever since, and, wherever the facts can be determined, the lavas are found to rest on greatly eroded surfaces of the upturned strata. With reference, however, to the greatest eruptions the facts are not known, since they constitute ranges by themselves, surrounded by secretive blankets of Quaternary gravel. On the other hand, the denudation of the trachytes themselves has been great—so great that it is measured by the same order of unit that is applied to the denudation of the sedimentary beds. Not merely is the original surface removed from even the most recent of the trachytes, but all craters have been destroyed, and cones of mingled tuff and lava, that must have assumed the most imposing proportions, have been reduced to the merest ruins. Great dislocation, as well as denudation, has succeeded, in places, the accumulation of trachytes and rhyolites, and mineral veins have been formed within them and along their contact planes. Great erosion certainly, and probably dislocation also, of early eruptions, have been succeeded by later eruptions, and stand in proof of the great duration of the trachytic epoch.*

Basaltic eruptions have bridged over the chasm from the trachytic to modern times. Mr. Marvine found them alternating with rhyolite at Truxton Spring. They overlie all the sedimentaries up to and including the Bonneville beds. They underlie also the Bonneville beds, and are interstratified with the subaerial drift. At the Cathedral Mesa on the Colorado, between Bowlder and Iceberg Cañons, a basalt bed rests on 200 feet of this drift, and is covered by 300 more. Its antiquity is expressed by the 300 feet of deposition over it, plus the 500 feet of denudation that has laid bare the escarpment. Unless some unknown change of levels has occurred, this denudation has only kept pace with the erosion of Bowlder Cañon, ten miles long, through tough Archæan rocks. At the mouth of the Grand Wash a stream of basalt reached the river bed when it was 200 feet higher than at present, and its antiquity is measured by so much degradation of Iceberg Cañon. At a point in the Grand Cañon below Diamond Creek, a *coulée* has entered from a side gorge, and the river has since descended 75 feet into the granite. Camp Apache is built in a valley several miles broad and 1,200 feet deep, excavated in Carboniferous sandstone and limestone by the White Mountain River since the flow of the basalt which caps the adjacent uplands. A second lava stream, and a third, have flowed down the new valley, and have been in turn cut through by the creek, the channel of which is now but 50 or 75 feet below the last lava surface. (The oldest lava of the Uinkaret or North Side Mountains, identified as basaltic by Professor Powell, preceded the denudation that has retired the lower

*The localities upon which these observations are based are, for the most part, mentioned, either in the *résumé* of distribution in the earlier part of the chapter, or in the special descriptions at the end. Trachyte rests on Tertiary strata east of the Sevier Valley, from Panquitch to Glendale, and has been faulted with them. Trachyte overlies subaerial drift in the El Paso Mountains, at Red Rock Cañon, and on the eastern side of Death Valley; it passes under such drift at the foot of nearly every trachytic mountain. At Belmont, Nev., rhyolite rests on uptilted edges of Silurian slates; near Boundary Cañon, on Lower Silurian quartzite, from which, as proved in the immediate vicinity, many thousand feet of superior strata have been worn; in Bowlder Cañon, of the Colorado, it is seen to rest on Archæan schists. Of great post-trachytic denudation, Pilot Mountain, San Francisco Mountain, and Pine Valley Mountain afford illustration; and San Francisco Mountain shows a later eruption of acidic lava. Bedded trachytes are disturbed at Burnt Rock Mountain, and at Red Rock Cañon, Cal.

Triassic escarpment, (Vermilion Cliff,) here 1,500 feet high, to a distance of thirty miles. In contrast with this, there is perched upon the very slope of this escarpment, near Virgin City, a fresh built cone, and other cones dot the intervening plain, and especially surround the base of the Triassic island preserved by the older eruption. Basalt streams and cones, so recent that their surfaces yet afford no soil for vegetation, were seen in Owens Valley, near San Francisco Mountain, and in Utah, near Glendale, near Toquerville, in Diamond Valley, (Howell,) near Skumpah, near Pauquitch, near the Cedar range, (Howell,) and near Fillmore. The last named are the freshest of all, and may fairly be called modern, although there is no tradition of their eruption. The weathering of the frail scoria, that caps the latest crater rim, does not seem to have begun; the frothy, taffy-like pellets that, spattered from the bubbling caldron, fell half cooled upon its wall seem as though congealed but yesterday. Only the consideration of the extreme aridity of the climate can countenance the possibility that centuries, instead of years merely, may have elapsed since the termination of this eruption; and no one who studies its monuments can avoid the feeling that it is so far an affair of the present, that no surprise would be occasioned by its recurrence. Indeed, when we compare the stupendous denudation that has transpired during the period of basaltic vulcanicity in this region, with the differential film that has been removed since this last manifestation, and when we consider, in addition, that intermittence is a characteristic of volcanic activity, we are not merely permitted to think of a renewal of that activity as possible, but are logically compelled to regard it as probable. There is really no more reason to believe that the epoch of basalt has closed in this region, than that it has barely begun; and it is certainly probable that the few centuries we can know by history and tradition, belong to one of the intervals of quiet, such as separate the more or less convulsive efforts of volcanoes; an interval to be terminated sooner or later by a renewal of activity.

More detailed description will be given of a few localities:

The Fillmore Group of cones and lava beds rests on the broad floor of the Sevier Desert, west of the Pah-vant range, and far enough removed from it to be considered entirely independent. The Pah-vant Butte, the largest and one of the most northerly of the group, is seventeen miles from Fillmore, in a northwest direction. The Ice Spring cluster lies ten miles west of Fillmore, and four miles south of it is the Tabernacle cluster. Southwest from the Tabernacle, and six miles distant, stands a small cone that was not visited, and four miles north northeast from Pah-vant Butte is a low lava cone. All of them are surrounded by more or less recent lava beds, and these unite (except two narrow gaps) to form a continuous field twenty-five miles long and three to five miles broad. A full description of the group would probably include also some cones observed by Dr. H. C. Yarrow further south, in the vicinity of Corn Creek settlement.

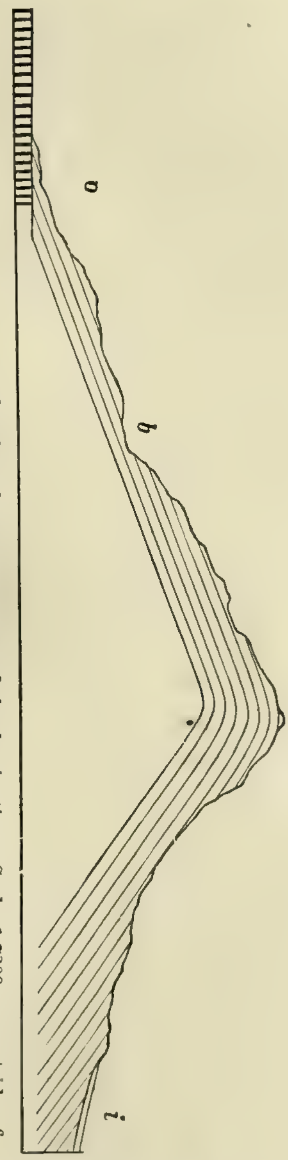


Fig. 52.—Section of Pah-van Butte, showing the arrangement of the lamination. Scale, 1-7200. o, outside of crater; i, inside; b, Bonneville beach.

Pah-vant Butte is the only tuff-cone of the group. It is in crescent form, preserving about two-thirds of the wall of its crater. The southwestern portion of the wall has been removed, and the highest remaining point is northeast of the crater. The external diameter of the crescent is about one and a half miles. The culminating point stands 800 feet above the base. The material is a tuff of very light cinders. It is firmly coherent, but the cement does not fill the pores of the cinder fragments. The prevailing color on fresh fractures is an ochre yellow; on weathered surfaces, a dark gray. Successive surfaces of deposition are marked by a rude lamination, conspicuous in large masses, but not inducing a decided cleavage. This lamination dips both ways from the rim; inward, at about 35°; outward, at from 20° to 25°; the two slopes being united at top by a curve. The Bonneville beach is carved upon the outer slope 300 feet above the lava floor at its foot, and all of the associated lava beds were covered by the Bonneville waters. The lavas are in part concealed by Bonneville sands, but, where bare, have a tolerable freshness, the convolutions of the once flowing paste being yet well preserved. The tuff-cone rests upon them.

The Ice Spring cluster includes three perfect craters, and vestiges of one, and perhaps two others. The oldest of all is preserved only in a fragmental ridge, 260 feet in extreme height, so curved as to indicate an original internal diameter of one-half or two-thirds of a mile. (*a*, Fig. 53.) Within its arc is slight indication of the existence of a smaller cone of softer material, and at once later than this and earlier than the others. Of the three perfect cones, marked *b*, *c*, and *d* on the diagram, the newest is the central and largest, *c*, and the inter-relation of the others was not ascertained. They are all very recent. The smallest, *b*, has a rim of uneven height, ranging from 150 to 90 feet above the surrounding lava bed, and the descent from the lowest lip to the bottom of the crater is 30 feet. The exterior surface is regularly conic, and as steep as the falling scoriæ would lie, but shows very little loose material, a great part of the ejected matter having fallen in a molten or viscous condition, so as to cohere in a firm mass. The inner slopes are made of angular fragments, large and small, fallen from the rim, and meet at the bottom, where is a little cool water and a solitary tuft of grass. The water appears to be much resorted to by birds, and a game trail leads to it over the lowest sag of the rim. The central crater is of precisely similar character. The highest and lowest points of its rim are, respectively, 250 and 100 feet above the outside base, and the dry bottom of the crater is 100 feet lower than the lowest rim.

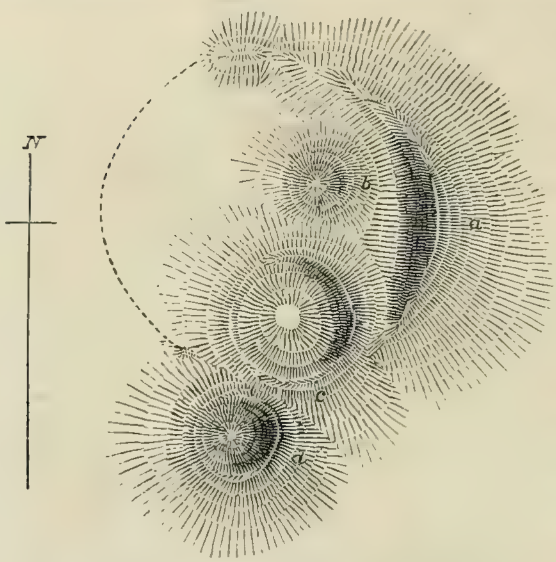


FIG. 53.—The Ice Spring cluster of lava cones, near Fillmore, Utah.

The remaining cone, *d*, is especially interesting, since the lava of which it is built has not fallen down and choked the interior, but all remains precisely as the retreating fluid left it. It is about as broad as the last mentioned, but comparatively low, its rim rising only from 60 to 100 feet above the outside lava field. It is possible that its flanks are partially buried by later eruptions. Its eruption does not appear to have terminated with the ejection of scoria, but, at the last high tide of its lava, a crust was formed about the eastern border of the crater. When the subsiding flood withdrew its support, a portion of the crust fell, but the remainder still forms a shelf upon the slope. The retirement of the lava was so rapid that no other floor was produced, and the flue through which it entered and departed is unclogged. The relations of the shelf and flue to the crater walls are shown in the sectional diagram. (Fig. 67.) The flue is eccentric, oblique, and unevenly cylindric, with a diameter of 12 feet. Its walls are flecked with arborescent accretions of white calcite. Descent into it is checked at a few rods by water, which fills it to an unknown depth; the level of the water surface being 50 feet below the outside lava plain. The features of this spot were peculiarly impressive. Not often can the eye so fully aid the imagination to picture the former life of a dead crater. Through the narrow sloping tube in which we stood had poured the molten tide that overwhelmed miles of the plain, and down its throat had been swallowed what remained in the crater mouth when the force that expelled it gave way. Black drops of the pasty flood still hung in witness from every angle of the roof and sides, and the crust without was corded with the ropy foldings of the seething caldron. Below the floor that marked the last high tide there was no sign of lingering. With one movement the hollow had

Fig. 54.—Section and sketch of cone *d* of the Ice Spring cluster, showing shelf of congealed lava and lava conduit.

been emptied, and the lava that had formed a glowing lakelet, acres in extent, sank back to the source from which it came.

About these cones there are at least two distinct lava floods. The older may have the same date as the old fragmental cone; the newer must pertain to the same eruption as the perfect craters. In the immediate vicinity of the cones the older flood shows only a few islands, and is conspicuous in the possession of a soil on which the sage has taken root. The newer is soilless and plantless—not even a lichen clinging to its surface—for all that can be seen, just as the cooling left it. Its surface is a chaos of black, ragged slabs of lava crust, piled as are the ice cakes that, in spring-freshets, dam our northern rivers. In places the congealed crust was deserted by the lava beneath and fell in. Elsewhere it was possibly torn by the force of steam from the moist ground over which part of the lava ran. Everywhere the flood is thrown into ragged waves, 10, 20, and even 40 feet in height. The more compact masses are divided by sharp edged fissures, often several feet in width and 10 or 20 in depth. At many places we saw a peculiar, harsh, papillate surface, produced by the dragging of viscous lava against what was already hard—such a surface as a trowel leaves on very stiff mortar. (See Plate XII*.)

In one of the lowest depressions of this recent lava is Ice Spring, from which the cluster of cones is named. Lieutenant Marshall found there in July not only water at 32°, but enough ice to justify the name. He regards it, not as a phenomenon of evaporation—for evaporation in that sheltered and shaded place is very slow—but as a natural ice house, storing the winter's snow.

The Tabernacle cluster is named from the resemblance of the distant profile of the chief butte to the Mormon tabernacle at Salt Lake City. The resemblance vanishes on nearer view, and the seeming oval dome is seen to be the fragment of an old crater wall. It is 150 feet high and about 2,000 feet long, and other fragments of the same indicate that the crater once inclosed had a diameter of half a mile. It is now quite flooded by more recent lavas, and within it are two smaller craters, one of which overlaps

* The upper of the blocks represented in the plate was taken from the crest of crater c of the cluster, the lower from the adjacent lava-stream.

the other; but none of the eruptions have the freshness of those just described. The surrounding lava field, also, is comparatively old, though still nearly bare. Soil enough has gathered in its lowest places to support a growth of bushes and grass. Its most interesting feature is the existence of a number of caves, produced by the escape of lavas from their channels, after the formation of a self-sustaining crust. The caves lie entirely below the general level of the lava field, and we discovered them only where portions of their roofs had fallen. Descending through one of these roof openings, Lieutenant Hoxie and I followed the tubular aperture for one or two hundred feet, and climbed out at another break. The width of the cave averaged 30 feet and the depth 18, and in length it extended indefinitely beyond the section we explored. The original bottom was not visible, being strewn with fallen fragments of rock, and covered to an unknown depth by the ordure of owls and bats.

The margin of this lava shows an obscure beach line of the Bonneville series, from which were gathered shells of *Limnæa desidiosa*, but it was not examined with sufficient care to determine fully its relation to that series. The cones and streams of the Ice Spring cluster were certainly untouched by the Bonneville waters, although their highest points are 200 feet below the Bonneville mark on the foot slope of the Pah-van range.

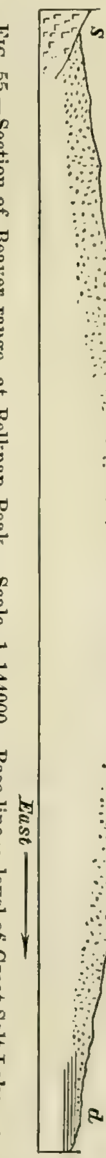


FIG. 55.—Section of Beaver range, at Belknap Peak. Scale, 1-144000. Base line = level of Great Salt Lake. s, syenite; d, sedimentary rocks; r, rhyolite.

Beaver Range.—A partial section of the Beaver Range, Utah, was obtained at Belknap Peak, one of its culminating points. The peak was ascended from the west, and the character of the eastern base was afterward ascertained by a visit to the Ohio mining district. The range at this point rises 5,500 feet above the adjacent valleys, and is eighteen miles broad. At the western base a foot hill, lying chiefly between North and Indian Creeks but cut across by the latter, consists of syenite. The mass has a north and south trend, and is probably flanked at the east by quartzite. I say "probably," because portions of the adjacent rhyolite were afterward found to so closely simulate quartzite that doubt was thrown on the determination after all opportunity for re-examination was past. Under the eastern base of the range, the cañon of Pine Creek reveals 300 feet of nearly level strata, including sandstone of several varieties and shale or slate, but containing no fossils, save obscure fucoid casts. The whole have been partially metamorphosed, but show no folding. Except these basal exposures, the entire profile is volcanic, and, either way from the crest, the first 4,000 feet of descent is upon lava. Pine Creek exposes a great mass of tough porphyritic oligoclase-trachyte, in great part brecciated, and containing the metalliferous veins of the Ohio district. Surrounding and overlying this, and extending to the syenite of the opposite base of the range, is an immense body of rhyolite, presenting some diversity of character, but consisting chiefly of the variety already described as the close counterpart of certain sandstones. Northward this lava cover continues for about fifteen miles, but probably diminishes in thickness as the range diminished in height. Southward, for twenty-five miles, to Frémont's Pass the crest of the range, while it grows broader, loses little in height, and it is probable that the lava mass is even greater in that direction. Opposite Circleville, twenty miles south of Pine Creek, the range presents a bold eastward front 6,000 feet high, the whole of which appears to be volcanic. There is probably no exaggeration in estimating the dimensions of this great lava mass at: length, forty miles; average width, fifteen miles; average depth, 2,500 feet; which gives a total of two hundred and eighty-four cubic miles.

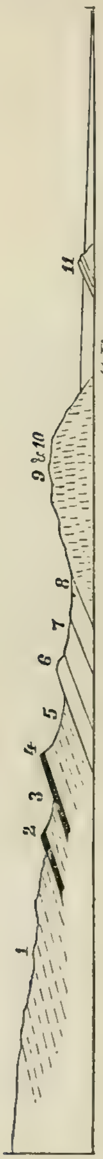


FIG. 56.—Section of Red Rock Cañon beds, Southern California. Scale, 1-14400.

Red Rock Cañon.—In the vicinity of Walker's Pass there is a long, low, detrital slope from the Sierra Nevada to the desert at the east, and the same exists thirty miles farther south. In the interval the slope is interrupted by the low, irregular El Paso Mountains, which appear to have risen, in part at least, since the establishment of the detrital slope. Red Rock Cañon, having a southeast course, intersects a southerly spur of the El Paso Mountains, and rises among detrital beds that lie between this spur and the Sierra Nevada. For two or three miles it cuts obliquely a series of beds dipping westward from the El Paso spur, at angles ranging from 15° to 30°. Fig. 56 gives a section normal to the strike, but based on notes taken along the oblique cutting of the cañon. No. 1 is a lightly cemented coarse sand or fine gravel, pale umber to ochre in color, and consisting of rounded grains of quartz, mica, feldspar, and divers volcanic rocks. Upward it is inseparable from the granite sand of the Sierra slope. It does not cleave into strata, but the direction of bedding is conspicuous in the exposures, and different layers weather so unequally that the whole is carved into a series of escarpments, the faces of which are beautifully fluted by rain The thickness exceeds 400 feet. Nos. 2 and 4 are basalts, 30 and 50 feet respectively in thickness. No. 3, 100 feet, No. 5, 200 feet, and No. 7, 100 feet, are like No. 1, but more coherent, the cementing material being insoluble in acids. No. 6, 100 feet thick, is a homogeneous, pale pink, volcanic tuff, containing all the constituents of the adjacent sands, with the addition of pumice and a definite matrix. No. 8 is a sand like No. 1, but well cemented by oxide of iron. No. 9 is an orange, massive, subspherulitic rhyolite, and No. 10, a massive fine-grained compound of hornblende, pyrite, and a feldspar. The two, whose correlation was not made out, constitute the spur of the range and wall the cañon for a half mile. Beyond them the sands are resumed (11) with the same dip, but their relation was not established. The line of section, produced eastward, would reach out on an open desert—that in which is the Desert Wells stage station.

The chief interest of the section lies in the close relationship of the sand beds to the intercalated tuff. The latter is a product of eruption, endowed with a light vesicular paste, and separable by no sharp line from typical lavas. The former is so closely affiliated to the tuff, on the one hand, and to the ordinary desert detritus on the other, that we are left in doubt whether it was transported and distributed by volcanic or by meteoric waters.

Meadow Creek Chimney.—The cañon of Meadow Creek, near Belmont, Nevada, is cut through a flow of compact rhyolite, and at one point lays bare a peculiar structure that probably pertains to a point of issue. The rock is divided by a set of curved joints, concentric, and, in vertical as well as horizontal section, concave toward their common axis. The whole mass is apparently homogeneous, but is unequally eroded in a manner somehow dependent on the arrangement of the joints. The core has disappeared, and in its place is an amphitheatric cove opening to the cañon. The walls of the amphitheater are composed of sectile lava, in concentric leaves, like those of an onion bulb, and have somewhat the form of a crater. Outside them a circular line of weakness is marked by an eroded valley, and beyond this lies the general lava sheet. The crateriform wall has a height of 100 feet, and a diameter from crest to crest of about 300 feet. Its relation to the lava field is shown in the annexed diagram, (Fig. 57,) which presents substantially the section afforded by the creek, and the structure of its wall is shown in Plate V, which reproduces a photograph of the portion represented at *a* in the diagram. I conceive that the amphitheater, *c*, is immediately above the opening through which the lava issued, and that the concentric division surfaces are in some way a function of the movement of the lava. If a viscous fluid issue from an aperture in a level surface and spread equally in all directions, the portion emerging at any one instant will assume successively some such positions as are represented in the curved lines of Fig. 58, and a lamination resulting from a motion of this character would correspond in form with the divisions just described. The structure of the rhyolite, however, is spe-

FIG. 57.—Section of lava flow exhibited in Meadow Creek Cañon, near Belmont, Nev., showing the arrangement of cleavage planes. The base-line is the level of the creek bed.

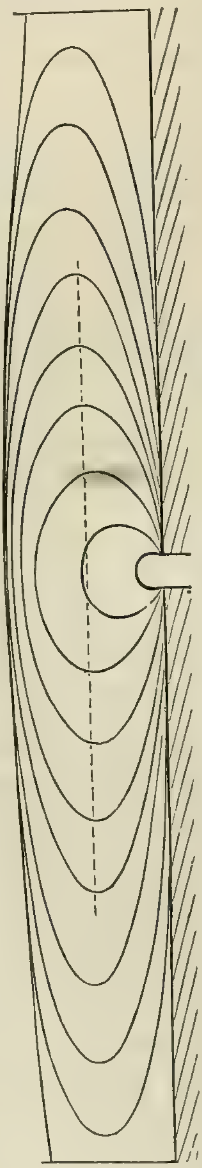


FIG. 58.—Ideal section of Meadow Creek lava-flow. The dotted line indicates the level of the creek bed.

cifically a cleavage, and there is, strictly speaking, no visible lamination. The cleavage planes frequently divide the inclosed crystals of quartz and feldspar.

Thermal Springs are so often associated with volcanoes, that they are regarded by many writers as volcanic phenomena, notwithstanding their frequent occurrence in regions not otherwise marked as volcanic. The problem of their relation to vulcanism has so far interested me that I have been led to look somewhat beyond the limits of our explorations for material bearing thereon. A portion of the material gathered led to no conclusion and need not be rehearsed, but the results indicated by some facts of general distribution are so little ambiguous, that I may be pardoned for presenting them in this place, even though they involve a *conspectus* of the entire country.

In the present state of our knowledge and speculation in regard to the structure of the earth's crust, there are several explanations that may be offered of the existence of thermal springs. It is now beyond question that there is an increase of temperature downward from the surface of the earth, and observations are so far accordant, that the range of recent estimates of the rate of increase is only from one degree Fahrenheit for 50 feet of descent to one degree for 90 feet. So we have reason to expect that water, which, between the region where it enters the earth, and the point at which it emerges, passes far beneath the surface, will have been heated and will issue with a temperature higher than the average local temperature of the ground and air; that is, that it will be thermal. Since all spring water passes underground, we should expect, as is found, that spring water as a rule will be, however slightly, thermal. The deeper the water passes in its subterranean transit, the more heat it will receive. The greater its volume and the more rapid its rise to the surface, the less heat will it lose by contact with the upper and cooler portions of its channel walls. So hot springs may be found where the rock structure is such as to lead subterranean water by quick routes from great depths; and, since water follows either fissures or the partings of strata, these conditions will be met only where the rocks are greatly inclined or are fractured. The tilting and the fracturing of strata are concomitant features of mountain corrugation, and to regions of such corrugation we should look for thermal waters, while in regions of unfractured and horizontal strata they cannot arise from this cause.

The theory of mountain building, advocated by Messrs. Hunt, Mallet, and Le Conte, and which is now the most prominent, if not the dominant theory, calls mountain corrugation a result of mechanical "work," due to horizontal pressure, (a function of the secular cooling of the earth,) and announces as a second result of the same work, the development of heat in the *loci* of the work. It is held that, in some places, corrugation does not take place, but, instead, there results a local crushing of the rock, accompanied by sufficient heat to produce local fusion, and furnish the material for volcanoes. If this be the true theory of volcanoes, then the equilibrium of the heat of the crust may be disturbed by the production of local *maxima*, not only where the rocks are pierced by molten dikes, but also in the places, not necessarily very deep seated, where lava is formed, and also along the axes of corrugation; and these regions would naturally contain hot springs. The inequalities of temperature would be greatest during the formation of mountains, whether by corrugation or eruption, and would slowly diminish by conduction after the activity ceased; and hydrothermal phenomena arising from such cause would be most intense where mountains are forming, or have been formed at a late date. In any case, except that of waters heated by fresh dikes, the conditions must be such that the currents rise from considerable depths; and the only difference between the manifestations in a region now undergoing corrugation, and in one that has rested and cooled for many ages, would be a difference of degree. The most intense action would be produced by recent dikes. Where the discharge is small, and the temperature high, the source of heat cannot be remote, else the heat would have been lost in transit; and, as this is the rule with geysers, they are probably regarded with propriety as strictly volcanic phenomena, indicating the recent injection near the surface of hot lava, whether or not it has been extruded.

The thermal springs of the United States are now sufficiently known to afford some criterion of the value of such speculations, and, for the purpose of comparing their distribution with that of mountain structures, I have collected such data as are available. In the accompanying table are included, with insignificant exception, only such springs as exceed in temperature the local annual mean by not less than 15° Fahrenheit. It is not a list of individual springs, but of localities, and the temperatures given are the highest noted at the several localities, except that, where there is reason to believe that a change has occurred, the latest record is quoted. Where no references are given to publications, the data were gathered by members of our expedition.*

The accompanying map represents the same localities, save a few so closely adjacent to others, that the signs by which they are indicated would overlap. Where the temperature is known the figures expressing it are used to mark the locality; where it is not, a cross. Upon the same map are indicated some of the principal structural divisions of the country. At the east is the Appalachian region of corrugation; at the west a larger and complex corrugation system, continuous from the western limit of the Plains to the Pacific. This latter district it will be convenient to call the Western Mountain region. In the interval, a region nearly coincident with the basin of the Mississippi, the strata are nearly horizontal, and corrugation is known only at a few insular points, of which the chief are the Black Hills of Dakota, the Wichita Mountains of Indian Territory, and the Ozark ridges of Missouri and Arkansas. Conversely, the Western Mountain region surrounds an island of strata little disturbed, and constituting the Colorado Plateau region, north of which the Laramie Plateau either forms a separate island, or an insular promontory of that of the Colorado. In the region of the Appalachians the phenomena of eruption have always been subordinate to those of corrugation, and they appear to be in no wise connected with thermal springs. In the western region eruption has been nearly as universal as corrugation, and, in places, even rivals it in the magnitude of its monuments.

In examining the map, the first thing to note is that the Mississippi region contains no hot springs, nor does the plain of the Atlantic coast. The single locality in Arkansas is referable to the Archæan Ozark corrugation. In the Colorado Plateau region but five localities are noted, a number decidedly below the mean of the Western Mountain region, which, for the same area, averages thirteen localities. It is true that it is not yet fully

* Except in the case of three localities, observed by Prof. J. W. Powell, in the cañons of the Colorado.

explored, but it is nevertheless probable that the record of its hot springs is nearer complete than that of the mountain region.

The distribution of hot springs is thus shown to coincide very exactly with that of corrugation, there being none in undisturbed regions, and few in regions of little disturbance.

The second result of an inspection of the map, or of the table, is the observation that the range of temperature is far higher in the western region than in the eastern. Omitting the localities without record of temperature, there are 67 in the former region to compare with 15 in the latter; of these the former shows 47 as high as 100° F., and the latter but two. This is probably an exaggeration of the contrast, due to the comparative imperfection of our data from the West; but the contrast cannot be imaginary. The list probably includes every group at the East that shows a temperature above 65°. It is yet possible that future travel shall double the list of western localities, and it is probable that the present list includes a far larger proportion of the very hot springs than it does of those of lower temperature, such as are not always noted, even though they are visited.

Of the same tendency is the fact that the number of localities is relatively greater at the West. The regions, as we have limited them, have areas proportioned as 13 to 3, while the numbers of recorded localities are as 24 to 3; and, if all the localities could be given, the preponderance of the West would necessarily be greater, since it is now the less known region. So too the weight of individual localities is greater at the West. It is safe to say that a score of the western localities surpass, in number and volume of springs as well as in temperature, the greatest group of the Appalachians; and geysers are known only in the larger area. In a word, the larger region is in every way far more strongly characterized by hot springs.

The geological relations appear to accord with this hydrothermal contrast. The corrugation and the eruption of the Appalachian region are things of the past, not known to have continued so late as Cretaceous time; while in the West these actions have persisted to so late a period that we have good reason to believe they have not ceased. It is dangerous to argue from single coincidences, but, certainly, so far as these facts go, they tend to confirm the explanations of the phenomena that have grown out of the


BRITISH POSSESSIONS
PACIFIC OCEAN
WESTERN MOUNTAIN REGION
COLORADO PLATEAU REGION
MISSISSIPPI REGION
APPALACHIAN REGION
MISSISSIPPI RIVER
ATLANTIC OCEAN
MEXICO
GULF OF MEXICO
MAP OF
HOT SPRING LOCALITIES
OF THE
UNITED STATES,
Showing Their Relation To The General
STRUCTURAL DIVISIONS.
Explanation.
Springs of Unknown Temperature are marked by a Cross, thus +
Those of Known Temperature, by figures indicating the temperature.
The heavy Lines indicate boundaries of Divisions described in the text.

theories of mountain building. We may consider the heat of springs in the Appalachians due entirely, as argued by Rogers, to the normal—we might almost say static—downward increase of temperature, brought to bear by the means of deep-seated water-courses, following faults and curved strata. In the Western Mountain region a greater heat is obtained by the same means, because of local upraisings of the geisothermal planes, produced by progressive corrugation, and the intensity of the phenomena is further heightened by the intrusion and extrusion of lavas.

It is not easy to draw a comparison between the different portions of the western province. The clustering of localities upon some parts of the map, and their sparseness on others, is in part due to inequality of observation. The superlative manifestations of the Yellowstone Park district appear to be intimately associated with volcanic features, but the great lava-field of Washington, Oregon, and Western Idaho is almost a blank on our hot spring map. Another blank, in Southern Arizona and adjacent parts of California, has been too often traversed by good observers to be regarded as due entirely to omission, but I am at a loss for its interpretation.

The following table is an essay toward a list of the known localities of thermal springs of the United States. So many of the references were disentombed almost accidentally that I cannot doubt that many could still be added by research. Of one hundred and twenty localities, enumerated in the region west of the Plains, fifty-three were visited by expeditions in charge of Lieutenant Wheeler, and, of these, thirty were, so far as I am aware, neither published nor mapped before our examinations. Record of three localities was furnished by Prof. J. W. Powell from unpublished notes of his exploration of the Colorado. So far as temperatures are definitely known, only those are included which exceed the mean annual temperature of the air by 15° Fahrenheit. To this rule the spring at Las Vegas, Nevada, (73°,) is perhaps an exception; and the *Fontaine qui bouille,* near Colorado Springs, Colorado, (60°,) certainly is. The latter was included because the observations of Long and Frémont indicate that it had formerly a higher temperature. Further information in regard to springs visited by our expeditions will be found in individual reports, and especially in the chemical report. In this place will be given only a few specifically geological data.

LOCALITIES OF THERMAL SPRINGS IN THE UNITED STATES.

Locality.	Authority and reference.	Fahrenheit.
1. REGION OF THE APPALACHIANS.		°
New Lebanon, New York	W. W. Mather, Nat. Hist. N. Y., Geol. 1st Dist., p. 105.	73
Mount Pisgah, Perry County, Pennsylvania	J. Bell, "Mineral and Thermal Springs of the U. S.," p. 174.	*72
Bath, Morgan County, West Virginia	W. B. Rogers, Rept. Am. Geols. and Nats., vol. i, p. 328.	74
New Milford, Page County, Virginia	W. B. Rogers, *loc. cit.*, p. 330	66
Warm Springs, Bath County, Virginia	W. B. Rogers, *loc. cit.*, p. 328	97.5
Hot Springs, Bath County, Virginia	do	108
Sweet Alum Spring, Bath County, Virginia	do	85
Snake Run Springs, Sweet Springs Valley, Virginia	do	72
Strecklor's Springs, Rockbridge County, Virginia	W. B. Rogers, *loc. cit.*, p. 330	70
Sweet Springs, Alleghany County, Virginia	W. B. Rogers, *loc. cit.*, p. 328	78
Red Sweet Springs, Monroe County, West Virginia	J. Bell, *loc. cit.*, p. 235	80
Buford's Gap Springs, Bedford County, Virginia	W. B. Rogers, p. 330	75
McHenry Springs, Scott County, Virginia	W. B. Rogers, p. 328	68
Warm Springs, East Tennessee	J. H. Kain, Sill. Jour. I, i, 66	95
Warm Springs, Buncombe County, North Carolina	E. D. Smith, Sill. Jour. I, iii, 117	104
2. REGION OF THE OZARK.		
Washitaw, Hot Spring County, Arkansas	D. D. Owen, Geol. Ark., 2d Am. Rep., p. 22	148
3. REGION WEST OF THE PLAINS.		
Hot Spring Mining District, Montana	A. C. Peale, U. S. Geol. Sur. Ter., 1872, p. 172.	124
East Fork Madison River, Montana	A. C. Peale, U. S. Geol. Sur. Ter., 1871, p. 198.	199
Snake River, below Upper Cañon, Idaho	A. C. Peale, U. S. Geol. Sur. Ter., 1872, p. 178.	144
Twenty-five miles east of Flathead Lake, Idaho	J. Mullan, Pac. Ry. Rept., i, 518	....
Lou-Lou Fork of Bitter Root River, Idaho	J. Mullan, Pac. Ry. Rept., i, 530	*132
Deer Lodge Prairie, Upper Hellgate River, Idaho	J. Mullan, Pac. Ry. Rept., i, 343	....
Big Hole Prairie, Wisdom River, Idaho	J. Mullan, Pac. Ry. Rept., i, 326	132
Steamboat Spring, Bear River, Idaho	A. C. Peale, U. S. Geol. Sur. Ter., 1871, p. 193.	85.5
Near Fort Hall, Idaho	A. C. Peale, U. S. Geol. Sur. Ter., 1872, p. 175.	87
North of Snake River, near Fishing Falls, Idaho	J. C. Frémont, Rept. 1st and 2d Exp., p. 170	164
Hot Springs on Gardner's River, Wyoming	A. C. Peale, U. S. Geol. Sur. Ter., 1872, p. 175.	162
Yellowstone River, from Yellowstone Lake to Tower Fall, Wyoming.	A. C. Peale, U. S. Geol. Sur. Ter., 1872, p. 176.	198
Snake River, near southern boundary of Yellowstone Park, Wyoming.	A. C. Peale, U. S. Geol. Sur. Ter., 1872, p. 178.	158
Geysers of Firehole River, Wyoming	A. C. Peale, U. S. Geol. Sur. Ter., 1872, p. 176.	199
Upper Cañon of Snake River, Wyoming	A. C. Peale, U. S. Geol. Sur. Ter., 1872, p. 178.	194
Hot Spring Gate, Platte River, Wyoming	J. C. Frémont, *loc. cit.*, p. 55	....
Hot Spring, Big Horn River, Wyoming	Land-Office Map, 1868	....
Near Laramie, Wyoming	H. Stansbery, Exped. to G. S. Lake, p. 55	71
Near Colorado Springs, Colorado	A. C. Peale, U. S. Geol. Sur. Ter., 1872, p. 102.	60

* About.

Localities of Thermal Springs in the United States—Continued.

Locality.	Authority and reference.	Fahrenheit.
		°
Mound Soda Spring, Park County, Colorado	W. L. Marshall	70
Mound Sulphur Spring, South Park, Colorado	do	107
Sulphur Springs, Hertzel's Ranch, Park County, Colorado.	do	
Chalk Creek, Lake County, Colorado	do	98
Ojo de los Caballos, San Luis Park, Colorado	do	111
Pagosa, Upper San Juan River, Colorado	do	142
Sulphur Spring, 12 miles north of Del Norte, Colorado	George M. Wheeler	
Arkansas River, three miles below the mouth of the South Arkansas, Colorado.	do	
Poncho Creek, one and a half miles above junction with South Arkansas, Colorado.	do	
Four miles east of Cañon City, Colorado	do	
Twelve miles northeast of Pagosa, Colorado	do	78
Three miles southeast of Pagosa, Colorado	do	120
Idaho Springs, Colorado	H. Montague	114.7
Grand River, above Grand Cañon, Colorado	F. V. Hayden, U. S. Geol. Sur. Ter., 1870, (reprint, p. 184.)	112
Warm Spring, Juab Valley, Utah	Pac. Ry. Rept. xi, Beckwith's map	
Head of Jordan Valley, Utah	T. V. Brown	128
Sixteen miles west of Minersville, Utah	E. E. Howell	185
Spanish Fork Cañon, Wahsatch Mountains, Utah	T. V. Brown	145
Spanish Fork Cañon, Utah	George M. Wheeler	111
Mouth of Ogden Cañon, Utah	A. C. Peale, U. S. Geol. Sur. Ter., 1872, p. 175	121
Ten miles north of Ogden, Utah	J. C. Frémont, *loc. cit.*, p. 150	136
Twelve miles north from Brigham City, Utah	A. C. Peale, U. S. Geol. Sur. Ter., 1872, p. 175	132
Near Pah-van Butte, Sevier Desert, Utah	L. Nell	
Fish Springs, south end House range, Utah	H. C. Yarrow	74
Near Cave Spring settlement, Utah	do	90
West base of Mineral range, Utah	Froiseth's Map of Utah	
Geyser, (?) 25 miles southwest of Pauquitch, Utah	G. K. Gilbert	
Warm Spring, north end of Utah Lake, Utah	H. Stansbery, Exped. to Gt. Salt L., map	
Near Salt Lake City, Utah	H. Stansbery, Exped. to *loc. cit.*, p. 129	128
Warm Spring, north end of Onaqui Mountains, Utah.	H. Stansbery, Exped. to *loc. cit.*, p. 117	74
Head of Provo Cañon, Utah	George M. Wheeler	72
Near Midway, Utah	E. E. Howell	108
Undine Springs, Labyrinth Cañon of the Colorado, Utah.	J. W. Powell	
"Narrow Cañon" of the Colorado, Utah	do	91
Lava Springs, Grand Cañon of the Colorado, Arizona	do	89
East base of Kern Mountains, Eastern Nevada	H. Crueger	
East base of Humboldt Mountains, Nevada	E. G. Beckwith, Pac. Ry. Rept., ii, p. 30	170
Near Pyramid Lake, Nevada	J. C. Frémont, *loc. cit.*, p. 215	208
Las Vegas, Southern Nevada	J. C. Frémont, *loc. cit.*, p. 266	73
Boiling Spring, north end of Mud Lake, Nevada	E. G. Beckwith, Pac. R. R. R., xi, map	

Localities of Thermal Springs in the United States—Continued.

Locality.	Authority and reference.	Fahrenheit.
		°
Ash Meadows, Southern Nevada	W. J. Hoffman	81.6
Silver Peak, Nevada	D. A. Lyle	117.8
Diamond Valley, 30 miles north of Eureka, Nevada.	W. J. Hoffman	*150
San Antonio, Nye County, Nevada	T. V. Brown	
Hot Spring, 10 miles south of Ophir Cañon, Nye County, Nevada.	G. K. Gilbert	
Hot Sulphur Spring, Carlin, Nevada	do	
Hot Springs, Reese River Valley, Humboldt County, Nevada.	do	130+
Warm Spring Creek, Independence Valley, Nevada.	George M. Wheeler	
Hyko, Lincoln County, Nevada	D. W. Lockwood	90
Hot Creek mining district, Nevada.	Maps	
Five miles east of Patterson, Nye County, Nevada.	E. E. Howell	
Warm Sulphur Spring, Spring Valley, Eastern Nevada.	Maps	
Hot Spring, north of Winnemucca, Humboldt County, Nevada.	Bancroft's Map of Pac. States and Ter'ys	
Hot Spring on Central Pacific Railroad east of Winnemucca, Nevada.	do	
Hot Spring, 20 miles southeast of Winnemucca, Nevada.	do	
Hot Spring, Elko County, Nevada	do	
Hot Spring, Elko, Nevada	George M. Wheeler	192
Hot Spring, 30 miles south of Argenta, Lander County, Nevada.	Bancroft's Map of Pac. States	
Hot Spring, 30 miles east of Walker's Lake, Esmeralda County, Nevada.	do	
Thirty miles east of Austin, Nevada	Simpson's Map	
Steptoe Valley, White Pine County, Nevada	Land-Office Maps	
White Pine Valley, White Pine County, Nevada	do	
Pahghun Spring, Northwestern Arizona	T. V. Brown	*100
Near Tubac, Southern Arizona	Pac. Ry. Rept., vol. vii, Appendix, ixc, p. 30	
Opposite Burke's station, on Gila River, Southern Arizona.	Eng. Map of Ter'y W. of Miss	
Prieto River, Eastern Arizona	R. L. Hoxie, (by report)	
Sixteen miles southeast of Camp Bayard, New Mexico.	T. Antisell, Pac. Ry. Rept., vii, p. 456	130
Apache Tahoe, seven miles south of Camp Bayard, New Mexico.	F. Klett	97
Twelve miles northeast of Jemez, Santa Anna County, New Mexico.	O. Loew	169
Cañada Alamosa, Socorro County, New Mexico	do	84
At copper mines of the San Francisco River, New Mexico.	do	130

* About.

Localities of Thermal Springs in the United States—Continued.

Locality.	Authority and reference.	Fahrenheit.
		°
Ojo Caliente, 50 miles north of Santa Fé, New Mexico.	Colton's Map of N. Mexico	....
Five miles west of Las Vegas, New Mexico	F. V. Hayden, U. S. Geol. Sur. Ter., 1870, (reprint,) p. 164.	140
Diamond Creek, near its mouth, Socorro County, New Mexico.	E. E. Howell	151
Ten miles south of Zuni, New Mexico	......do	....
Gila River, near Diamond Creek, Socorro County, New Mexico.	W. N. Maguet	*100
On the Rio Grande, below Fort Quitman, Texas	Mex. Boundary Survey Map	....
Deschutes Valley, Oregon	J. S. Newberry, Pac. R. R. Rept. 2, p. 74	145
Malheur River, Oregon	J. C. Frémont, *loc. cit.*, p. 120	164
North shore of Goose Lake, Oregon	Foley's Map of California and Oregon	....
Near Honey Lake, California	E. G. Beckwith, Pac. Ry. Rept., xi, map	....
Near Mohave River, Southern California	U. S. Engineer Map	....
Thirty miles south of Lake Tahoe, California	J. C. Frémont, *loc. cit.*, p. 224	....
Near Fort Crook, Northern California	E. G. Beckwith, Pac. Ry. Rept., ii, p. 56	....
Deep Spring Valley, Inyo County, California	D. A. Lyle	74.6
Benton, Inyo County, California	Mr. Partz, (quoted by W. J. Hoffman)	170
Ten miles east of Telescope Peak, Inyo County, California.	W. J. Hoffman	80.7
Saratoga Springs, south end of Death Valley, California.	T. V. Brown	*70
Near Mission of San Miguel, San Luis Obispo County, California.	Pac. Ry. Rept., vol. xi, Parke's Map San Fran. Bay to Los Angeles.	....
Guayamas Valley, San Luis Obispo County, California.	Pac. R. R. Rept,, vol. xi, Parke's Map	....
Napa Valley, California	F. Shepherd, Sill. Jour. II, 12, p. 153	169
Geysers, Sonoma County, California	......do	....
Mud Volcanoes, 60 miles northeast of San Félipe, San Diego County, California.	J. A. Veach, Proc. Cal. Acad. Sci., 1857	....
Shasta Peak, California	J. D. Dana; quoted by J. Bell, Min. and Therm. Springs U S., p. 353.	....
Near Warner's Ranch, San Diego County, California.	W. P. Blake, Pac. Ry. Rept., vol. v, part 2, p. 116.	142
Border of Colorado Desert, California	W. P. Blake, *loc. cit.*, p. 94	120
San Bernardino Valley, California	W. P. Blake, *loc. cit.*, p. 83	172
Near Walker's Pass, Kern County, California	Bancroft's Map	....
Bridgeport, Mono County, California	J. D. Whitney's Map	....
Geyser and Hot Springs, 25 miles south of Mono Lake, Inyo County, California.	......do	....
South of Fort Bidwell, California	Foley's Map of California and Nevada	....

* About.

Of the localities noted within the Colorado Plateau region, (see map, Plate III,) one is only presumably the site of a hot spring; for at the time of my visit there was no flow of water. The lake named by Lieutenant Wheeler, "Mountain Lakelet," lies close to the brow of a westward facing cliff of denudation. The strata dip gently to the northeast, and the upper beds were carved by streams flowing in the same direction, into a series of northeast and southwest valleys and ridges, with a magnitude of 500 feet, before the cliff had been eaten back to its present position, and a natural cross-section of these valleys is exhibited on the face of the cliff. Two miles back from the face of the cliff one of these troughlike valleys has been stopped by a recent lava stream, behind which stands the lake. Perched almost on the top of a ridge of nearly level strata, it is not in a position to receive water from deep-seated springs, and its water supply is not sufficient to give it a permanent outflow. Its water level consequently fluctuates, and we saw it about 25 feet below its highest mark. Between high and low water there are on its sloping shore four crater-shaped pits, that I believe to be the seats of intermittent but violent springs. The accompanying diagram represents a cross-section of one of them. The upper line, *b*, *s*, shows the slope of the shore from the upper beach to the water. The outlet, *o*, is 7 feet higher than the bottom of the pit, and the sides are about as steep as the soft soil will lie. The bottom, 6 feet broad, is flat, and consists of clean, coarse, well-rounded gravel, piled, at one or two points, into little cones. Three of the pits were perfectly dry, and the fourth had an inch of stagnant water. From the depth of the excavation, and from the coarseness of the gravel that remained in the bottom, I inferred that the action was violent. From the absence of a surrounding ridge, and from the shallowness of the dry channel that led from it at *o*, I was led to suspect that it was chiefly active when the lake covered it. The close vicinity of very new lava cones suggested that it

FIG. 59.—Diagram of supposed geyser on the shore of Mountain Lakelet, Southern Utah. *b*, high-water line; *s*, shore at low water.

might communicate with a hot dike as the source of its energy. Upon such meager data I have noted the locality in the list under the title of "geyser(?)." If it is a geyser it is certainly a purely volcanic phenomenon.

A second locality, noted within the Plateau area, is that of a copious hot spring, ten miles south of the Zuni pueblo in New Mexico, and affords one link of a chain of evidence showing that the usual continuity of the strata is here broken. It is upon one margin of the broad dry Zuni Valley, here limited, east and west, by low sandy hills, in which the geological structure is not displayed. In journeying along and across this valley, from Zuni to Ojo de Benado, a distance of twenty miles, I parted from upper Trias rocks in such manner as to suppose that hidden beneath me were lower Trias, and I was greatly surprised to find the next outcrop at Benado Cretaceous. Mr. Howell, who afterward crossed the same interval by a different route, experienced the same surprise, and we regard the hot spring as a phenomenon of the fault which we are compelled to assume in the correlation of the stratigraphical facts.

Of the warm springs found by Professor Powell in the gorges of the Colorado, one, the "Lava Spring," issues from the Toroweap fault, in the immediate neighborhood of the Uinkaret group of basalt cones, some of which are of very recent origin; but the springs in Labyrinth and Narrow Cañons have no ascertained relation either to eruptions or to dislocations.

The hot springs observed by Mr. Nell near Pah-vant Butte, Utah, by Dr. Yarrow near Cove Creek, Utah, and by Lieutenant Lyle near Silver Peak, Nevada, are in the close vicinity of basalt cones of no great age.

CHAPTER VI.

THE STRATIFIED ROCKS.

Our knowledge of the distribution of the sedimentary rocks representing the several divisions of geological history is very unequal in the two provinces of our field. Among the level, cañon-cut rocks of the Plateaus, the sequence of the strata is never lost. Save where covering lavas are crossed there is no break in observation. One bed is followed with the eye until it either dips beneath the surface or is ended by denudation, and another bearing a definite and evident relation to it is then taken up. Every newly discovered deposit of fossils falls at once into its appropriate place in the general scheme, and conformity and nonconformity are seen at a glance. Nearly every line of cliffs on the topographical map is a geological boundary ready drawn. In the Basin Range System the case is reversed. The mountains divide the space with the valley gravels, and only the imagination can fill the gap between range and range. Eruptive rocks serve still further to mask the sedimentary, and the outcrops of the latter are reduced to the condition of islands, each of which is a problem in itself, which dislocation, metamorphism, and unequal denudation serve to complicate.

The best of the stratigraphical sections obtained by the writer are included in the following series, and accessory data helping to correlate them will be given in the sequel.

The notation is invariably from the top down, as one reads a page, and this rule is followed throughout my report. The numbers given to the strata in the several sections are independent, each section standing by itself as a fact of observation.

At the time of the preparation of this report the collections of fossils have not been studied. A preliminary examination was made of the invertebrates by the distinguished paleontologist, Mr. F. B. Meek, and the species mentioned in the sections and elsewhere in the text have nearly all the authority of his identification. A few, however, of the more familiar forms were determined by myself.

SECTION I.—East face of Sam Pitch Plateau, at Wales, Utah. The thicknesses, except of the coal seam, are estimated—

	Feet.
1. Calcareous and argillaceous beds, with pale ochreous, and gray tints: *a.* Massive limestone, with some chert, 75 feet. *b.* Tender, argillaceous limestone, with some calcareous sandstone, 500 feet. *c.* Fine-grained limestone, nearly white, 50 feet. *d.* Soft shales, with restricted beds of limestone and calcareous sandstone, [*Viviparus,* like *V. Conradi,*] 400 feet.	1,025
2. Gray, sectile limestone, containing coal and numerous fossils, [*Viviparus trochiformis, Goniobasis Nebrascensis,* and seeds of *Chara*:] *a.* Limestone, 30 feet. *b.* Slaty coal, 9 inches. *c.* Limestone, 2 feet. *d.* Bituminous coal, 40 inches; reduced by calcareous bands to 36 inches, net. *e.* Limestone, 10 feet.	46
3. Gray and cream, soft shales, with thin bands of limestone, [*Viviparus trochiformis, Viviparus* ———; *Goniobasis tenuicarinata, G. Nebrascensis, Planorbis, Physa, Unio vetustus*:] *a.* Shale, 18 feet. *b.* Arenaceous limestone, 1 foot. *c.* Shale, 10 feet. *d.* Calcareous sandstone, 2 feet. *e.* Shale, 175 feet. *f.* Dark gray limestone, 1 foot. *g.* Shale, 2 feet. *h.* Sandstone, 2 feet. *i.* Shale, 10 feet.	221
4. Cream and gray soft shales, with cream calcareous sandstones: *a.* Sandstone, 10 feet. *b.* White, sandy shale, 50 feet. *c.* Sandstone, 3 feet. *d.* Shale, 20 feet. *e.* Limestone, 1 foot. *f.* Sandstone, 10 feet. *g.* Shale, 50 feet. *h.* Sandstone, 3 feet.	147
5. Red shale, base not seen	40
Total	1,479

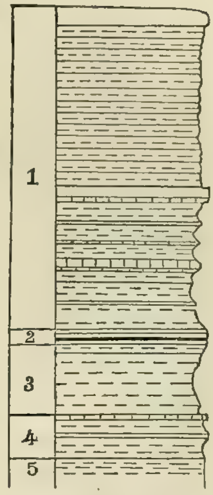


FIG. 60.—Sec. I.—Wales Utah. Scale, 1–7200.

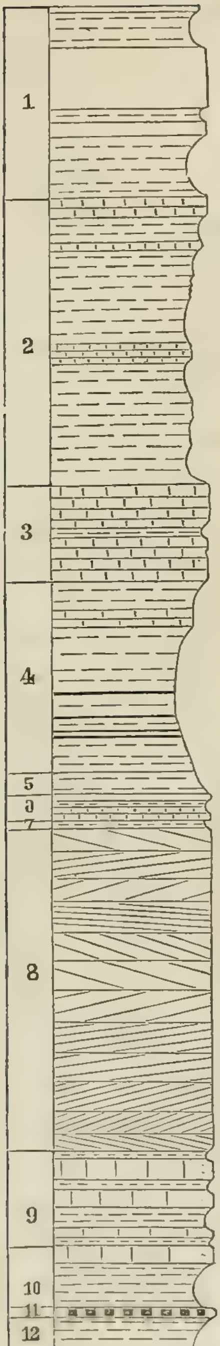


FIG. 62.—Sec. III.—North fork Virgin River. Scale, 1-14400.

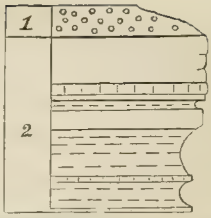


FIG. 61.—Sec. II.—Asay's, Utah. Scale, 1-7200.

No. 1*a* caps the escarpment of the plateau. Back of the escarpment the surface rises in a series of terraces, that were not visited, but which are constituted of superior strata, with a total thickness of not less than 500 feet.

SECTION II.—Two miles west of Asay's Ranch, near the head of the main Sevier River, in Southern Utah.

	Feet.
1. Basaltic gravel	100
2. A variable, calcareous, and argillaceous series, characterized by white and pink coloring. The subdivisions are not traceable over large areas: *a.* White to cream limestone, in part concretionary, also brecciated and cherty, 150 feet. *b.* Coarse, friable, yellow sandstone, 40 feet. *c.* White limestone, with chalcedonic geodes, 20 feet. *d.* Pink and white marls, 20 feet. *e.* Brecciated white limestone, 70 feet. *f.* Pink and white marls, 150 feet. *g.* Gray sandstone, weathering with vertical flutings, 15 feet. *h.* Red marl, 85 feet. *i.* Gray sandstone, with vertical flutings, 15 feet.	560
Total	660

SECTION III.—The rocks exposed by the north fork of the Virgin River, from the vicinity of Mountain Lakelet to Rockville, Southern Utah. All thicknesses estimated.

	Feet.
1. White and pink, calcareous beds, limestones and marls, subdivisions extremely variable: *a.* Pink to cream limestone, 50 feet. *b.* White marl, 20 feet. *c.* Pink marl, 100 feet. *d.* White marl, 30 feet. *e.* Pink marl, 50 feet. *f.* Brecciated limestone; white to pink on fracture, pink on weathered face, 400 feet. *g.* Pink (limestone ?) softer than *f*, 75 feet. *h.* Pink and white limestone, 100 feet. *i.* Pink (limestone ?) softer than *f*, 375.	1,200

	Feet.
2. Pale green-yellow, soft sandstone and sandy shale	1,800
3. Pale green-yellow, massive, calcareous sandstone, divided by a shaly zone into two principal beds, [*Corbicula* (*Veloritina*) *Durkeei*]	600
4. Shales, with coal. A large portion of this was not exposed. A portion toward the top is arenaceous and white. The highest coal-bed seen is near the middle of the series, and the shales below it are chiefly gray [*Corbula*].	1,200
5. Gypsiferous shales: *a.* Red clay-shale, 100 feet. *b.* White clay-shale, with bands of gypsum, 50 feet.	150
6. Cream-colored, sectile, fossiliferous, calcareous, and arenaceous beds: *a.* Bedded limestone [*Camptonectes*, *Inoceramus*], 30 ft. *b.* Calcareous shale, with the same fossils, 60 feet. *c.* Calcareous sectile sandstone, shaly toward the base [*Pinna*], 60 feet.	150
7. Soft red shale	50
8. Massive cross-bedded sandstone, cream-colored above, banded with red below	2,000
9. An alternation of red and slate-colored, saline, sandy shales, with deep red, bedded, in part cross-bedded, sandstones; the latter in three principal masses....	700
10. Variegated gypsiferous clays	300
11. Yellow conglomerate, with silicified wood	50
12. Chocolate sandstone, changing below to sandy shale, and banded near the base with slate-colored strata.....	200
Total	8,400

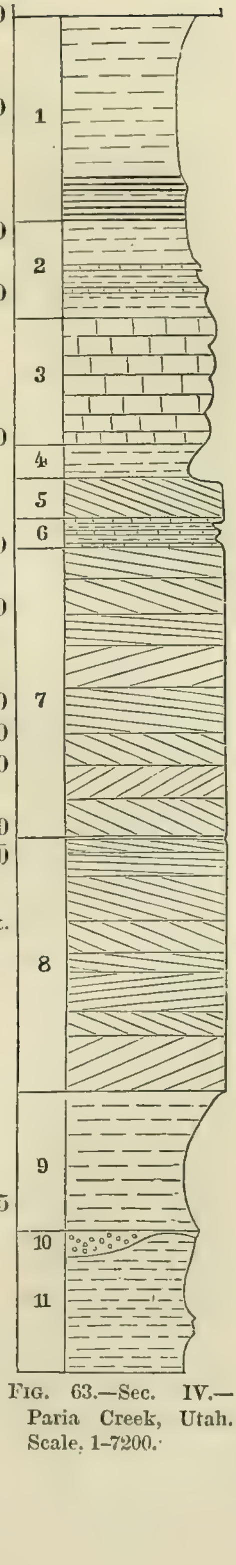


FIG. 63.—Sec. IV.—Paria Creek, Utah. Scale, 1–7200.

SECTION IV. West fork of Paria Creek.

	Feet.
1. Argillaceous shales, with coal: *a.* Blue-gray shale [*Inoceramus problematicus*], 50 feet. *b.* Coal, 4 feet. *c.* Bituminous shale, 1 foot. *d.* Soft gray shale, 25 feet. *e.* Yellow shale, 3 feet. *f.* Shell-limestone [*Ostræa*, *Inoceramus*, *Trigonia*], 1 foot. *g.* Soft yellow-gray shale, 2 feet. *h.* Coal, 4 inches. *i.* Soft gray shale, 6 feet. *j.* Coal, 1 foot. *k.* Soft gray shale, 50 feet. *l.* Coal, 3 feet. *m.* Shale, 15 feet. *n.* Coal, 1 foot 6 inches. *o.* Bituminous shale, 1 foot. *p.* Coal, 2 feet 4 inches. *q.* Arenaceous shale, 17 feet. *r.* Coal, 2 feet 2 inches.	635

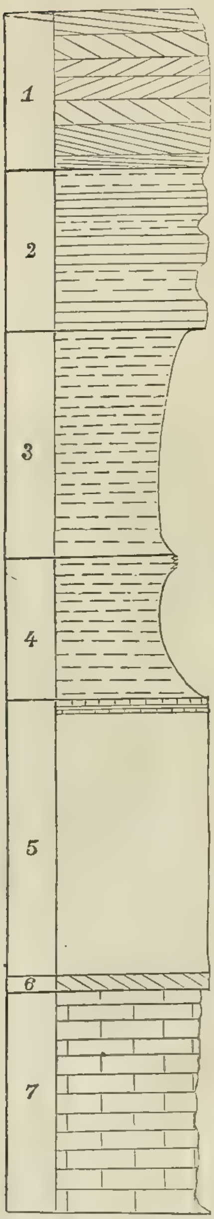


FIG. 64.—Sec. V.—Jacob's Pool, Utah. Scale, 1-7200.

	Feet.
2. Cream shale, with occasional fillets of red shale, and of sandstone	300
3. Dark red, brown, and purple, soft (gypsiferous ?) sandstone	400
4. Soft arenaceous shales: *a.* Slate-colored to cream shale, 50 feet. *b.* Purple shale, 75 feet.	125
5. Cream, cross-bedded, friable, massive sandstone	120
6. Alternations of shale and sandstone: *a.* Red sandstone, 5 feet. *b.* Gray shale, 30 feet. *c.* Red sandstone, 10 feet. *d.* Gray shale, 30 feet. *e.* Gray shaly sandstone, 20 feet.	95
7. Massive cross-bedded sandstone, cream to ocher in color	900
8. Massive cross-bedded sandstone, yellow, banded with vermilion, the latter staining the escarpments	800
9. Variegated gypsiferous clays, with silicified wood	450
10. White (to yellow) conglomerate, with silicified wood, resting on eroded surface of 11	0 to 75
11. Chocolate gypsiferous clays: *a.* Soft chocolate shale, 225 to 300 feet. *b.* The same, harder and sandy, 50 feet. *c.* Soft brick-red shale, base not seen, 100 feet.	450 to 375
Total	4,275

Thicknesses estimated except in the coal series, No. 1.

SECTION V. Jacob's Pool, Northern Arizona.

	Feet.
1. Massive cross-bedded sandstone, red, with bands of buff	500
2. Bedded red sandstone, with alternations of sandy red shale; a transition from 1 to 3	500
3. Gypsiferous cherty clay-shale, red at top, variegated below. Numerous silicified logs near base	700
4. Gypsiferous cherty clay-shale: *a.* Chocolate arenaceous shale, 50 feet. *b.* White soft shale, 100 feet. *c.* Chocolate soft shale, 300 feet.	450

	Feet.
5. Cherty limestone series:	
a. Soft red sandstone, 20 feet.	
b. Dark gray limestone, [*Pleurophorus*, *Bakevellia*, *Schizodus*,] 20 feet.	
c. Red sandstone, 10 feet.	850
d. Cherty limestone, light gray, heavy bedded; a few feet at top sectile and shaly, the remainder standing in a sheer cliff, [*Meekella*, *Pseudomonotis*, *Aviculopecten occidentalis?*, *Hemipronites*, *Productus ivesii*,]* 800 feet.	
6. Gray, cross-bedded, calcareous sandstone	50
7. Red shaly sandstone	700
Total	3,750

Beds 1, 2, and 3 were measured; the remainder estimated. A few miles east, in the same escarpment, a red conglomerate appears under No. 3, with a thickness of 75 to 100 feet, and cuts out No. 4 *a* and part of No. 4 *b*. Nos. 5 *b* and 5 *c* are also replaced in a neighboring exposure by a gray, cherty, calcareous conglomerate, resulting apparently from the local degradation of 5 *d*.

SECTION VI. The lower cañon of Kanab Creek. Above No. 1 are chocolate and gray shales, equivalent to No. 4 of Section V.

	Feet.
1. Massive sandstone, (*a*, dark red; *b*, yellow; *c*, red, calcareous)	150
2. Cherty limestone series:	
a. Yellow limestone, with much white chert (weathering black) and a belt of sandstone, 140 feet.	
b. Gray and white heavy-bedded to massive limestone, with much chert, [*Meekella striato-costata*, *Productus ivesii*, *P.* (*non des.*) *Spirifer lineatus*, *Orthis*, *Athyris subtilita*, *Hemipronites*, *Fenestella*, *Chætetes*, *Zaphrentis*,] 300 feet.	770
c. Shaly limestone, cream to gray, 60 feet.	
d. Gypsiferous shale, with massive gypsum, and bands of white, friable sandstone, 90 feet.	
e. Heavy-bedded, cream to gray, limestone, crinoidal and somewhat cherty, [*Productus ivesii*, *Spirifer lineatus*, *Fenestella*, ? *Chætetes*,] 180 feet.	

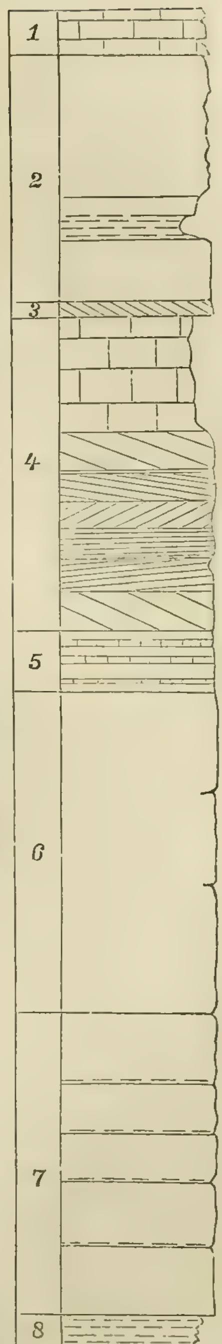


FIG. 65.—Sec. VI.—Kanab Cañon, Ariz. Scale, 1–7200.

* The form designated by Dr. Newberry, *Productus ivesii*, is considered by some paleontologists to be undistinguishable from *Productus semireticulatus*. Whether it deserves to rank as a separate species or only as a variety of the long-established species, it is important to recognize the existence of the form, since it is diagnostic of the Aubrey limestone, being confined, so far as is now known, to that horizon, while *P. semireticulatus* ranges in the same region through the entire Carboniferous series.

	Feet.
3. Shaly and sandy limestone, or calcareous sandstone......	50
4. Red sandstone: *a.* Deep red, friable, bedded sandstone, 350 feet. *b.* Red heavy-bedded sandstone, 130 feet. *c.* Dark gray limestone, 2 feet. *d.* Massive, cross-bedded, red and purple sandstone, 400 feet. *e.* Massive, cross-bedded, buff sandstone, 50 feet. *f.* Massive, cross-bedded, purple sandstone, 50 feet.	980
5. Purple and white, heavy-bedded, arenaceous limestone, with pink chert; in one bed, passing into cross-bedded sandstone......	200
6. Massive saccharoid limestone, gray to cream, [*Spirifer, Orthis, Chonetes*]................................	1,000
7. Massive gray limestone, with some chert; interrupted by bands of hard calcareous shale, and characterized, toward the base, by coralline mottlings............	950
8. Green, arenaceous, and micaceous shale..................	100
Total........................	4,200

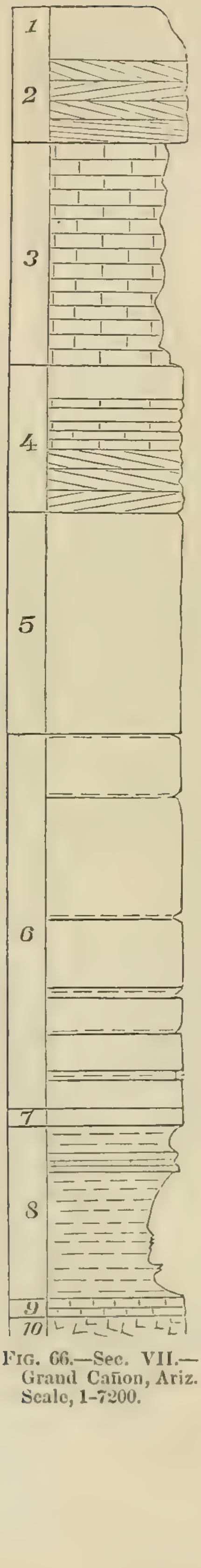


FIG. 66.—Sec. VII.—Grand Cañon, Ariz. Scale, 1-7200.

SECTION VII. The wall of the Grand Cañon of the Colorado at its mouth. Nos. 1, 2, and 3 were not measured nor crossed at this point; they constitute an upper terrace, retreating several miles from the immediate front of the chasm. The remainder of the section was measured by aneroid barometer.

	Feet.
1. Gray, saccharoid, cherty limestone....................	200
2. Massive, cross-bedded, yellow sandstone................	300
3. Friable red sandstone	800
4. Alternating limestone and sandstone: *a.* Cream fine-grained limestone, [*Archæocidaris*,] 75 feet. *b.* Dark gray fine-grained limestone, 25 feet. *c.* Cream fine-grained limestone, 20 feet. *d.* White calcareous sandstone, 35 feet. *e.* Gray fine-grained limestone, 40 feet. *f.* Red and purple cross-bedded sandstone, 315 feet.	510
5. Gray limestone, massive to heavy-bedded, and in part cherty; standing in sheer cliff with red-stained face, [*Spirifer cameratus*]..........................	800
6. The same limestone, alternating with calcareous shale...	1,365
7. Massive limestone, with coralloid mottling............	75

		Feet.
8. Shale series, (Tonto shale:)		
a. Soft green shale, with intercalated pale red sandstone, 100 feet.		
b. Arenaceous limestone, with obscure coralloid mottling, 25 feet.		
c. Greenish shaly sandstone, 40 feet.	}	605
d. Limestone, like *b*, 25 feet.		
e. Green and purple shales, arenaceous toward the base, and in part hardened to a shaly sandstone, [*Cruziana*], 415 feet.		
9. Vitreous sandstone, white to yellow and red; heavy-bedded, (Tonto sandstone)		80
10 Granite, gneiss, &c., unconformable		90
Total		4,825

SECTION VIII. Aubrey Cliff, fifteen miles southeast of Bill Williams Mountain, Arizona. Roughly measured by aneroid-barometer.

		Feet.
1. Basalt		65
2. Cherty limestone:		
a. Gray, heavy-bedded, cherty limestone, [*Orthoceras*, *Bellerophon*, *Productus*,] 200 feet.	}	335
b. Gray calcareous shale, 15 feet.		
c. Gray cherty limestone, 60 feet.		
3. Massive, cross-bedded, yellow sandstone		700
4. Friable red sandstone		200
5. Alternating fine-grained limestones and calcareous red and yellow sandstones		400
6. Massive gray limestone; red in escarpments, (base not seen)		400
Total		2,100

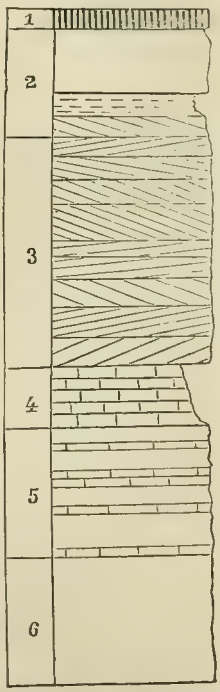


FIG. 67.—Sec VIII.—Aubrey Cliff, Ariz. Scale, 1-7200.

SECTION IX. Aubrey Cliff, at Cañon Creek, Northern Arizona Beds 2, 3, and 4, constituting the cliff proper, were measured by aneroid barometer; the remainder were estimated only. Bed 1 does not conform, and was seen near by resting on 5 *b*.

	Feet.
1. Coarse uncemented gravel, of quarzite and gneiss bowlders	20
2. Massive, cross-bedded, yellow sandstone	525
3. Compact gray limestone, [*Spirifer cameratus*]	65
4. Red and purple sandstone, soft at top, massive below	500

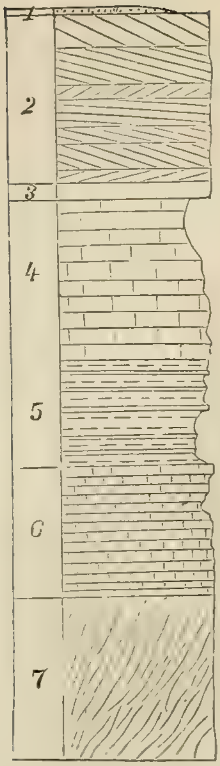


Fig. 68.—Sec. IX.—Cañon Creek, Ariz. Scale, 1-7200.

	Feet.
5. Alternation of gray limestone and red shale: *a.* Limestone, 5 feet. *b.* Unseen; shale(?) 100 feet. *c.* Limestone, [*Athyris subtilita*,] 10 feet. *d.* Red calcareous sandstone, 4 feet. *e.* Shale, 40 feet. *f.* Limestone, 4 feet. *g.* Unseen; shale (?) 25 feet. *h.* Massive limestone, 10 feet. *i.* Unseen; shale (?) 75 feet. *j.* Limestone, 2 feet. *k.* Unseen; shale(?) 50 feet.	325
6. Sandstone: *a.* Brown to red, coarse vitreous sandstone, massive to shaly, 100 feet. *b.* Gray fine-grained sandstone, weathering red, falling apart in angular blocks, 75 feet. *c.* Shaly calcareous sandstone, 75 feet. *d.* Vitreous, red, purple, and white sandstone, 150 feet. *e.* Coarse siliceous conglomerate, 25 feet.	425
7. Hornblende rock and schists; unconformable	500+
Total	2,360

Section X. On Carrizo Creek, Northern Arizona. Thicknesses estimated.

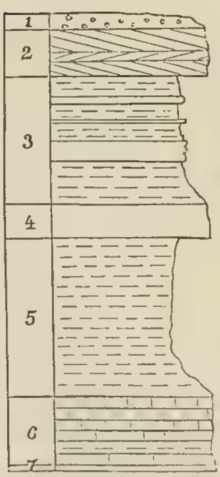


Fig. 69.—Sec. X.—Carrizo Creek, Ariz. Scale, 1-7200.

	Feet.
1. Coarse gravel of vitreous sandstone or quartzite and gneiss; unconformable	50
2. Massive, cross-stratified, yellow sandstone	150
3. Red and gray shales, interrupted by calcareous beds	400
4. Dark gray limestone, [*Nautilus occidentalis*, *Bellerophon crassus*, *Euomphalus*, (like *E. nodosus*,) *Macrocheilus*, *Pleurotomaria*, *Murchisonia*, *Allorisma*, *Aviculopecten interlineatus*, *Productus semireticulatus*, *Archæocidaris*, *Fenestella Shumardi* (?), *Glauconome*]	100
5. Alternating cream, or gray, and red shales; soft, and carved by rain with vertical flutings	500
6. Bedded red sandstone, shaly at base	200
7. Gray limestone, with carnelian fossils and chert, [*Athyris subtilita*, *Spirifer cameratus*]	20
Total	1,420

SECTION XI. North from and near Camp Apache, Arizona. Measured by aneroid barometer.

	Feet.
1. Basalt and basalt gravel	70
2. Pale pink, slightly coherent, massive sand and gravel, resting uncomformably on No. 3	520
3. Calcareous sandstone:	280
a. Yellow, 100 feet.	
b. Red, 180 feet.	
4. Soft red and gray shales, interrupted by sectile limestone:	429
a. Unseen; shale (?), 190 feet.	
b. Soft red shale, 50 feet.	
c. Gray limestone, 10 feet.	
d. Gray shale, 10 feet.	
e. Yellow limestone, 4 feet.	
f. Red and gray shales, 60 feet.	
g. Gray to cream limestone, with minute fossils, 25 feet.	
h. Red shale, 80 feet.	
5. Fossiliferous gray limestone:	125
a. Thick-bedded limestone, 25 feet.	
b. Unseen; red shale (?), 25 feet.	
c. Limestone, sectile to massive, with some chert, [*Productus*, *Bellerophon*, *Spirifer*, *Archæocidaris*], 75 feet.	
6. Red gypsiferous shales, with sandstone and limestone:	836
a. Unseen; shale (?), 160 feet.	
b. Cream-gray thin-bedded limestone, 15 feet.	
c. Unseen; shale (?), 85 feet.	
d. Green-gray impure limestone, 15 feet.	
e. Red gypsiferous shale, 70 feet.	
f. Massive gypsum, 10 feet.	
g. Red shale, graduating below to soft red sandstone, 240 feet.	
h. Red and gray shale, interlaminated with gypsum, 70 feet.	
i. Calcareous sandstone, with prints of mud-cracks, 1 foot.	
j. Red, shaly, ripple-marked sandstone, with red clay-shale, and red sandy shale, 120 feet.	
k. Unseen; shale (?), 50 feet.	
Total	2,260

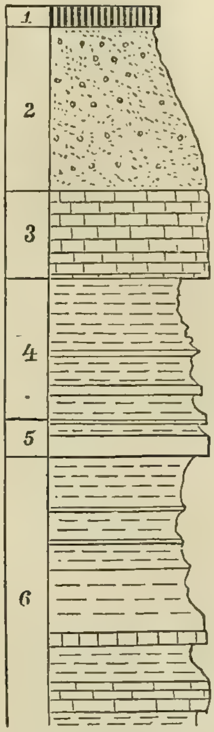


FIG. 70.—Sec. XI.—Camp Apache, Ariz. Scale, 1–7200.

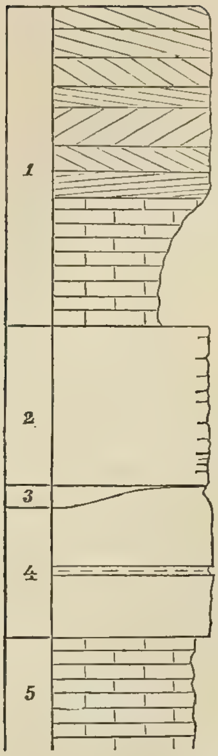


FIG. 71.—Sec. XII.—Spring Mountain, Nev. Scale, 1–7200.

SECTION XII. East front of the Spring Mountain range, twenty miles west of Las Vegas, Nevada; Cottonwood Creek. Only the limestones were measured.

Above the massive sandstone (1) is a dark-gray limestone, not examined in place.

	Feet.
1. Massive red and yellow sandstone: *a.* Yellow, 250 feet. *b.* Red, 150 feet. *c.* Yellow, 200 feet. *d.* Red and shaly, 400 feet.	1,000
2. Bedded, fine-grained to saccharoid, limestone, gray and cream-colored; beds separated by shaly layers, so as to weather in steps, [*Phillipsia* (?), *Macrocheilus* (*non des.*), *Naticopsis*, *Aviculopecten*, *Avicula*, *Meekella*, *Myalina*, *Productus semireticulatus*, *Spirifer lineatus*, *Athyris subtilita*, *Synocladia*]	500
3. Massive gypsum, white and red, in lenticular masses	0 to 70
4. Gray, massive, cherty limestone: *a.* Limestone, [*Meekella*, *Productus*, *Chaetetes*, *Syringopora*,] 250 feet. *b.* Unseen; red (shale ?), 25 feet. *c.* Limestone, 200 feet.	475
5. Friable sandstone, in places shaly or marly; variegated with brilliant iron colors	350
Total	2,395

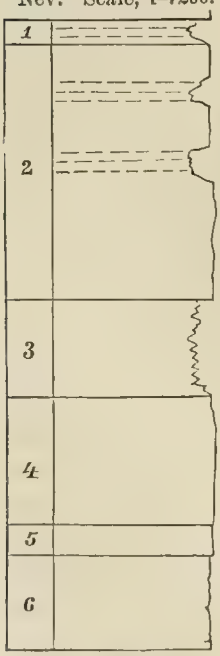


FIG. 72.—Sec. XIII.—Ophir City, Utah. Scale, 1–7200.

SECTION XIII. Oquirrh range, at Ophir City, Utah. The rocks were not measured except in total. Above the strata examined lies conformably a series of strata, chiefly limestone, that cannot be less than 2,000 feet in thickness. (See Fig. 15).

	Feet.
1. Blue-gray, calcareous shale, with bands of limestone, [*Productus*]	75
2. Bedded gray limestone, divided by shaly bands into three principal beds; in the lowest, fossils, [*Phillipsia*, *Chonetes*, *Athyris subtilita*, *Polypora*]	800
3. Shaly limestone	300
4. Dark gray bedded limestone, [*Phillipsia*, *Straporollus*, (like *S. plano-dorsatus*,) *Conocardium*, *Hemipronites*, *Athyris*, *Ptylodictya*, *Syringopora*]	400
5. Light gray, massive, saccharoid limestone, [*Conocoryphe*, *Dikellocephalus*]	100

	Feet.
6. Massive (and sectile) limestone, marked, in light and dark gray, with coralline mottlings	300
Total	1,975

Beneath No. 6 Mr. J. E. Clayton found argillaceous shale with *Olenus Gilberti.*

SECTION XIV. House range, Western Utah, at Fish Spring. Measured with aneroid barometer.

	Feet.
1. Massive, light gray, calcareous sandstone	40
2. Dark gray, cherty limestone, massive; in part brecciated and in part pisolitic	700
3. Gray sandstone, weathering ocher brown; changing at base to arenaceous limestone	120
4. Sectile to shaly limestone	200
5. Massive, dark gray, brecciated limestone, with fossils near base, [*Asaphus*, *Paradoxides* (?), *Orthoceras*, *Bellerophon*, *Scalites*, *Strophomena*, *Orthis*, *Receptaculites*, *Phyllograptus*]	500
6. Dark, blue gray, massive limestone	520
7. Pale gray, massive, saccharoid limestone	180
Total	2,260

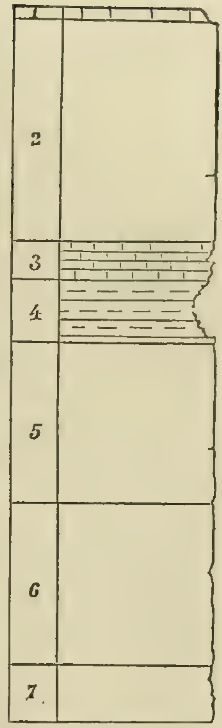


FIG. 73.—Sec. XIV.—Fish Spring, Utah. Scale, 1-7200.

SECTION XV. House range, Western Utah, at Dome Pass and Antelope Spring. Measured in total only.

	Feet.
1. Gray massive limestone	200
2. Blue-gray calcareous shale, [*Bathyurellus* (*Asaphiscus*) *Wheeleri*, *Conocoryphe Kingii*, *Agnostus* (*non des.*), *Discina*]	200
3. Gray limestone, light and dark, chiefly massive	900
4. Vitreous sandstone, umber-brown on weathered face, base not seen	1,000
Total	2,300

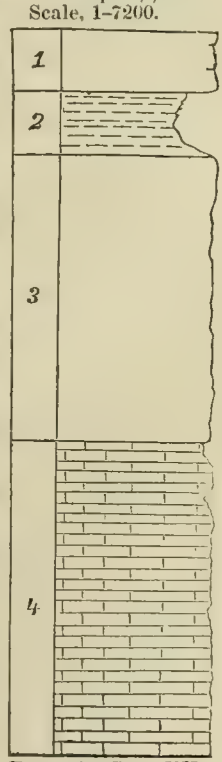


FIG. 74.—Sec. XV.—Antelope Spring House range, Utah. Scale, 1-7200.

SECTION XVI. Schell Creek range, Eastern Nevada, at White's Peak. Thicknesses roughly measured.

Above No. 1, and appearing in a parallel ridge to the west are heavy gray beds, probably of limestone. (See Fig. 22.)

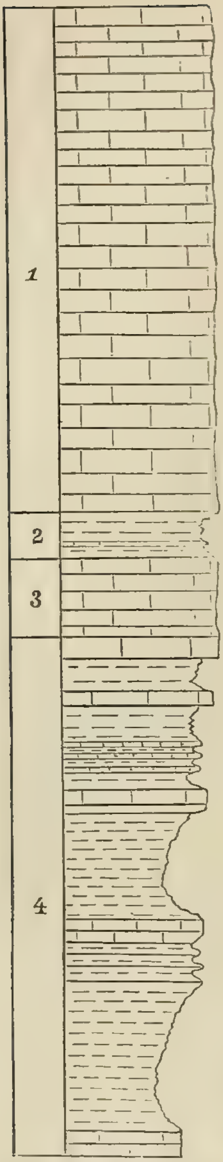


Fig. 75.—Sec. XVI.—White's Peak, Nev. Scale, 1-21600. (See Fig. 31.)

	Feet.
1. Quartzite:	
a. Rose quartzite, of fine texture, 1,100 feet.	
b. Reddish quartzite, 100 feet.	
c. Rose quartzite, 500 feet.	
d. Pale gray quartzite, 500 feet.	4,780
e. Alternating pink and gray quartzite, 1,100 feet.	
f. Dark gray vitreous conglomerate, 100 feet.	
g. Coarse-grained gray quartzite, 1,200 feet.	
h. Reddish-gray vitreous conglomerate, 180 feet.	
2. Green quartziferous schist:	
a. Schist, 250 feet.	430
b. Pale gray quartzite, 20 feet.	
c. Schist, 160 feet.	
3. Pale gray quartzite	850
4. Siliceous and argillaceous schists, alternating with quartzite; prevailing colors gray to green:	
a. Dark green-gray, sectile quartzite, 250 feet.	
b. Changing to green-gray quartzose schist, 300 feet.	
c. Gray quartzite, weathering yellow, 175 feet.	
d. Green-gray schist, 375 feet.	
e. Gray quartzite, 20 feet.	
f. Schist and quartzite, in rapid alternation, 500 feet.	5,520
g. Reddish gray quartzite, 250 feet.	
h. Gray to brown clay-slate, 1,000 feet.	
i. Gray quartzite, 250 feet.	
j. Alternation of clay-slate and quartzite, 375 feet.	
k. Green-gray quartzose schist, 1,800 feet.	
l. Gray quartzite, with frequent bands of schist, 300 feet.	
Total	11,580

Section XVII. Pahranagat range, Eastern Nevada, at Silver Cañon. The upper portion of the section, beds 1 to 4, was measured by barometer; the remainder estimated. The section is not shown in a single exposure, but was compiled from the examination of a series of faulted masses, extending from Quartz Peak nearly to Fossil Butte. The fossils from beds 2 and 4 were lost. The lists given are from field-notes.

	Feet.
1. Massive, white, vitreous sandstone (quartzite)	150
2. Black shaly limestone, [*Asaphus, Calymene, Orthis lynx, Chætetes, Strophomena alternata* (?) *Orthoceras*, &c.]	350

	Feet.
3. Massive, white and yellow, vitreous sandstone	400
4. Gray fossiliferous limestone, with some yellow sandstone, and a little shale; in part with coralloid mottling, [*Receptaculites, Strophomena, Atrypa, &c.*]	1,100
5. Gray sandstone, weathering umber brown	50
6. Hard, massive, siliceous limestone: *a.* White, 1,000 feet. *b.* Nearly black, 300 feet.	1,300
Total	3,350

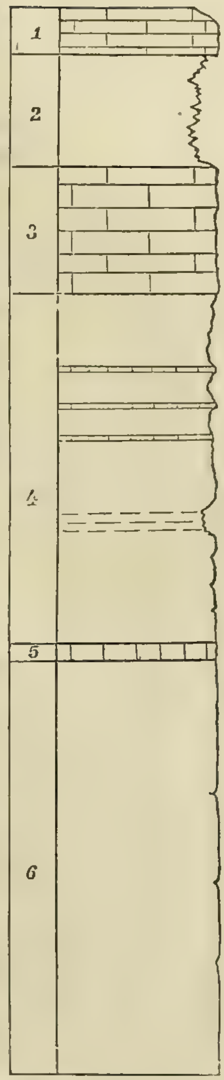


Fig. 76.—Sec. XVII.—Silver Cañon, Nev. Scale 1-7200.

SECTION XVIII. South end of Timpahute range, Eastern Nevada. Thicknesses estimated.

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

SECTION XIX. Amargosa range at Boundary Cañon, Southern Nevada. Thicknesses estimated.

	Feet.
1. Massive, dark gray limestone, with white bands	500
2. Micaceous and other schists, with some quartzite, and limestone, [Obscure fossils like those of No. 2 *c*, Sec. XVIII]	500
3. Purple quartzite, massive and sectile, with some coarse conglomerate	900
4. Mica and chlorite schists, with occasional harder beds	600
Total	2,500

SECTION XX. Rocks exposed on the east face of the Inyo range, at the pass between Deep Spring Valley and Owens Valley. Thicknesses estimated.

	Feet.
1. Quartzite and siliceous schist: *a.* Greenish siliceous schist, with blue-gray quartzite at base, 500 feet. *b.* Calcareous quartzite, pale-gray, 50 feet. *c.* Hard, pale green schist, with bands of quartzite and limestone, 200 feet.	750
2. Massive blue limestone, veined with white calcite	75

	Feet.
3. Clay-shale and calcareous quartzite: *a.* Yellow quartzite, 20 feet. *b.* Shale, 200 feet. *c.* Yellow quartzite, 20 feet. *d.* Umber brown quartzite, 50 feet.	290
Total	1,115

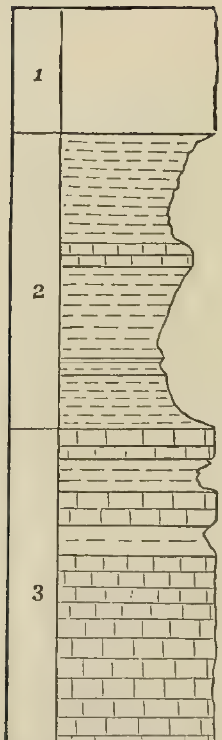


FIG. 77.—Sec. XVIII.—Groom District, Nev. Scale, 1-7200.

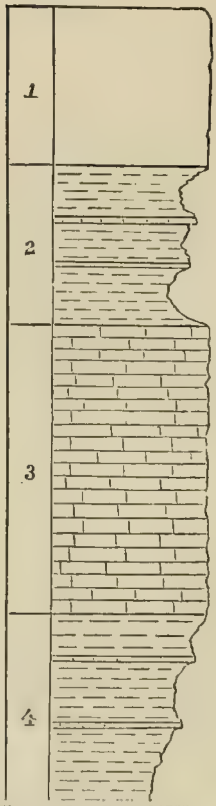


FIG. 78.—Sec. XIX.—Boundary Cañon, Cal. Scale, 1-7200.

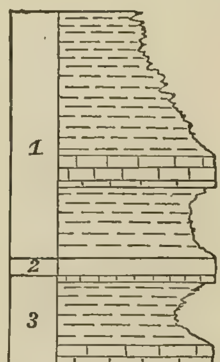


FIG. 79.—Sec. XX.—Inyo range, Cal. Scale, 1-7200.

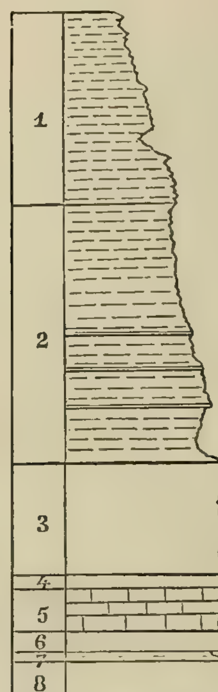


FIG. 80.—Sec. XXI.—Saratoga Springs, Cal. Scale, 1-7200.

SECTION XXI. Funeral Mountains, at Saratoga Springs. Thicknesses estimated, except of lower beds.

	Feet.
1. Gray clay-slate	600
2. Yellow slates, with beds of shaly limestone	800
3. Bedded and shaly limestone, banded in purple, yellow, and brown	350
4. Crystalline limestone	40
5. Dark brown, quartzose and argillaceous conglomerate	140
6. Crystalline limestone	85
7. Green shale	20
8. Massive hornblende rock, black to green	120
Total	2,155

The accompanying table exhibits the relation of the above sections to each other, and to the general stratigraphical scheme. It will be observed that all the great divisions of geological history are represented; and these will now be noticed in order.

Table showing the correlation of the sections.

Archæan.	Lower Silurian.	Lower Carboniferous, Devonian, and Upper Silurian.	Upper Carboniferous.	Trias.	Jurassic.	Cretaceous.	Tertiary.	Quaternary.	
							1 to 5		I. Wales.
							2	1	II. Asays.
				8 to 12	5 to 7	4	1 2 3		III. Virgin River.
				7 to 11	3 to 6	1 2			IV. Paria Creek.
			5 to 7	1 to 4					V. Jacob's Pool.
	7	?	1 to 6						VI. Kanab Creek.
10	7 to 9	?	1 to 6						VII. Grand Cañon.
			2 to 6					1	VIII. Aubrey.
7	6	?	2 to 5					1	IX. Cañon Creek.
			2 to 7					1	X. Carrizo Creek.
			5 6	?				1 2	XI. Camp Apache.
			1 to 5						XII. Spring Mountain.
	5 6	4	1 to 3						XIII. Ophir City.
	2 to 7	1 ?							XIV. Fish Springs.
	1 to 4								XV. Antelope Springs.
	1 to 4								XVI. White's Peak.
	1 to 6								XVII. Silver Cañon.
	1 to 3								XVIII. Groom.
	1 to 4								XIX. Boundary.

Quaternary.—The Bonneville beds, a calcareous series deposited during the Glacial Epoch, have already been described in the chapter devoted to that epoch. They are restricted to the lower parts of the Great Salt Lake and Sevier Lake basins.

The unconsolidated gravels and clays that flank the ranges and floor the valleys of the Cordillera region, have likewise received mention. They are of Quaternary age at top, but the antiquity of their lower portions is unknown. It is not improbable that they have, in some valleys, accumulated through all Tertiary time, and they may have been begun even earlier.

About Camp Apache there are preserved, under basalt covers, portions of a sand and gravel deposit (Section XI, 2) that rests unconformably on what are now the highest portions, topographically, of the Carboniferous and Mesozoic rocks. The evenness of the basalt sheets that spread over its original surface, indicate that the formation floored a plain, and suggest a relation of altitudes far different from the present. The region is now so elevated that its erosion is very rapid. Streams have sunk their channels to a depth of two thousand feet below the old plain, and carried the eroded material to the modern plain of the Lower Gila, which lies so little above the ocean level, that its slopes are slightly inclined, and its arroyos shallow. To this Apache sand bed may probably be referred the bowlder accumulations that have been found, by Mr. Marvine and myself, to cap the mesas and hills at numerous points in Arizona. When they were first seen a glacial origin was suspected, but a search failed to discover upon the bowlders, which are well rounded, any glaciated surfaces.

Tertiary.—The difficulty that geologists have found in the separation of the Tertiary and Cretaceous, along the line of the Union Pacific Railway, is equally encountered in Southern and Central Utah. The progressive conditions, recorded in the sediments, are marine, estuary, and fresh-water. So long as the fauna is purely marine, there is no question; the facies is unmistakably Cretaceous. But the estuary or brackish fauna that succeeded is made up of forms of doubtful affinities, and after the disappearance of all indications of salt water, the remaining animals and plants are of Tertiary aspect. It is not improbable that the two groups of living forms existed at the same time, and shifted their common border, as the line separating the salt water from the fresh was shifted. When the inland sea became finally separated from the ocean, and was deprived, by dilution, of its salt, the marine Cretaceous fauna may still have flourished beyond the limits of the continent. However this may be, there is no immediate hope that the facts of the case will be demonstrated—we cannot yet even point out the barrier that kept out the ocean. But, while we are not certain that our rock series records the termination of the Cretaceous age, we do find in it a history of the local extinction of the Cretaceous marine fauna, and the substitution of a continental fauna ; and it is convenient, in the present condition of our ignorance, to call this latter Tertiary. With this somewhat arbitrary assumption, it is still impossible to draw a sharp line of demarkation, because the change of conditions was not abrupt.

Of the three sections given of Tertiary strata, the second and third are but fifteen miles apart, while the first is one hundred and fifty miles to the north. My own data were not sufficient to connect them, but Mr. Howell was able to follow and study the strata more thoroughly, and considers No. 1 of section I equivalent to No. 2 of section II, and No. 1 of section III. Section I includes the Sam Pitch coal seam, which is closely associated with a fauna that Mr. Meek recognizes as identical with that of the Fort Union group of New Mexico. Among the fossils are *Goniobasis Nebrascensis*, *G. tenuicarinata*, *Viviparus trochiformis*, and *Unio vetustus*.

The area mapped as Tertiary lies entirely within the borders of Utah, and caps the highest portions of the Plateau region west of the Colorado. It forms a belt, forty to sixty miles broad, with a north-northeast trend, and coincides very nearly, in its western limit, with the western limit of the Plateau region. It terminates southward, in latitude 37° 25′, in a line of bold escarpments, the Pink Cliffs, from which to the Grand Cañon of the Colorado, eighty miles away, there is a continuous geological descent. (See Figs. 22 and 23.) Eastward also its edge is usually marked by a cliff, and, in a general way, this is parallel to the course of the Green and Colorado. Northward the belt passes beyond our field, and probably terminates on the flanks of the Uintah Mountains, with a total length of two hundred and fifty miles. From Panquitch northward for seventy miles it is completely covered by volcanic rocks.

Cretaceous.—The Cretaceous rocks are characterized by pale colors, with a preponderance of yellow, and are largely argillaceous. They afford the economic coal series of Southern Utah and of Castle Valley. In a general way their outcrop flanks the Tertiary area on the east, south, and southwest, but its configuration is far more complicated by folds and consequent inequality of denudation. Its delineation on the maps is almost entirely the work of Mr. Howell, and the reader is referred to his report for descriptions of the beds which compose it.

Jurassic.—Rocks of this age are known in both Plateau and Range regions. In the latter, the only localities that have furnished fossils are the Wahsatch Mountains, near Salt Lake City; the Mineral range, near Adamsville, Utah; and the Spring Mountain range, near Good Spring, Nevada. At none of these places were the limits and relations of the beds determined. The rock in each case is a gray limestone. In the Plateau region of Utah, beds referable to the Jura are always found beneath the Cretaceous, but they are not everywhere fossiliferous. Upon both forks of the Virgin River and upon Kanab Creek I found Jurassic forms, (including *Camptonectes bellistriatus* and *Pentacrinus asteriscus*,) in a cream-colored, arenaceous limestone, and they appeared to be restricted to a brief vertical range. Farther east, in the basins of the Paria and Dirty Devil, Mr. Howell found the same species in gray shales overlying the cream-colored beds, which are there sandstones. Above these fossiliferous beds, and beneath strata recognized by their fossils as Cretaceous, there are several hundred feet of highly colored gypsiferous beds, ranging from sandstone to clay in texture, and usually including a thick bed of solid gypsum. (Sec. III, 5, and Sec. IV, 3.) In this series the search for marine fossils is well nigh hopeless, since the physical conditions under which gypsum is accumulated are inimical to life, and unless Cretaceous fossils shall be discovered below them, or Jurassic above, their age will always be conjectural.

The outcrop of the formation is in detail exceedingly tortuous. In Southern Utah it strikes from west to east across a region interrupted by faults and deeply carved by erosion in a direction at right angles to its course. Between the Paria and Escalante rivers it is carried in a loop far to the southeast by a broad synclinal fold, and further north it becomes so greatly flexed as to lose all semblance of parallelism to the Tertiary escarpment. In about the latitude of the town of Salina it passes eastward beyond the limits of our survey. To the west of the Tertiary belt, and in part within it, the Jura was found, with characteristic fossils, by Mr. Howell, the localities being the eastern flank of the Wahsatch range, the west base of the Sam Pitch Plateau, and the east margin of the valley from Salina to Manti.

Trias.—From the fossil horizon of the Jurassic downward to that of the Permo-carboniferous—a vertical distance, in Southern Utah, of 2,500 to 3,500 feet—the age of the rocks is not fixed by fossils. Prof. J. Marcou, who was the first geologist to examine this series, referred it to the Triassic from lithological resemblance of its beds to rocks of that age in Europe; and the same reference has been provisionally made, though on different grounds, by Dr. Newberry. The question is probably not insoluble. Dr. Newberry has found evidence, as yet unpublished, in the valley of the San Juan, to confirm the assumption, and Mr. Howell and the writer have discovered fossil localities that promise, when thoroughly searched, to throw additional light. In Southern Utah and adjacent Arizona the series is constituted by massive, cross-bedded sandstone above, and variegated, saliferous and gypsiferous clays below. The sandstone is usually parted by a soft layer near the middle, and forms two lines of cliffs, terraces of the great south-facing escarpment. The upper division has a light buff or cream color, and its cliffs are usually capped by the cream-colored beds of the Jurassic. The lower division is banded with red, the stain from which dyes the whole face of the escarpment, and toward its base is red throughout. The transition from sandstone to shale or clay is usually not abrupt, and the upper part of the clay has the same deep red hue as the superjacent sandstone. The principal mass of clay is beautifully banded with brick red, pale rose, dark lavender, Naples yellow, maroon, pale sienna, white, and chocolate, the last mentioned color predominating toward the base. In the midst of the clays is a bed of conglomerate. The lower shales were somewhat eroded by the current which spread it, as is shown by the inequality of the surface on which it rests. Its thickness is variable, and it is not universally present; but its persistence over large areas is nevertheless such as to excite wonder. In the conglomerate and in the superjacent clays are silicified tree trunks in great numbers. The fossil horizon discovered by Mr. Howell near Toquerville, and another that was noted south of Kanab, are lower than the Shinarump conglomerate.

The first geological belt, in the descending series, which, in our field, crosses the Colorado, is that of the Trias. Beginning west of the town of Saint George, and not far north of the Utah and Arizona boundary, it passes east, and a little south, for one hundred and thirty miles, to the Colorado, at Monument Cañon, expanding in the middle of this course to a width of thirty-five miles, and including the boundary line for most of the distance. Its chief inequalities of form are caused directly by erosion, but primarily by the faults and folds which cross the belt at right angles. The Kaibab fold throws the belt twenty-five miles to the north, by making a sinus of that depth in its southern limit, and a corresponding salient in its northern. From Monument Cañon, where the belt crosses the river, it runs south-southeast, in Arizona, to the Colorado Chiquito, when, turning more to the east, it follows that stream nearly to its head, and finally disappears beneath the lavas of the Mogollon region, two hundred miles southeast from Monument Cañon. Throughout the whole outcrop, from Saint George to the head of the Colorado Chiquito, the general dip of the strata is to the north, or northeast, at a low angle, and, except in the region of that stream, the mural escarpments of the heavy sandstones overlook, at the southwest, a broad floor of Carboniferous limestone that reaches to the margin of the Range system of Arizona. Upon this floor stand a few lava-guarded islands of Trias, testifying to the former extent of the formation.

Above the mouth of Monument Cañon, the Colorado is flanked on both sides by the Trias as far as the limit of our field, and this river outcrop, dividing the Cretaceous areas of the two banks, serves to connect the southern Trias outcrop, just described, with more northerly outcrops, mapped by Mr. Howell to the east of the great trachyte field of Southern Utah.

Carboniferous.—Strata of this age have great depth and cover large areas, both in the Plateaus and among the Ridges, and they are characterized by thick masses of limestone, filled with organic remains. They are best exposed for study in the former region, and it was found convenient there, by Mr. Marvine and myself, to attach local names to the more important subdivisions. They are the Aubrey limestone, the Aubrey sandstones, and the Red Wall limestone. The Aubrey limestone and sandstones constitute the Aubrey cliff, which faces Aubrey Valley, in Northern Arizona, and stretches southeastward nearly to Camp Apache. The Red Wall limestone is so named from the red appearance of its escarpments on either side of the Grand Cañon.

The Aubrey limestone has a thickness of 820 feet on Kanab Creek, (Sec. VI, 2 and 3,) and this is about its maximum. Its characteristic fossils are *Productus Ivesii*, *P. semireticulatus*, *Spirifer lineatus*, *Athyris subtilita*, *Meekella striato-costata*, a *Hemipronites*, and an *Aviculopecten* closely allied to *A. occidentalis.* At a few points were found in the topmost layer, *Pleurophorus*, *Schizodus*, and *Bakevellia*, a group of shells suggesting the Permo-carboniferous of the Mississippi Valley, and indicating that the great lithological change at this horizon marks the absolute close of the Carboniferous age. Lithologically the limestone is characterized by the great abundance of chert, which, toward the top, sometimes constitutes half the mass. Near the middle it is, in some places, interrupted by a belt of shale, with gypsum. The soft Trias clay above it has yielded so rapidly to denuding agents, and the limestone has resisted so stubbornly, that its belt is a very broad one. From the Aubrey Cliffs, northeastward, to the Shinarump Cliff, a distance ranging from sixty to one hundred miles, the country is floored by the Aubrey limestone, save only where the gorge of the Colorado bares the lower rocks.

The Aubrey sandstone series (Secs. V, 6 and 7; VI, 3 and 4; VII, 2 and 3; VIII, 3, 4, and 5; IX, 2, 3, and 4,) has a thickness, in the Aubrey Cliffs and along the Grand Cañon, of about 1,000 feet. In every exposure a portion of this body is massive and cross-bedded, and another portion soft and gypsiferous, but the order of these parts is not constant. In the Aubrey Cliff, the compact rock is at top, and, together with the Aubrey limestone, holds a sheer bluff, at the foot of which the softer portion spreads a broad slope. Along the Grand Cañon, at Kanab Creek, and near the Uinkaret Mountains, the upper sandstone is soft, and produces a slope in the profile, while the lower is hard, and unites its steep escarpment with that of the Red Wall limestone. The sandstones contain no fossils, but an intercalated limestone, below the middle of the series at Cañon Creek, (Sec. IX,) bears the familiar Coal Measure shells.

The Red Wall limestone (Secs. VI, 5, 6, and 7; and VII, 4, 5, and 6,) has, upon fresh fracture, a gray color, and shows its red rust only on weather-stained cliffs. In its general character it is heavy-bedded to massive. At top, sandstone alternates with the limestone for from 200 to 500 feet. Through its lower half, the firm limestone is interrupted by occasional shaly bands, which serve to break its escarpment into a series of narrow terraces; but above them stands a sheer, perpendicular face, of from 800 to 1,000 feet. The average total thickness is 2,500 feet. Fossils are abundant near the top, but difficult to find in the lower portions. The lowest horizon from which I obtained fossils of value is a trifle below the middle of the series, and they are doubtfully referred, by Mr. Meek, to the Lower Carboniferous. The fauna of the upper portion is rich in species; and, while differing from that of the Aubrey limestone, is equally referable to the Coal Measures. It includes *Platysomus*, *Phillipsia*, *Nautilus occidentalis*, *Euomphalus* (like *E. nodosus*), *Murchisonia*, *Macrocheilus*, *Bellerophon crassus*, *Pleurotomaria*, *Aviculopecten interlineatus*, *A. occidentalis*, *Myalina*, *Productus semi-reticulatus*, *P. Nebrascensis*, *Spirifer cameratus*, *Spiriferina* (like *S. Kentuckensis*), *Athyris subtilita*, *Hemipronites crassus*, *Archæocidaris*, *Synocladia Shumardi*, and *Glauconome*, of which list, all of the genera and every identified species belong to the Coal Measures. With these fossils in view, the provisional assignment by Dr. Newberry of the *whole* limestone to the Lower Carboniferous or to the Lower Carboniferous and Devonian is seen to be erroneous; but we are not yet enabled to demonstrate a complete correlation.* Of the 4,000 to 4,500 feet of strata that I have assigned to the Carboniferous, a very few feet at top may be called Permo-Carboniferous, and not less than 3,000 feet are to be referred to the Coal Measures. Below this is a single point recognized as "probably Subcarboniferous," and the remainder is blank. The base of the system is arbitrarily assumed at the first marked lithological change, and it is not impossible that it has been placed so low

* Professor Marcou (Geol. of N. A., pp. 23, 24, and 62) calls the Aubrey limestone, Permian; the Aubrey sandstone, Coal Measures, and the Red Wall limestone, "Carboniferous limestone," or "mountain limestone."

as to include the Devonian, or even the Upper Silurian, if those formations are represented in the series. Considerations bearing upon this point will be adduced in speaking of the Silurian rocks.

The classification adopted for the Carboniferous rocks in the Grand Cañon and along the southern margin of the Carboniferous plateau, is of local value only. Seventy-five miles to the west, in the Spring Mountain range, I was unable to correlate the series in detail, and eastward, from Cañon Creek to Camp Apache, the progress of a rapid transformation can be traced. The lower, shaly portion of the Aubrey sandstone becomes interrupted by numerous bands of limestone, and red shales appear in the Red Wall limestone; and in this way the two series approximate in character, until the division can no longer be recognized.

Among the Basin Ranges of Western Utah and adjacent Nevada, Carboniferous strata are recognized oftener than any other, except the Silurian, but our observations do not suffice for a comprehensive view of the lithological series. Limestones predominate, the prevailing color is gray, and, with few exceptions, the fossils gathered are of the age of the Coal Measures. In a section upon the western face of the Wahsatch Mountains, near Provo, Mr. Howell found Carboniferous fossils, stratigraphically more than 5,000 feet apart, and the rock characters included between the two horizons are continued for 3,000 feet below the lower. The entire Lake range, and nearly the entire Oquirrh range, are built of Carboniferous strata. They are seen on both flanks of the Stansbury range (Howell) and along the western base of the Pah-vant. They appear at the south end of the Mineral range, and, in the Picacho Mountains, they include a portion of the argentiferous veins of the Star and North Star mining districts. They constitute a large part or the whole of the Confusion Range, and they form the eastern face of the Virgin range. They are in great force in the Spring Mountain Range, in the vicinity of Cottonwood Creek and Crystal Spring, and include the lead deposits of the Yellow Pine district. They were recognized by Prof. J. J. Stevenson in the stratified axis of the Reveille range, and the Reveille silver mines are within and by the side of them. They were identified by Mr. Howell and Mr. Clayton in the Highland and Schell Creek ranges, and they were found in low ridges near Elko and Carlin on the Humboldt River.

At Mountain Spring, in the Spring Mountain range, a point on the old wagon-road from Salt Lake City to Los Angeles, a suite of fossils of facies older than the Coal Measures was obtained by Mr. C. A. Ogden. Among the forms are *Phillipsia*, *Spirifer*, (two species of Devonian aspect,) *Rhynchonella*, *Hemipronites*, *Athyris*, (distinct from *A. subtilita*,) *Chonetes*, *Terebratula* (?), *Productus*, (like *P. subaculeatus*,) and *Fenestella*. The horizon is referable to the Subcarboniferous, and it is, in our collections, the only one between the Coal Measures and the Cincinnati group that is well characterized by fossils.

At Ophir City, Utah, a limestone with Coal Measure mollusks is separated from another with Primordial trilobites, by 700 feet of limestone, the whole being conformable. Near the middle of the interval is a fossiliferous horizon, exhibiting *Phillipsia*, *Straporollus planodorsatus* (?), *Conocardium*, *Hemipronites*, *Athyris*, *Ptylodictya*, and *Syringopora*, and referable to the Subcarboniferous. There remain less than 400 feet of strata to represent Devonian and Upper Silurian, and we have no evidence, by fossils, of their presence.

In our whole field the Carboniferous rocks are not coal-bearing, and we have found vestige of but a single coal plant, a leaf of *Pecopteris*, preserved in arenaceous shale of the Coal Measures, fifty miles northwest of Camp Apache. In my preliminary report for 1871, the premature announcement of coal in the true Coal Measures, near Camp Apache, was made on an imperfect description of the locality, which I was unable to visit. Later evidence indicates that the coal in question is probably of Cretaceous age.

Silurian.—Among the Basin Ranges we have identified the Lower Silurian by fossils at fourteen points; and by other evidence, based primarily on the fossils, we have extended the recognition to include portions of seventeen mountain ranges. At Belmont, Nev., the slates which wall the argentiferous veins contain *Graptolithus bicornis*, *G. ramosus*, and *G. pristis* (?). The shales of the range next west—the Toquima—are probably of the same age They also contain the celebrated Murphy and other silver mines, and above them are limestones, in which Mr. Emmons found Carboniferous fossils Primordial trilobites were bought by Mr. J. Koehler from Eureka, from the Roberts Creek range, and from a point between San Antonio and Silver

Peak, and by Lieutenant Lyle from Silver Peak.* An *Orthis* resembling *O. plicatella*, but believed to be new, was discovered by Mr. C. G. Heath at Fossil Butte, near Hyko, Nev., and at about the same horizon, in the adjacent Pahranagat range, I found a score of species. My collection from this locality was unfortunately destroyed in transit, but the field notes, though based on a very hasty examination, suffice to indicate the horizon very nearly. They include *Calymene Blumenbachii*, *Asaphus gigas*, *Orthis lynx*, *Strophomena alternata*, and *Receptaculites*. (See Sec. XVII, 2 and 4.)† Silurian rocks, chiefly limestone, here constitute the chief mass of the mountain, and in them are the silver mines of the Pahranagat district. In the next range to the west, the Timpahute, are metalliferous veins, dividing yet lower strata. They are walled by shales, in which are calcareous bands filled with the disjointed armor of a spiny Primordial trilobite, *Conocoryphe.* Above the shale (Section XVIII) are limestones, that may correspond to those of the Pahranagat range, and below are vitreous sandstones, closely resembling the Potsdam sandstone of New York. The same sandstone was recognized in the Belted Mountain range, where it is almost buried by rhyolite, and in the Amargosa range. (Section XIX, 3, and Fig. 12.) At the last station the overlying shale is altered to schist, but retains obscure vestiges of the trilobite spines. In *débris* from the same range was found a single specimen of *Maclurea* (*magna?*).

At the base of the anticlinal arch exposed in the cañon at Ophir City, in the Oquirrh range, are limestone and shale, with *Conocoryphe*, *Dikellocephalus*, and *Olenus Gilberti;* but a few acres include the whole outcrop. In the next ridge to the west, the Stansbury range, Silurian strata are thought by Mr. Howell to form the crest. Close to the "Old River Bed Station," at the north end of the McDowell mountains, I found *Bathyurellus Wheeleri* in a black limestone overlying vitreous sandstone, and the identity of rock series renders it probable that the Thomas range also is built chiefly of Silurian strata. The House range, which has a simple structure, appears to be built, for fifty miles of its length, exclusively of Silurian rocks. A lime-

*Prof. J. D. Whitney announced to the California Academy of Science their independent discovery at Silver Peak and Eureka.

†A collection of fossils, including Lower Silurian and Devonian forms, had, at some time previous, been sent to Dr. Newberry from the vicinity, but I do not know their relation to my section.

stone mass at top, 2,000 feet thick (Sections XV, 2 to 7, and XVI, 1) yielded, together with other forms, *Paradoxides* (?), *Scalites*, *Receptaculites*, and *Phyllograptus*, and a shale beneath it is filled, at Antelope Spring, with beautifully preserved specimens of *Bathyurellus* (*Asaphiscus*) *Wheeleri*, *Conocoryphe Kingii*, and an undescribed *Agnostus*. Beneath this are another limestone and a vitreous sandstone, making a total section of more than 4,000 feet, of which nearly 3,000 feet are limestone. Fossils of Canadian age were found in the Schell Creek range at Schellbourne, and it is highly probable, though there is no paleontological evidence, that the Snake range, lying between the House and Schell Creek, contains Silurian rocks. At the mining town of Pioche, built on a spur of the Schell Creek or Highland range, Mr. Howell found Primordial trilobites (*Olenellus Howelli* and *O. Gilberti**) in a shale overlying the quartzite which contains the argentiferous veins, and covered in turn by limestone.

The following species had been named, and I quote here Mr. Meek's descriptions, which will re-appear, with figures, in the paleontological volume.

Olenus (*Olenellus*) *Gilberti*, Meek.

This species is so very closely allied in all of its characters known to *O. Vermontana*, Hall, that it may be sufficiently indicated by mentioning the few characters in which it differs. In the first place, the anterior end of its glabella differs from that of *O. Vermontana* in not reaching the anterior margin of the head by one-half to one-third its breadth instead of abutting close up against the marginal rim. The anterior ends of its eyes also extend farther forward, so as to come more nearly in contact with the anterior to be of the glabella, than represented by the published figure of *O. Vermontana*. Again, our specimens show a narrow marginal rim along the posterior edge of the head, extending all the way out to the lateral angles, not seen in the figure of the Vermont species. A still more marked difference is lobe seen in the direction taken by the posterior margin of the head, near the posterior lateral angles, where in the Vermont species this margin curves gracefully backward to the lateral spines, while in our specimens it

* The paleontological collections had been placed in the hands of Mr. F. B. Meek for study, and the work barely begun when he was prostrated by sudden illness and compelled, to our great regret, to relinquish it.

curves rather abruptly forward, so as to form a kind of notch at its connection with the bases of these spines on each side.

Only a single detached specimen of one of the pleuræ is contained in the collection. This is the large third one, which is prolonged and deeply furrowed as in *O. Vermontana*, but it is not near so abruptly bent backward as in that species. Some specimens indicate that the species under consideration attained nearly twice the linear dimensions of *O. Vermontana.*

The specific name is given in honor of G. K. Gilbert, geologist of Lieutenant Wheeler's survey.

Olenus (*Olenellus*) *Howelli*, Meek.

This species seems to be related to *O. Thompsoni*, Hall, from the Vermont slates. Its cephalic shield, however (the only part known), differs in some of its proportions, particularly in being much more convex than it seems possible that the corresponding part of the type-species of the Vermont species could ever have been, even after making full allowance for accidental pressure. Its anterior outline is also much more narrowly rounded, and its length proportionally greater than in *O. Thompsoni*, the cephalic shield of which is about twice as wide as long, while the length of this part in the species under consideration is to its breadth as 5 to 7. Professor Hall also figures and describes his species as having the neck furrow passing entirely across, while in our type it ends abruptly at about one-third of the distance across on each side. Its neck segment also projects back beyond the posterior margins of the cheeks, while that of *O. Thompsoni* is figured on a line with the same.

The specific name is given in honor of Edwin E. Howell, of the geological corps of Lieutenant Wheeler's survey.

The localities that I have thus rapidly enumerated, are scattered through a region extending four degrees in latitude, and five and a half degrees in longitude, and it is not to be expected that, over so large a space, there shall be found constancy of lithological succession. Still it may be noted that the series, in a great number of instances, exhibits limestone at top and vitreous sandstone (quartzite) at base, with usually shale between—the typical sequence of deposits upon a continent slowly sunk beneath the ocean.

The base of the quartzite is usually not seen. The quartzite of the Toyabe range, which may be the base of the Silurian, has, according to Mr. Emmons, a depth of several thousand feet, and overlies granite. At Wheeler's Peak an anticlinal of the quartzite appears to have a core of granite, but the fact was not fully established. In the Amargosa range, (Section XIX,) Silurian quartzite, 900 feet thick, rests conformably on 600 feet of schist, and what supports the latter is not known. There is strong presumptive evidence that the White's Peak section (Fig. 9 and Section XVI), showing the Schell Creek range at a point between Schellbourne and Pioche, exhibits Silurian strata, although no fossils were found at that point, and, if it does so, then we have the siliceous rocks at the base of the Paleozoic locally developed to the enormous thickness of 11,500 feet.

The Virgin range, exhibiting, in Iceberg Cañon, the entire Grand Cañon rock series, is believed, for reasons that will be given below, to include therein Silurian strata.

The region of the Plateaus shows Silurian rocks only along its margin and in the Grand Cañon of the Colorado. The strata which underlie the Red Wall group in the Grand Cañon are, (1) the Marbled limestone, 75 feet thick, (2) the Tonto shale, 600 feet thick, and (3) the Tonto sandstone, 80 feet thick; and the last rests unconformably on crystalline schists. The Marbled limestone is characterized by ramifying stem-like markings, which suffuse the whole mass and give it a mottled appearance. The stems usually indicate their organic character merely by their outward forms, but a few specimens gathered by Dr. Newberry exhibit a coralline structure and appear to belong to the genus

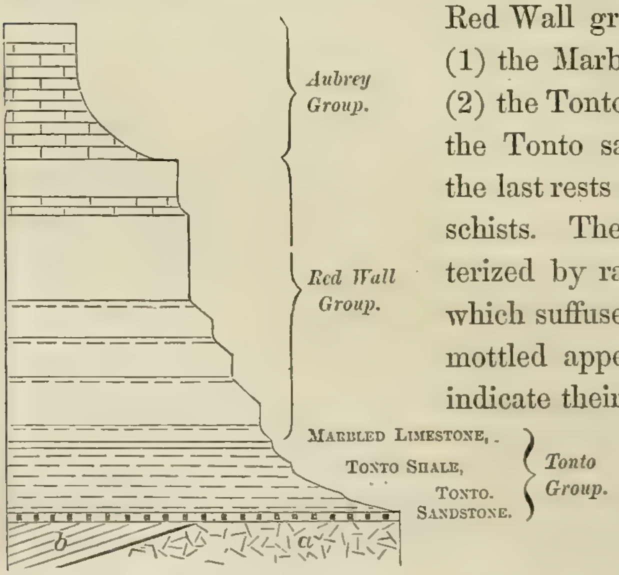


FIG. 81.—The Grand Cañon rock system and its subdivisions.

Chaetetes. The limestone has a thickness at the mouth of the cañon of but 75 feet, but there is a hint of its recurrence 100 feet lower, (Sec. VII, 8 *b*;) and in tracing it forty miles up the cañon, it is found to gradually increase in importance and encroach on the shale below, until, at Diamond Creek, it has a total depth of 200 feet.

The coralline stems are not sufficient to identify the bed which contains them, since similar branching forms are known alike of Carboniferous, Devonian, and Silurian ages; but it is a noteworthy fact that a mottled limestone similar to that of the Grand Cañon has been observed at a number of points in Utah, Nevada, and New Mexico, and the fossils associated with it are invariably Lower Silurian, and usually Primordial. The only other fossils yet discovered in the group are a *Trilobite* in the Marbled limestone and a supposed sea-plant in the Tonto shale. The *Trilobite* is represented by a poorly preserved *Pygidium* too obscure for the determination even of its genus. Still, enough of it can be made out to warrant the assertion that it does not belong to any known Carboniferous genus, and, hence, that the rock is at least as old as Devonian. The fossil from the Tonto shale is represented in our collections by a number of specimens; and, though its biological position is uncertain, its geological relations are beyond question.

The genus *Cruziana* was first described by A. D'Orbigny from the Lower Silurian of South America. It has since been found in Lower Silurian strata in France and Sweden; in Primordial strata in England, Newfoundland, and Montana; in the Chazy group in Canada; and in the Clinton group (Upper Silurian) in New York. Its known vertical range is thus entirely within the Silurian and its broadest distribution in the Lower Silurian.

<table>
<tr><td rowspan="4">Carboniferous.</td><td>Cherty limestone.</td><td rowspan="2">Aubrey group.</td></tr>
<tr><td>Cross-bedded, and other sandstones.</td></tr>
<tr><td>Limestone and sandstone.</td><td rowspan="3">Red Wall group.</td></tr>
<tr><td>Limestone.</td></tr>
<tr><td>Place of Devonian and Silurian, (except Primordial.)</td><td>Limestone and calcareous shale; without fossils.</td></tr>
<tr><td rowspan="3">Primordial.</td><td>Mottled limestone, &c.</td><td rowspan="3">Tonto group.</td></tr>
<tr><td>Arenaceous and argillaceous shales.</td></tr>
<tr><td>Vitreous sandstone.</td></tr>
</table>

By these facts I am led to conclude that the Tonto group is certainly Lower Silurian in age, and probably Primordial.

In the accompanying table is a correlation of the Grand Cañon rock system with the rocks of other countries.

Archæan.—Metamorphic sedimentary rocks, of undetermined age, were seen at a number of points in the region of the Basin Ranges, and have been regarded provisionally, in mapping, as Archæan, and with them have been grouped the granitoid rocks, the age and origin of which I have rarely been able to determine. I will enumerate only those localities at which the observation determined something more than the mere presence of crystalline rocks.

In the Grand Cañon of the Colorado (see Fig. 30 and Fig. 81 *a*), the Tonto sandstone rests directly on plicated and eroded schists and associated granites, and demonstrates them pre-Silurian. Following down the river, the same relation is seen in the Virgin range; and in the next ridge to the west, through which the river has cut Bowlder Cañon, are gneisses so similar to those of the Virgin range, that they may safely be classed with them. In Music Mountain, in the Black Hills near Prescott, and on Cañon Creek, or, more generally, all along the southwestern border of the Plateau region in Arizona, the Archæan schists and granites are seen beneath nonconforming members of the Grand Cañon rock system; usually the Tonto sandstone. To the south and west of this line stretches a great ocean of metamorphic ridges, in which no one has found fossils. Whether a portion of the rocks are altered Paleozoic, or whether the Paleozoic has been completely removed in the progress of erosion, or whether the Archæan rocks have been covered by no later ocean sediments, has not been decided. The purity and great thickness of the Carboniferous limestones, up to the very margin of the region, would appear to negative the idea of a permanent continent from Archæan time; if, indeed, it is not negatived by the survival of acute mountain ridges.

Résumé.—The Archæan strata had been deposited, plicated, raised above water, and eroded, before the epoch of the Tonto group, the first that, in this region, has contributed paleontological data to the geological record. In that epoch a coast line slowly encroached upon the Archæan continent, paring its ridges, filling its hollows, and spreading over all, first, the coarse siliceous detritus that constituted the advancing beach; secondly, the finer mud, sorted out by the waves, and spread by currents in the shoal water that progressively followed the beach; and, thirdly, the limestone that was slowly formed, when the shore became so distant that the currents brought no more matter in mechanical suspension. Where the shore then was we cannot tell, nor do we know what islands remained. The record of the ocean's advance has been traced as far west in Nevada as longitude 117°, and as far east as longitude 109°, and I know no reason to doubt its continuity, beneath newer strata, to the region of the Great Lakes. From this time the shore did not return to a large portion of our field until late in the Carboniferous age. From the close of the Carboniferous to the beginning of the Cretaceous age, a great area, including the whole Plateau country, appears to have been covered by an inland sea, entirely separate from the ocean; a sea in which were accumulated, probably from local sources, minerals that the world-wide ocean, constant in its generalities, cannot be supposed to have furnished in such quantity. The deposits are pervaded by gypsum and colored by the peroxide of iron, and contain no indigenous fossils, only logs and leaves drifted from the shore. Once only did the ocean regain temporary sway, bringing with it a Jurassic fauna, and then retreating, until, in Cretaceous time, the domain of the shut sea was finally abolished. Through the Cretaceous age the Plateau country was the scene of a shallow ocean, the shore of which crossed and recrossed it, and was never remote; while the Range Province had become finally continental. Then, by the upraising of some remote barrier, the Cretaceous sea, or bay, was converted into a fresh lake; and, with the gradual drainage of this, the whole region became terrestrial. Since the expulsion of the sea, the elevation of the continent, which caused it, has continued; and the Plateau region, which, from early Silurian to late Cretaceous, sank (as referred to the ocean) no less than 8,000 feet, has been bodily uplifted to its former altitude. Erosion, which began in the Ranges and the Plateaus, as they were successively exposed to the atmosphere, has labored, during the elevation, to remove the results of the deposition which accompanied and recorded the subsidence, but has accomplished only a small fraction of its task.

PART II.

REPORT

ON

THE GEOLOGY OF ROUTE FROM ST. GEORGE, UTAH, TO GILA RIVER, ARIZONA.

EXAMINED IN

1871.

BY

A. R. MARVINE.

WASHINGTON, D. C., *May* 10, 1873.

SIR: I have the honor to transmit herewith my report on the geology of a portion of the region traversed by "Party No. 2" during the field season of 1871. In the earlier part of this season, duties incident to my position as astronomical assistant prevented my making any geological observations worthy of record here. Between Saint George, Utah, and Prescott, Arizona, though the route followed was hurriedly passed, the object really in view being the speedy establishment of an astronomical station at Fort Whipple, near Prescott, still such facts as were then observed are given in the first part of the following chapter.

Fort Whipple being the last point, this season, whose position was determined by the more elaborate astronomical methods of the field, I was here formally transferred to geological work, and such observations as were made from this point throughout the remainder of the trip, to Tucson, form the rest of the report.

Hoping the results may be satisfactory to you,

I am, very respectfully, your obedient servant,

ARCH. R. MARVINE.

GEO. M. WHEELER,

First Lieutenant of Engineers, U. S. A.

CHAPTER VII.

GEOLOGY OF ROUTE FROM SAINT GEORGE, UTAH, TO THE GILA RIVER, ARIZONA.

SECTION I.

SAINT GEORGE, UTAH, TO CAMP VERDE, ARIZONA.

A line trending nearly southward from Saint George, in the extreme southwestern corner of Utah, to the Colorado River, and thence southeastward to Camp Verde, indicates approximately part of a remarkably sharp and well-marked boundary between two regions which, in their geological and topographical aspects, are strikingly the opposites of one another.

To the southwest of this line lies the Basin Range System of numerous and nearly parallel mountain chains, for the greater part devoid of sedimentary strata, with large areas of plutonic and highly metamorphic rocks, and large detrital filled valleys, which increase in area toward the lower reaches of the Colorado and Gila Rivers.

To the northeast of the line, and rising abruptly from it in sloping terraces and precipitous escarpments, are the edges of several thousand feet of sedimentary strata, which, dipping at first gently away from their exposed edges, and acquiring, in a succession of abrupt steps, the various members of the overlying geological series, stretch eastward to the Rocky Mountains and from the great Colorado Plateau.

The line separating these two regions is approximately the route traveled. South of the Colorado, though rising for a short distance upon the summit of the lowest step or terrace of the sedimentary series, most of the way was upon the crystalline rocks on which the latter rest, and which mostly form the Basin Range System, &c., to the southwest. Of these, nothing more can be stated than their names, the nature of the journey not developing any geological relations among them. North of the Colorado, and between it and Saint George, the Plateau border differs much from that south of the river.

Saint George is situated on rocks belonging near the base of the Trias. This formation here consists of many hundred feet of dark red cross-bedded massive sandstones which rest upon a series of shaly and often highly gypsiferous sandstones, having among them occasional heavier beds, all being approximately horizontal, or dipping slightly toward the northeast, and sustaining a most sparse and drear vegetation. It is at the base of the massive sandstones that Saint George stands. They here form red bluffs facing south or west, and trending from the town both eastward and toward the northwest in lines approximately parallel with the Virgin and Santa Clara rivers respectively. These two rivers, in fact, here roughly indicate the southern and western boundary of the formation, though its lower shaly portions often stretch beyond them.

About sixteen miles above the mouth of the Santa Clara, the river flows directly at the western base of the massive Trias sandstone, which rises above it in a most striking bluff. The dip is here quite decided, and from beneath the bluff, in leaving it westward, outcrop the lower shaly members of the group. From beneath these, in turn, appears the upper bed of the Carboniferous formation, and, with increasing dip, the upturned edges of its lower members successively outcrop as they gradually rise upon the eastern slope of the Virgin Mountains. These mountains trend in nearly a north and south line west of Saint George, and lying all along upon their eastern flanks may thus be seen the outcropping edges of the inclining strata. Where crossed by the old Salt Lake road, these strata rise high upon the mountains, in places forming their highest points, and, resting below on the underlying crystalline rocks which here form the opposite side of the range, give it a monoclinal character.* This upturned series here

* I understand from Mr. E. E. Howell, who, in 1872, crossed the range farther south, and near where it is cut through by the Virgin River, that it there presented an anticlinal structure. Later, he found that at the north a fault existed along the east base of the range. I am also indebted to Mr.

apparently presents the same sequence of strata as near the Colorado River,* all the upper part certainly being of Carboniferous age, though proof of the actual age of the lowest beds is yet wanting (1872).

Beyond the base of the mountains, and near Saint George, are several streams of black basaltic lava, which have flowed down from the north,† and end not far from the city. South of Saint George, the Triassic gypsiferous shales extend some distance beyond the Virgin River. The dip of the formation, however, being somewhat greater than the slope of the southern side of the Virgin Valley, the Carboniferous beds here also gradually outcrop in going southward, first appearing not far from the Arizona border. Passing gradually down through the Upper Carboniferous strata, as the ascent is made, the Red Wall limestone is found exposed upon the divide between the Virgin and Colorado rivers at the head of the Grand Wash. In descending into the latter, the rocks are again found for a while dipping somewhat more steeply than the general incline, thus forming of the divide, where crossed, a gentle anticlinal whose axis apparently rises at the west upon the flanks of the Virgin Mountains, and which probably dies out at the east in the main plateau, or else is separated from the latter by a fault which may be just commencing at this point, but which further south, as will be seen, becomes very large.

In descending the "Wash," there gradually appears upon the east a line of abrupt cliffs, which gradually become higher as the valley is descended, until they form an enormous mesa-wall nearly 2,000 feet high, composed of the banded and ribbon-like edges of the sedimentary strata, which appear perfectly horizontally bedded. This mesa-wall, rising in alternate slopes and precipitous palisades, with its high colors and strangely eroded outlying buttes, forms the abrupt eastern side of a great valley whose western boundary is the slopes of the Virgin Mountains, and which runs from the vicinity of the divide before mentioned, southward to the Colorado.

The eastern mesa-wall is exposed down to the base of the sedimentary series only near the river. The following section, made at the mouth of the

Howell for corrections and information upon several points in the geology about Saint George, which will be found more fully and accurately presented in his report.

* See *ante*, p. 184.

† From craters in Diamond Valley.—C. A. Ogden.

Grand Cañon, has been furnished me by Mr. Gilbert, and gives an idea of the general series of rocks which have already been passed, as well as of those to follow. (See Fig. 82.)

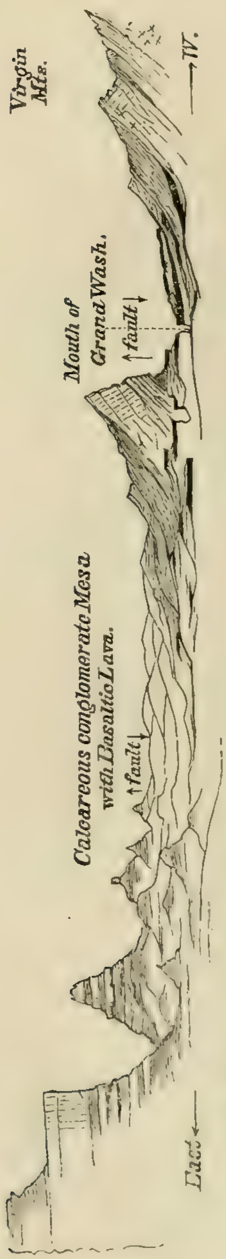


Fig. 83.—Section of the valley of the Grand Wash near Colorado River; distant view from the north.

All along the western side of the valley and inclining on the slopes of the Virgin Mountains lie the upturned edges of the same strata. At the north, upon descending from the mountains these may possibly continue out and join the Plateau strata uninterrupted. Lower in the valley, however, they dip off from the mountains beneath the detrital filling of the valley, are not continuous with the Plateau rocks, but must be separated from them by a fault of many hundreds of feet. Still lower in this valley, and near the Colorado, a ridge rising from below the valley detritus shows still another fault. A more correct section of these faults was obtained by Mr. Gilbert in the natural section presented along the Colorado River. (See p. 54.) In the following figure I try to give an idea of the main features of the valley, as seen from a point at the north.

A maze of the eroded remains of the Carboniferous mesa lines the eastern side of the valley; the upturned strata occupying the western. Among and resting upon the latter are large masses of black basaltic lava, extending all along the base of the mountains, and in places a long distance across the detrital filling which occupies the middle of the valley, but apparently not reaching entirely across to the eastern side. In this wide valley are several lines of drainage, of which the main one, and that into which most of the others finally enter, is called the "Grand Wash." These washes generally have the cañon form—flat, gravelly bottoms, sloping talus, and steep escarpment above; and as, in all but the western side, the intermediate country is rather flat or rolling, the system, though in a valley, has all the characteristics of a mesa country. In the upper part of the valley

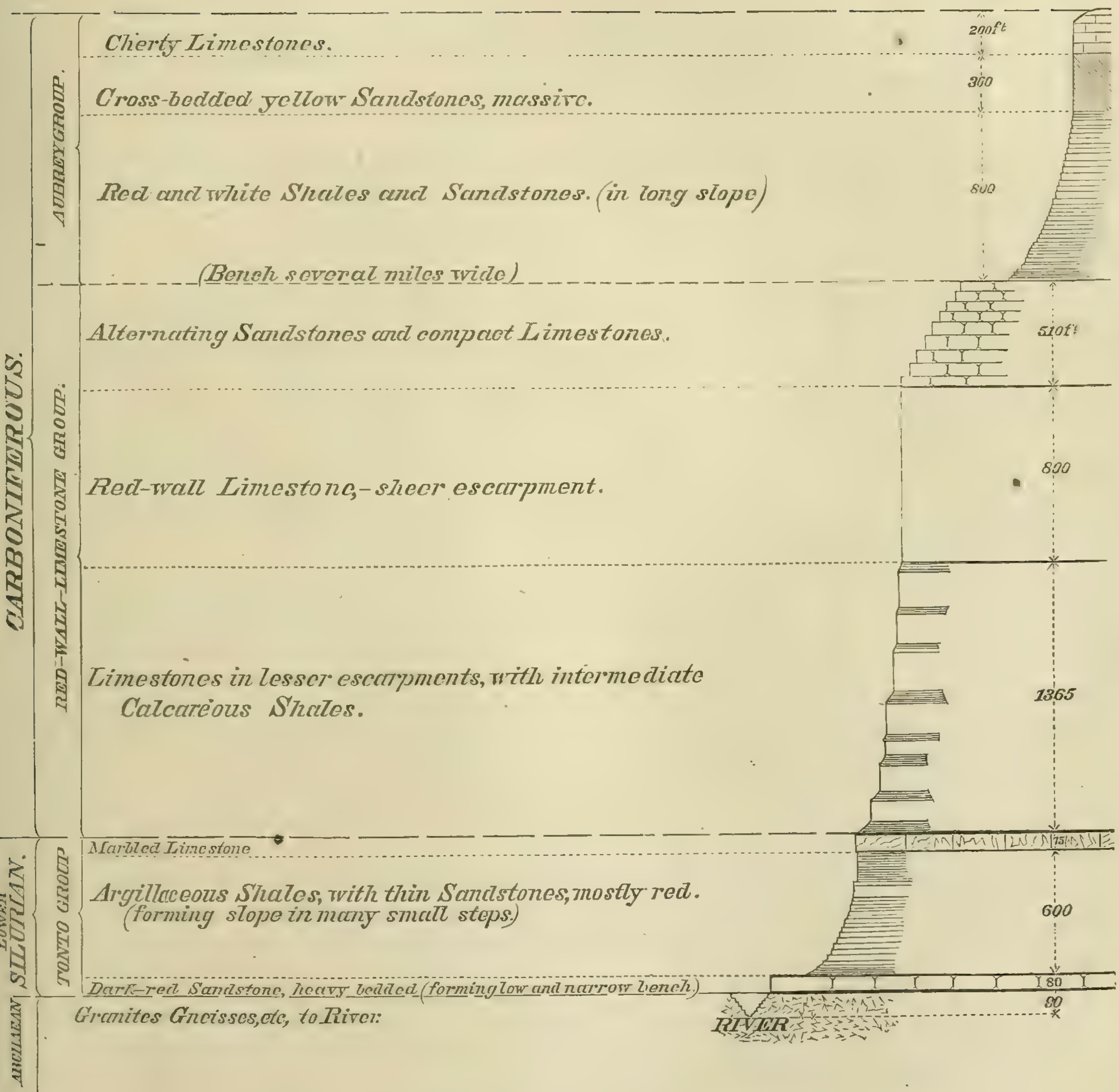


FIG. 82.—Section of the Sedementary Series at the mouth of the Grand Cañon.—G. K. Gilbert.

these cliffs may be several hundred feet high, as at the spring about twenty miles above Pah-ghun Springs, where they are composed of the same rocks, as the adjacent plateau, with a capping of basalt. Lower down, the Grand Wash and adjacent cañons are not deep, are generally in the detrital filling which here hides the older sedimentary rocks below, and have usually a basalt escarpment. This lava may be but a few feet thick, while in places the cañon has not yet penetrated it, several hundred feet being exposed.

Above this lava there almost always occurs more of the detritus. This is composed of a curious mixture of limestone and sandstone fragments derived from the adjoining formations, mostly white, and often containing nodules of chert and Carboniferous fossils. This sometimes has the character of a breccia, and again of a conglomerate, while often it is so cemented together that its structure is not apparent. This "calcareous conglomerate" is in places covered by a second basaltic lava flow. Thus, at "Moccasin Spring," there was shown upon the eastern side of the Grand Wash, above the main detrital conglomerate, a lower lava, about 20 feet thick, covered with 30 feet of the calcareous conglomerate, which in turn had 15 feet more of lava above it, forming the top of the cañon wall. About twenty miles above Pah-ghun Springs, and upon the high cliff above the spring there found, it was estimated that there was 150 feet of this conglomerate lying between the two lava flows. East of the section mentioned, at Cave Spring, the edge of the upper lava is soon reached, and then, also, that of the lower one, the valleys exposing many feet of the conglomerate, which must compose an enormous amount of the valley filling. Where free from lava it forms a rolling or hilly surface, often with deep valleys; it is horizontally bedded, and abuts unconformably against the upturned Carboniferous strata which protrude from beneath it.

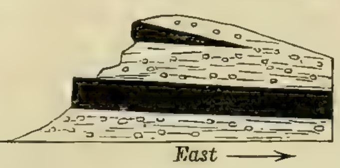


FIG. 84.

Lower down in the valley, and in the vicinity of the river, a true conglomerate of large and well worn pebbles occurs. Where observed this was divided into two portions: an upper, containing many pebbles from the sedimentary series close by, separated by an uneven but well marked line from a lower conglomerate, which was very coarse, composed mostly of granite rocks, among which were very conspicuous, large bowlders, often five feet in diameter, of very compact and hard white granulite, having but little quartz and large crystals of white feldspar. The narrow cañon leading directly to the river was in these gravels. All along its sides were rows of buttresses, with many columns of the compacted gravel supporting great bowlders upon their summits, and giving quite a gothic air to its architecture. These gravels extend to and along the river, resting on the same granite which above lies beneath the Tonto sandstones.

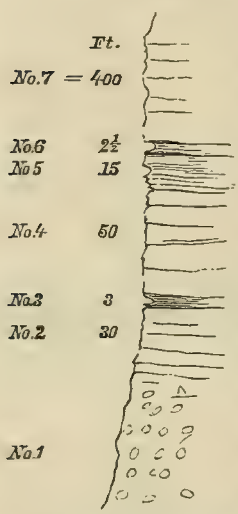


FIG. 85.—Section at west base of mesa extending from Colorado River, near mouth of Grand Cañon, southward twelve miles.

In going southward from the river, and following a wash lying quite near the foot of the mesa cliff, a section is encountered quite different from that passed in the Grand Wash. The same gravels are met near the river, growing finer and accompanied at top by fine calcareous shales which often contain much gypsum. One hundred feet is probably a small estimate for the thickness of these beds. Above them comes a series of calcareous tufas. These occur in well defined beds of 2 to 10 feet in thickness, mostly white or reddish-brown in color, and though usually full of rather large lenticular pores, the rock portion is often very compact and heavy, and at times slightly crystalline, though generally rather light. The beds are sometimes separated by a stratum, a few inches to a few feet thick, of a very light, fine, soft, ashen-like gray or white tufa. Dinoach Spring flows from one of these. This section was taken in a distance of about twelve miles, after which granite and schists were passed to Tinnahkah Springs. The thicknesses are about as in the above cut.

From the mouth of the Grand Cañon the general course of the Colorado, up stream, is at first nearly southeast. Upon meeting the river, the great Carboniferous escarpment, which forms the eastern side of the Grand Wash, turns and follows up the stream, forming the northeastern wall of its cañon. Only the lower beds of the escarpment, up to the great bed of the Red Wall limestone, form the first step of the westward facing mesa-edge upon the southern side of the river. These at first continue the line of cliffs at the north, trending south to Tinnahkah Springs, when they swing more and more to the eastward to Music Mountain,* near Truxton Springs.

The accompanying sketch gives the lower beds of the escarpment series, as shown at the mouth of the Grand Cañon, somewhat more in detail than in the preceding section. The two snuff-colored sandstones, though quite subordinate in thickness, form a prominent feature of the section, and seem quite persistent, Mr. Gilbert having traced them to Diamond Creek. They seemed also to be exposed upon the bluff opposite Tinnahkah Springs, about twenty miles south of the river. In going southward, however, the Tonto shales seem to diminish in thickness, the thickness from the granite to the snuff-colored sandstone at Tinnahkah Springs being estimated at less than 400 feet. It will be observed that the base of the series has been gradually elevated in going south.

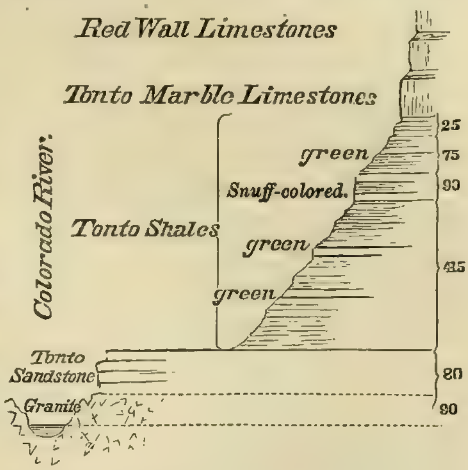


FIG. 86.—Section of the lower beds of the Colorado Plateau at mouth of the Grand Cañon.

A few miles south of Tinnahkah Springs, and where the escarpment was ascended, the Tonto shales were much further reduced, their estimated thickness being less than 100 feet, so far as could be seen upon the winding path of ascent, and they apparently contained little or no calcareous material. The Tonto sandstone had increased much in thickness, and was composed of two rather distinct parts, being red below and yellow-white mottled with salmon colored spots above. That the limestones here are the continuation of those further north, and not the expansion of calcareous beds included in the Tonto shales, seems indicated by their lithological charac-

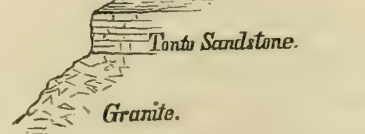


FIG. 87.—Mesa-cliff opposite Tinnahkah Springs. Estimated height of cliff, 1,200 feet. Estimated distance from granite to snuff-colored double sandstone, under 400 feet.

* This is not the Music Mountain of Lieutenant Ives's map, which lies several miles to the east.—Report upon the Colorado River of the West, Government Printing-Office, Washington, 1861.

ters, the lower bed being of a very dark drab, mottled with irregular red spots, like the lower "marble" limestone, near the Grand Cañon; while the upper beds, as farther north, grow gradually lighter-colored, becoming more uniformly compact and acquiring a conchoidal fracture. They all weather with very rough surfaces.

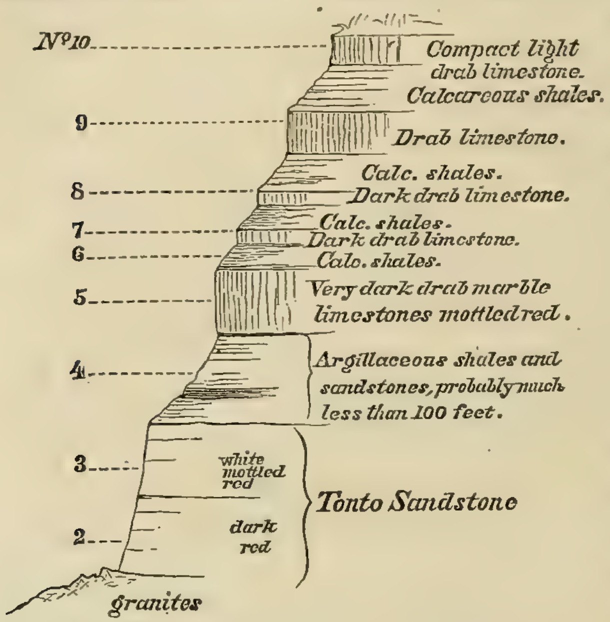


FIG. 88.—Section of mesa-edge where ascended south of Tinnahkah Springs.

The surface of this lower mesa presents a beautiful rolling or hilly country, which descends gradually northeastward to the Colorado, on the opposite side of which rises the great northern wall of the Grand Cañon. Southwestward its precipices overlook the Hualapais Valley, with the dry flat of "Red Lake" and the distant Cerbat Mountains, which appear composed mostly of plutonic rocks. In approaching Music Mountain, most of the limestones and Tonto shales are more and more eroded away from the surface of the lower mesa, and mostly remain as mesa hills, often bordering the Plateau edge, the intermediate valleys being sometimes cut to the granite below. Music Mountain is such a remnant, reaching up to the second limestone above the shales, the Tonto shales being thicker than at Tinnahkah Springs. The country does not fall away particularly as a result of this erosion, however, as the base of the sedimentary series, the Tonto sandstone, grows more and more elevated, the mesa edge being here as high or higher than near the river, but formed mostly of underlying granite

The drainage is away from the edge northeastward to the river. Upon the surface several patches of lava were met, forming limited areas of "malpais." The cañon of New River, which heads just north of Music Mountain, has served as a channel for a flow of the same lava. A new cañon has been cut in this lava, exposing the following section:

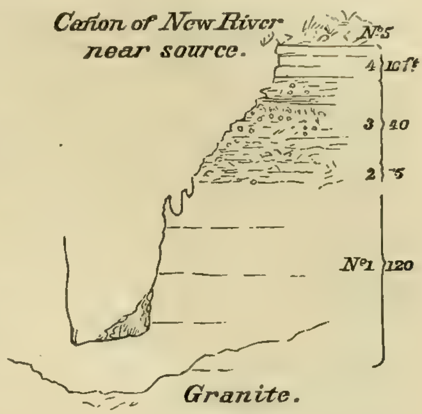


FIG. 89.

No. 5. Surface soil and *débris*, mostly of Tonto sandstone.

No. 4. Ten feet; compact and often banded calcitic tufa or a calcareous conglomerate so closely cemented as to appear homogeneous.

No. 3. Forty feet; very fine to coarse conglomerate, mostly of limestone, with sandstone, granite, and lava bowlders; horizontally bedded, filled in largely with lime.

No. 2. Fifteen feet; bowlders of No. 3, and the finer material of the same mixed, at the top, with bowlders of No. 1, but below serving only as a filling of cracks and spaces in the very scoriaceous and amygdaloidal top of No. 1. The amygdales of the latter are filled mostly with carbonate of lime with some zeolitic mineral, and the rock filled with soft, reddish-brown, crystal-like specks, as if of decomposed olivine.

No. 1. About 120 feet exposed in all, not cut through; very compact, grayish black lava, with smooth but uneven to hackly fracture, and occasional grains of a transparent green mineral, apparently olivine, which decompose to a reddish-brown soft material. This, and the lava met farther north are nearly typical basalts, and much like others met upon the Colorado Plateau.

At Music Mountain, the mesa edge suddenly turns eastward, leaving a deep bay or area extending toward Aubrey Valley, and in which Truxton Springs is situated. In descending from the bottom of the Tonto sandstone, which forms the base of Music Mountain, to Truxton, about 1,500 feet of granite and allied rocks are passed through, of which about half is in the first steep descent from the mesa. This granite, with the accompanying rocks—of which the most frequent is a very fine-grained gray syenite, composed of a uniform mixture of small white and jet black particles, as if a loose sandstone—at first forms abrupt hills, and contains frequent highly-feldspathic veins or dykes, which, being harder than the adjacent rock, generally protrude several feet above the surface. At two or three points several of these appeared in company, at one point as many as seven, all being parallel, trending nearly east and west, a few rods apart, and 2 to 5 feet thick. Some were of handsome white cleaving orthoclase.

Gradually the granite hills become capped and often wholly covered with a dark lava, like that at New River, and as the surface of this gradually becomes lower, it in turn becomes covered with a light pink or white rhyolite, the two being separated by several thin, soft, stratified layers of white tufa, which assist in causing the rhyolite to break in palisades which line the cañons.

The granite was subjected to much erosion before the lavas covered it, its surface being very irregular, points of it sometimes projecting through both lavas, while, again, some of the cañons cut through many feet of the lower lava without exposing the granite. These granite hills toward the west, where they form the low eastern edge of Hualapais Valley (in the extension of the line of higher mesa edge at the north), are quite free from the lavas; eastward, or back from the valley, as near Truxton, granite and lava both largely occur; while further east, in which direction the lava-cap gently dips, the lava appears to form large unbroken areas. Its relation to the sedimentary mesa which rises at the east I do not know. Toward the south and along the western valley border it occurs much as toward the north. As the hills grow higher the rhyolite first thins out and disappears, and finally the lower lava, leaving high hills of granitic rocks. It would thus appear that the rhyolite occupies a broad but shallow basin in the lower lava. I do not think that I observed it at any point thicker than 60 or 80 feet.

Near its northern limit, and where it was first observed beneath the capping rhyolite, the lower lava was almost precisely like that at New River. It is nearly black, or grayish black, and somewhat dull in color, and very fine-grained or compact, uniform, and close in texture, breaking with an uneven fracture. In this base are sprinkled from a few to numerous small grains of olivine. These usually show a discolored film upon their surfaces, while near the weathered surface of the rock the mineral is often changed throughout, having the color and nearly the consistency of hard brown soap. All stages of this decomposition may be observed. This lava has all the characteristics of true basalt, and is like the Plateau basalts that I have seen, excepting, perhaps, that the olivine is more prone to decomposition.

The greater part of the upper lava consists of a white, light, fine-grained, but rough and open textured mass, in which are scattered numerous colorless, cleaving crystals of sanidine, and occasional flakes of a bronze mica and small crystals of hornblende. A few grains of quartz are also present, and as the rock so strongly resembles some of the typical Nevada rhyolites, it probably also contains free silica disseminated through the mass unperceivable by the eye. In places the paste is more compactly textured, being then heavier, with a smoother and more conchoidal fracture, and ringing when struck much like phonolite. It is frequently of a delicate pink color, and weathers dark, dirty brown, while it often contains scoriaceous pebbles of the underlying lava. The following cut is a section observed near Truxton Springs. In this vicinity there are more than two strata of the basalt exposed in places; Mr. Ogden stating that he observed four at one point, all separated by stratified conglomerates, as in the accompanying section. I observed but two myself, in my hurried passage. These were both quite amygdaloidal, the amygdales being quite numerous, mostly small and round, and containing carbonate of lime; the dark, compact matrix being quite thickly sprinkled with the yellow-brown, decomposed olivine grains. At the scoriaceous summit of the lower beds, especially where they are much commingled with the overlying stratified volcanic sands, &c., the soft decomposed mineral largely abounds. The following is a detail description of the section, (figure 90:)

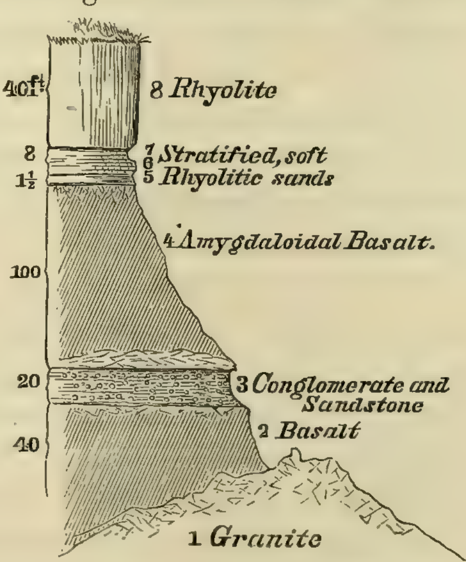


Fig. 90.—Section of lavas at Truxton Springs.

No. 8. Forty feet. Rhyolite; matrix grayish white, fine-grained, very finely porous, light; fracture rough, uneven. Embedded in this matrix are numerous crystals, often rectangular, of a colorless glassy cleaving feldspar, probably sanadine; a few small crystals of black hornblende, flakes of a bronze mica, and grains of quartz. It incloses frequent fragments of scoriaceous basalt, which contains decomposed olivine crystals. Near the base the matrix is more compact; fracture, conchoidal; embedded crystals fewer; color, light pink; rings like phonolite.

Between No. 7 and No. 8 is a narrow seam of very soft, fine rhyolitic sand, loosely compacted; color, light pink.

No. 7. Two feet very fine sandstone, thinly bedded, but much broken up. It is like the compact rhyolite near base of No. 8, only not so coherent, and containing fewer scattered crystals.

No. 6. Six feet rhyolitic sand, much like No. 7.

Between 5 and 6 is very soft seam, reddish and white bands.

No. 5. One and one-half feet soft, slightly coherent, stratified, grayish-white rhyolitic sand.

Junction between Nos. 4 and 5 is not well defined, the exceedingly amygdaloidal surface of 4 being much broken and mixed with 5. Former has compact black base, full of yellowish-red decomposed olivine crystals, and has about 50 per cent. of amygdules of carbonate of lime and perhaps a zeolite.

No. 4. One hundred feet, basalt; very compact, hard, black base, having conchoidal fracture, and numerous small, yellowish-brown, crystal-like spots of decomposed and decomposing olivine, with numerous very small and fewer larger white amygdules—former wholly filled and round, latter lined with carbonate of lime and apparently zeolites. Bottom much mixed with bowlders, &c., of—

No. 3. Twenty feet, conglomerate and sandstone, mostly white, of volcanic sand and many granite pebbles.

No. 2. Basalt like No. 4, but less amygdaloidal.

No. 1. Granite; whitish and pinkish; red and white feldspars, little quartz, and congeries of small flakes of green mica.

Near Truxton, however, considerable variations among the lower lavas occur, chiefly in the extent of amygdaloid character or amount of decomposition of the olivine. In fact, in these characters, but in these alone apparently, these lavas show considerable external differences at first from other basalts of the region, but the accompanying stratified beds show that the lavas also have been deposited under water, when the conditions have generally been supposed to be such as to promote peculiarities of texture and especially amygdaloidal character. The variation from the true basalt of the same bed a few miles at the north, however, is really small, and involves no change in specific character.

It would seem, then, that there is here a case in which *rhyolite is younger or more recent than basalt*, and one of the few known exceptions to the usual sequence of these volcanic rocks of the West, as first established by Richthofen.* I did not observe the source from whence these lavas came.

At one point between Music Mountain and Truxton Springs, in an expansion of a small cañon in basalt, with rhyolite above, there occurred, crossing the bottom of the cañon, the curious appearance of five parallel granite or feldspathic dikes penetrating the basaltic bottom, and all within a distance of about 500 feet. A short distance below there was granite exposed forming the cañon-floor. The lava, in flowing over the uneven surface of the granite, must have here covered a system of projecting dikes, such as have been described above, while the subsequent erosion has proceeded just far enough to expose them without removing the surrounding basalt.

In leaving Truxton, the road passed southwestward through granite hills, at first mostly lava-capped, but growing less so, to the eastern edge of an arm of Hualapais Valley, where it turned to the left and followed southeastward along the western edge of the granite hills. The valley's edge was rolling and covered with picturesque groves of low pines and junipers, but the center appeared sterile and flat, though probably cut with dry cañons. The Peacock Mountains, opposite, exhibit plutonic outlines, with considerable lava near their bases, the larger but more distant Hualapais Mountain, exhibiting similar outlines.

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* Natural System of Volcanic Rocks, by F. Baron Richthofen, California Academy of Sciences, 1867.

As the granite hills upon the left grow higher, the lavas upon them gradually disappear, till at Cactus Pass, where the road again turned in among the hills, none appeared. In the continuation of the road before turning, however, and upon the western side of the granite, a few large hills occurred apparently composed of dark lava.

The granite hills of the pass reach a considerable height, and form the northern extremity of a low range called the Aquarius Mountains. Feldspathic veins and metamorphic rocks as usual accompany the granites. Upon ascending through the pass, a region in which volcanic products predominate is again entered, being first encountered in a large flow of basaltic lava similar to that north of Truxton, and which is passed through in a shallow box cañon, in an expansion of which the deserted camp of Willow Grove is situated. Issuing from this cañon we found ourselves upon a beautifully rolling country, sprinkled with groves and open glades. While granite occasionally appeared, the surface seemed formed mostly of volcanic tuffs and occasional conglomerates, with some rhyolite (?). Upon the south and west are the low granite hills of the Aquarius Mountains, while curving around in partially circular form at the north and east is the Lower Carboniferous mesa edge with occasional solitary and broken outliers. At Fort Rock are several rhyolite capped hills, while the ranch at the place is partially built of fine white rhyolitic tuff quarried near by. This region of volcanic products is probably a part of that near Truxton, though I did not see the direct connection.

Cross Mountain, near Fort Rock, is a prominent mesa outlier, having a granite base, and reaching up through the Tonto sandstone and Tonto shales to the second or third of the more prominent limestone strata. Passing near the foot of Cross Mountain, and approaching Aztec Pass, the road, after passing through a short box cañon in dark basaltic lava, rises slightly upon a low table composed of loose volcanic material, mostly tuff and agglomerate, generally light colored, and having scattered upon the surface much obsidian. Standing on this table, a short distance to the southwest, is a remnant of a volcanic cone, Mount Gemini of Lieutenant Whipple. What the nature of its lava is I do not know.

In passing through Aztec Pass, we were once more upon the limits of the sedimentary rocks, the pass itself being in granite, which, upon the left, is capped with the lower strata of a southward projecting point of the lower mesa, called the Juniper Mountains. This series apparently consists of the Tonto sandstone at the base, with not so great a thickness of the Tonto shales, as at the Colorado, but greater than south of Tinnahkah Springs above, capped with three or four of the lower limestone and intermediate calcareous shaly strata. It presents, in fact, the usual lower beds of the stratified series of the region, and is similar to Cross Mountain and the many sections of the edge of the Tonto sandstones, shales, and upper limestones previously noted.*

Upon emerging from the pass and leaving Camp Hualapais, which is situated at its eastern end, the edge of the Juniper Mountains recedes upon the left to join the main mesa at the north, the road entering upon the large area of plutonic and metamorphic rocks which surrounds Prescott. This is in part a rolling country, and in part covered with abrupt hills, and even mountains, mostly sprinkled with junipers, or often with fine large pines, with their accompanying characteristic vegetation and frequent open valleys, all forming a most delightful region which is apparently susceptible of successful cultivation. Granite and allied rocks largely occur, but highly metamorphic rocks, as schists, slates, &c., also occur, often covering considerable areas, and with which many of the silver and gold bearing lodes of the country are associated. Lavas occur, but apparently in subordinate amounts.

Between Prescott and Agua Fria Valley basalt is encountered capping granite hills. The detrital filling of the valley is mostly of granite, with subordinate amounts of metamorphic rocks and lavas. Upon approaching

* The section as observed at this point, with the correlations founded on the same, by Mr. Jules Marcou, geologist of Lieut. A. W. Whipple's expedition, near the thirty-fifth parallel, will be found in Report on Pacific Railroad Exploration, (War Department,) Vol. III, Part IV, p. 156 and p. 170, and Geology of North America, p. 24, while Dr. J. S. Newberry's strictures and criticisms upon the same are in the Report on Colorado River, Lieut. J. C. Ives, Washington, 1861, Part III, p. 69. Hastening to Prescott with but two companions, to there establish an astronomical station, and in a hostile Indian country, there was no opportunity for detailed observation, even the notes having to wait a few days before they could be written. My many opportunities, however, for seeing even hurriedly the limiting edge of the sedimentary rocks along a continuous line, made me familiar with its characters, and they could hardly have been misunderstood in this instance. The section thus obtained differs somewhat from that given by Mr. Marcou, and still more from that inferred by Dr. Newberry from Mr. Marcou's notes.

the Black Hills, which lie between Prescott and Verde River, bordering the latter, much disturbed metamorphic rock is passed on their southwestern flanks. Where observed they consisted of some semi-schistose rocks and some highly changed shaly limestones. The main mass of the range following was of a very handsome syenite-granite, coarse-grained, and composed of a pretty uniform mixture of quartz and whitish feldspar, not well crystallized, and large, scattered, well-defined rectangular crystals of black hornblende. In the eastern part of the range the syenite became finer-grained, the feldspar reddish, while the hornblende, losing its crystalline form, became green, and occurred in irregular, small, apparently amorphous or fibrous spots and particles. On some of the low hills at the west, and on many of the higher ones along the eastern front of the range, were caps of black basaltic lava, often many feet thick and composed of many flows. The one of these observed was a very compact black basalt, containing very numerous scattered grains of green olivine.

In descending the eastern slope of the range a magnificent view is had of the Verde River and Valley lying at its base, with the abrupt edge of the Carboniferous mesa, which is here again encountered, rising in highly colored cliffs all along on the valley's farther side. Patches of its strata occur high up on the flanks of the Black Hills, and though not positive as to the geological relations between them and the syenite of the hills, I think that between the gently inclining strata, which certainly do rest upon their flanks, and the syenite, the strata are not upturned, though a fault may there exist. If not the latter, the Black Hills must have penetrated far up into the sedimentary rocks, and have been an island during the time that the older deposits were being formed. This was the impression received at the time.

Upon descending to the river, the valley-bottom was found to be in the Red Wall limestone.

SECTION II.

VERDE RIVER TO LITTLE COLORADO RIVER.

See Plate IV, (end of chapter,) Section 1.

The valley of the river Verde, in the vicinity of Camp Verde, occupies the line of demarkation between the edge of the Carboniferous mesa bounding it on the northeast and the Black Hills, which form its southeastern slopes. The latter, in fact, have here determined the course of the valley, the river having eroded its channel along their edge, and in the softer and horizontal sedimentary beds which formerly abutted against and rested upon their harder syenitic flanks, until it has finally worked its way some distance into the Red Wall limestone in which it now flows. The surface of this limestone here, as elsewhere, forms a bench or step, before reaching the overlying Aubrey group of rocks which forms the higher mesa beyond.

Verde Lake beds.

Toward the northwest, the upper and harder member of the Aubrey group, here a heavy cross stratified sandstone, is present, and protecting the underlying and softer members of the same series, molds the mesa's edge into a well defined escarpment, which stretches up the valley in long perspective, fading in the distance a banded ribbon of white, red, and white.

South and east of the post, the escarpment soon bends out of sight, leaving the Black Hills inclosing the view, and giving a distant glimpse of the Mazatzal range, both of the latter presenting the characteristic contours of the metamorphic and crystalline rocks which lie below the sedimentary, modified here and there by capping masses of lava. For several miles directly back (northeast) from the post, the eroding agencies, except in isolated instances, have removed the upper and protecting Aubrey bed, and left the softer and lower strata forming an undulating inclined plain, gently rising from the summit of the Red Wall limestone. Later, a flow of basaltic lava poured down from the north and east, covered the upper strata, surrounded, island-like, the old mesa remnants, in places ran down into the then existing cañons, and even to the main valley, or ended in a thin sheet upon the gentle slope.

Sycamore Canyon
Oak Creek Canyon.

Finally, subsequent denudation, having naturally its greatest hold upon these thin and weaker edges, and at those points where the lava had surrounded the older mesa islands, has broken the former into scattered patches of lava, which now cap outlying elevations, while at the latter it has commenced to carve cañons which now reach considerable depths and are often impassable. These cañons in their downward cutting have occasionally surrounded, narrowed the base, but not wholly removed the mesa remnants which originally determined their courses, so that they now stand isolated buttes, springing from the cañon bottoms, and reaching far above the surrounding plain of lava. Banded horizontally, as they are, in stripes of every width and of all colors, from white through yellows and browns to vivid reds, the sandstones and limestones of the Aubrey group, their precipitous sides buttressed and pinnacled, cathedral-like, from base to summit, they present some of the most weird of nature's architecture.

We scaled the Red Wall limestone escarpment a few miles above the post, and proceeded eastward up the gently undulating slope before mentioned. This was covered with vegetation, so that we unconsciously rose through the lower members of the Aubrey series, in which we found ourselves upon descending into the cañon of Beaver Creek. This creek unites with the Verde near the post, and in its lower reaches, which are cut in the Red Wall limestone, are many interesting and unique remains of the buildings of an ancient race. Some of these are several stories high, and carefully and methodically constructed of stones and adobe, with wooden beams, on which rest the floors. They are generally perched in almost inaccessible niches directly upon the faces of cliffs, or in crevices under overhanging bluffs 30 feet or more from the base. Besides these, there are some ruder habitations in caves in the limestone which are well defended by walls. Many relics of the ancient inhabitants, even pieces of cloth, have been gathered from this interesting locality, but there now remain only the ruined buildings and the scattered pieces of broken pottery.

Before descending into the cañon of Beaver Creek several low, lava-capped mesa outliers were passed, forerunners of the main sheet. From the cañon, as before mentioned, several buttes, composed of the Aubrey strata—red predominating near the base and lighter colors above, and probably capped with the cross stratified sandstones—rise far above the surrounding lava-covered plain. There seems to be a hardly perceptible dip to the eastward. The eastern side of the cañon is here about 1,000 feet high, the lower half being of red Aubrey sandstones, the upper half of layers of compact black basaltic lava, with a stratum of pinkish-white, calcareous, light volcanic mud or marl intercalated near the base. Some quite fresh-looking scoriæ was here observed on the surface, which was mostly covered with somewhat scoriaceous bowlders, often weathering in concentric spherical masses.

The greater resisting nature of the hard lava, as compared with that of the softer beds below, causes it to form the real western limit of the higher mesa. From its edge a commanding view is had of the Verde Valley and the Black Hills beyond. From this point the lava extends a continuous mass forty miles to the eastward, our route revealing no cañons which penetrated through the mass to the underlying strata, though north and south of the line both the cross stratified sandstone and overlying fossiliferous cherty limestone have been observed as thus exposed, the lava resting directly upon them. The highest point on this mass of lava passed by our route was about midway between its eastern and western limits, or about twenty miles east of Beaver Creek, where it reached an altitude of about 7,000 feet above the sea. Its greatest altitudes seemed to be along a line stretching from this point toward San Francisco Mountain. From this medial line the lava appears to extend, first as abrupt hills, then as more undulating country, until finally it flows out in all directions a nearly even, gradually descending and thinning sheet. It is impossible to give its limits accurately. Its western edge is nominally the mesa's edge, from which it extends eastward about forty miles, though, as stated, small outlying remnants line the margin and extend more or less far from it, proving both its original greater extent and the great erosion which has taken place since it was erupted. Toward the south it falls in a long slope, and must extend far past our trail; while at the northwest it descends toward the San Francisco Mountain.

When observed, its lithological character varied from a very compact to a rather fine-grained basaltic lava. The former is very compact, very dark-colored to black, and has plentifully sprinkled through it small grains of a transparent, green, or resinous-colored mineral, with not well-defined cleavage and vitreous fracture, *olivine.* Occasionally, it is somewhat amygdaloidal, with amygdales of carbonates and zeolites, or of quartz surrounded with a pellicle of green earth. The coarser-grained varieties, probably dolerites, are grayish in color, sometimes free from any past or matrix, and consist mostly of a granular crystalline aggregate of small white and colorless triclinic feldspar and an augitic (?) element, with frequent larger grains of olivine, as in the compact variety. The olivine in smaller grains seems to compose a considerable per cent. of the rock. The olivine is often affected by decomposition, being generally brownish or more resinous in color, with irridescence, and sometimes slightly resembling mica, and again apparently replaced by a soft iron mineral, producing numerous red spots.

This lava has probably been extruded into its present position from below through fissures, which probably extend approximately underneath its line of greatest elevation, and along which faulting may or may not have taken place. The causes which gave it birth are no doubt identical with those which have produced the many other basaltic masses which rest in a similar manner on the Colorado Plateau, while their occurrence probably has a connection with those deep-seated causes which have acted, and are yet probably acting, in modifying the plateau. The soil upon the lava is black and meager, and in places where but little exists the twisted scoriæ are often remarkably well preserved, seeming as fresh as if formed but yesterday. Large pines (*Pinus ponderosa*) clothe its higher altitudes, juniper (*Juniperus occidentalis*) and the piñon pine, opening out into grassy glades, the lower portions. The black color of the lava, and of its derived soil, or, more probably, of the dark green vegetation, as seen from a distance, has given to this part of the plateau the name of "Black Mesa," while from its rough surface is derived the term "Mal-pais," the Spanish equivalent of the more familiar French "Mauvaise Terre."

The eastern edge of the Black Mesa presents a very different order of things from the western. Instead of looking down into a deeply eroded valley, the eye wanders over an extensive plain lying a few hundred feet below the edge, and falling with a gentle inclination eastward toward the Little Colorado. The descent to this plain is precipitous. Where we passed it the basalt-cap was perhaps 100 feet thick, the lower limit being hid, however, by its own *débris*. Skirting the edge is a series of island-like remnants of the mesa, on which the cappings of basalt still remain. This lava here rests on a dark red shaly sandstone, which in turn rests at its base conformably on a grayish, somewhat cherty, limestone, the few feet of which that are here only exposed, being unfossiliferous, so far as observed.

From this point to "Sunset Tanks," a distance of about ten miles, this limestone composes most of the floor of the gradually descending plain before mentioned, a few others being exposed here and there. These are much like the first, of from a few to perhaps 15 feet in thickness, drab or gray in color, and usually cherty. About midway between the mesa edge and Sunset Tanks, a few imperfect fossils were obtained from one of these beds. Such as they are they present a general resemblance (one of them probably being a *schizodus*) to fossils obtained by Mr. Gilbert from about the same horizon near the Paria, about one hundred miles north, and which Mr. Meek considers as being the equivalent of the Permo-carboniferous fossils of Kansas.

These limestones, then, the top of the Aubrey cherty limestones probably, may be considered as forming the summit of the Carboniferous; the shaly sandstones above being conveniently considered as of Triassic age.*

At Sunset Tanks there occurs another line of several mesa outliers, approximately parallel with the mesa-edge, the higher ones being still capped with many feet of the same basaltic lava, and reaching an altitude of over 1,200 feet above the plain. These are also mostly made up of fine shaly sandstones, mostly red, some cream-colored, of the rocks of presumed Triassic age resting on the preceding limestones at the base, and mostly covered with the *débris* from the capping lava. Pieces of petrified wood were numerous near the top, this occurrence being in this region characteristic of the Lower Triassic beds. Though several feet of the lower sandstones are exposed in the cañon at the Tanks, no fossils were observed.

A comprehensive view is had from the top of these table-hills. San Francisco Mountain towers grandly up at the northwest, and the lava-

* See Newberry in Ives's Report of Colorado River, Part III, pp. 70 to 77, and Marcou, Pacific Railroad Report, Vol. III, Part III, pp. 153 and 170, and North American Geology, pp. 14, 15, and 23; also the latter, who first called these rocks Permian in "Dyas et Trias," Genêva, 1859, p. 38; and "Le Dyas au Nebraska," in Bulletin de la Société Géologique de France, Vol. XXIV.

streams east of it plainly show, reaching a point 30° west of north. The edge of the basaltic mesa, which was just left, here bends to the west and north, leaving a wide bay separating it from the lavas near San Francisco Mountain, while in the opposite direction it extends about 30° east of south as far as one can see, forming a long, even, thickly-wooded stretch of horizon. To the southeast, a distant view of the flatly conical Mogollon Mountains is dimly revealed. Below, and to the east and north, lies the long slope cut by many shallow box cañons in the limestones and overlying sandstones, descending with the slope eastward to join the river upon whose farther side a new mesa-edge is presented. This is of irregular and worn contour, though it rises, a step of dark-red color, to a considerable height. Far beyond, and resting on the preceding, is still another but far better marked step. It is the famous great white mesa. First visible at 20° east of north, it stretches, a thread of dazzling white, along the horizon until it disappears to the north behind the spurs of San Francisco Mountain.

In the vicinity of Sunset Tanks the eastward inclination of the Upper Carboniferous limestones which had formed the floor of the plain, being greater than that of the surface, they disappeared beneath it, becoming covered with red soil and flat mesa remnants, which give an indefinite rolling character to the general incline. These low hills are composed of dark-red shaly Triassic sandstone, often ripple-marked and gypsiferous, with occasional thicker beds. Patches of gravel generally occur scattered over the higher points, the pebbles being highly siliceous, well rounded, seldom larger than an egg, and of many colors, often brilliant, white, yellow, red, green, black, and often accompanied by fragments of silicified wood. These characters continued to the Little Colorado, which was forded at "Sunset Crossing." The same formation was found upon the opposite side of the river, but more marked, and rising a few hundred feet in irregular bluffs, while beyond to the northeast, and forming a still better marked series of cliffs, were more massive sandstones, the same line of cliffs that occur at Saint George, two hundred and twenty-five miles to the northwest, and mentioned at the beginning of this report. At this point, and above, the river is not at all typical of this region, inasmuch as it does not flow in a cañon. On the contrary, its flood plain is in places a mile or more in width, through which it winds its muddy current in quite a tortuous course. It practically occupies a monoclinal valley between the Carboniferous and the Triassic. Proceeding up along the north bank of the river to where it is joined from the south by the river Puerco, the irregular Triassic bluffs were upon the left, and we gradually rose through the strata composing them.

As on the opposite side of the stream, these are mostly composed of dark-red and chocolate-colored shaly sandstones, with occasional cream-colored and thicker beds, the shaly sandstones being often ripple-marked, and all often highly gypsiferous, numerous small veins of gypsum often ramifying through the mass. At the highest point reached, these beds were capped with a conglomerate of siliceous pebbles, the "Shin-aŕ-ump Triassic conglomerate" of Powell.

The irregular gravel deposits generally capping the gentle elevations west of the crossing, as mentioned above, have their origin in this bed; the erosion near the river removing the lower beds, but leaving the less easily removed pebbles which had resulted from the disintegration of the conglomerate. The dip of the formation here seems to be a few degrees toward the northeast, in which direction the formation, according to Newberry, flattens.*

SECTION III.

LITTLE COLORADO RIVER TO CAMP APACHE.

Plate IV, Section 2.

The route from the Little Colorado River southward to Camp Apache formed nearly a right angle with that from the Verde to the Little Colorado. Both approaching the edge of the Carboniferous Plateau at about the same angle, and being of about equal lengths, very nearly the same geological section was found in each. Even the Black Mesa south of San Francisco Mountain has its counterpart here in the Mogollon Mountains. The latter, about the nature of which there has been some speculation, are a mass of basaltic lava resting on the Upper Carboniferous strata in nearly all respects precisely similar to the Black Mesa mass. They are more abrupt in con-

* Ives. Report on the Colorado River, Part III, p. 77, Fig. 19.

tour, reaching a height of about 2,000 or 2,500 feet above Camp Apache, or about 7,000 feet above the sea, and trend more nearly east and west, but have the same lithological and structural characters.

The details of the section are as follows. Rising upon the long slope which forms the southern side of the valley of the Little Colorado, but descending through the eroded remains of the Lower Triassic, the friable yellow cross-stratified sandstone of the Upper Aubrey is found outcropping from beneath the latter and forming the rim or summit of the incline. The overlying cherty limestone was not here observed. The dip of the strata is quite strong to the north or northeast, while the predominant dip of the cross-strata of the Aubrey sandstone appeared to be eastward.

This sandstone forms a cedar sprinkled ridge a few miles south of the river, and bounds the northern side of a shallow, rolling depression. The latter is devoid of trees and covered with a red soil, derived probably from underlying shales and sandstones of the Aubrey group. Its southern boundary, about fourteen miles from the river, is a gentle step, ascending which the cross-stratified sandstone is again encountered. It here forms a low, rolling, cedar covered plateau, extending about eight miles along our route, and is cut through by a narrow box cañon 200 or 300 feet deep, in which flows Bouché's Fork. The general dip of the strata is toward the northward, and of the cross-strata mostly eastward. Descending from the southern edge of this sandstone plateau, and to the level of Bouché's Fork, the route was mostly in undulating Aubrey shales, the hills being often capped, however, with remnants of the sandstone.

Lava-capped hills also begin to occur, and finally the continuous lava-sheet from the Mogollon is met, forming a low, irregular edged mesa. This at first gradually rises as an even sheet, with occasional steeper slopes and more level benches, then as low hills, which finally merge into the larger and more abruptly contoured masses of the summit. No volcanic cones were encountered. Wherever observed, the rock was of dark, compact to fine-grained basalt, containing much olivine, and identical with that upon the Black Mesa.

From the summit, San Francisco Mountain, one hundred and thirty miles distant in the northwest, is distinctly visible.

The southern edge of these mountains is very irregular, erosion having cut valleys and cañons through the lava to the Aubrey rocks below, and which extend quite to the mountain mass, leaving the ridges as long, lava-capped promontories. There is, therefore, a belt of territory in which both volcanic and sedimentary rocks largely occur, and no well-defined line can be drawn separating the two, while the edge of the Carboniferous mesa, which elsewhere is generally so distinctly marked, can here hardly be said to exist. To the eastward are the White Mountains, running apparently north and south, which present the same aspect as the Mogollon. The masses of the two seem to unite at the northeast, and the two are probably identical in all their features, structural and otherwise. Generally along the border of the Carboniferous mesa, the dip of the strata is such that the water divide is directly at the mesa edge, so that but little water can accumulate upon the escarpment side to erode it away, this action being much greater in the monoclinal valleys lying between the softer and harder strata at the base of the cliff, and which tends to preserve the latter sharply defined. Here, however, the Mogollon and White Mountains throw the watershed several miles back from the bluff, so that there is directed upon it the powerful erosive action of all the waters that accumulate on their southern and western slopes. To this action, combined with the protecting effect exerted by the several lava flows which have descended from these mountains upon the softer beds they cover, is due that indefinite and broken-up mesa country which exists near these two ranges, and which presents such a strong contrast to the abrupt border which generally limits the plateau rocks.

In leaving the mountains, the North Fork of the White Mountain Creek was followed. Its valley rapidly sank through the basalt and into the soft Aubrey rocks below,* when it began to assume the true cañon form, the capping basalt on either side giving vertical walls. The Aubrey sandstones, &c., appear the same in character as near Camp Verde, and as the cañon deepens there is exposed upon its sides a similar series of red and yellow strata of all shades and intensities, banded in a most beautiful and wonderful

* The uppermost sediments encountered may have been higher than Carboniferous, the Mogollon Mountains, like the Black Mesa, probably including some of the higher beds beneath them, not represented in the section. The southward dip of the rocks north of Apache in the section is incorrect. They should have a gentle northward dip, except for a short distance south of the post.

manner, and with which erosion has in places played most fantastic freaks. Another feature lends interest to the valley. Since the main cañon was cut down through its lava capped sides to more than its present depth, a later flood of similar lava has poured down its channel and filled up all its bottom. Again, the aqueous agencies had to commence work upon the hardened bed, and now the stream flows in a narrow box cañon cut in the lower lava. Nor is the latter action the work of a day, for even this has in places already penetrated to the sedimentary rocks below, exposing several hundred feet of perpendicular lava cliffs.

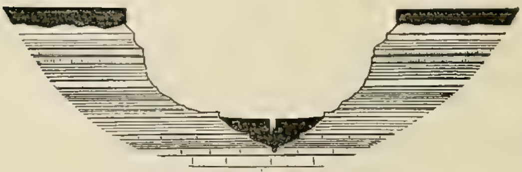

FIG. 91.

Upon nearing Camp Apache, the deepening valley cuts fossil bearing limestones, which belong to the Red Wall limestone, in the upper horizons of which the camp is situated, while the lava capped mesas, having also gradually fallen in height, here reach an altitude of from 800 to 1,200 feet. Throughout the valley the strata are all very nearly horizontal.

SECTION IV.

FROM CAMP APACHE TO THE GILA VALLEY.

Plate IV, Section 3.

Camp Apache is at the mouth and near the junction of the cañon valley of the North and East Forks of the White Mountain Creek. East of the post, lava seems to predominate, and in rising upon it toward the White Mountains, whence it seems to have come, a country similar to that described toward the Mogollon would probably be encountered. When there in November, much snow lay on both ranges.

West of the post is a more open country, the floor of which tends to be of the Red Wall limestone, though the preservative effect of the hard basalt has been to keep it covered with mesa-like buttes and ridges of the banded red and yellow Lower Aubrey beds. Where the protecting lava-caps of these is gone, a rolling and hilly country of the same beds takes the place of the more broken mesa country, while in places even these have disappeared, and level, open stretches, floored with the Red Wall limestone, occur. It was through this region that we passed before reaching Salt River, which was crossed at a point about eighteen miles west of the post. About midway in this distance, and near the river, a dip of the strata of several degrees to the southwest was observed, the general dip of the region being slightly to the northeast.

Where crossed, the Salt River flowed in a cañon in the Red Wall limestone, the northern side of which, being descended after nightfall, was not examined. It was much lower than the southern side, however, which reached a height of nearly 1,800 feet above the stream. Of this about ten or twelve hundred feet were of Red Wall, capped with some sandstone, the remainder being basaltic lava. At many points the limestone was highly fossiliferous, and affected by strong local dips. It reaches several hundred feet above the top of the limestone bench on the north side of the cañon, indicating a fault in the latter; while it must all be affected by a strong, constant northeast dip, for, passing over the high basalt top southward two or three miles, the Lower Tonto (vitreous) sandstone is encountered at a height equal to that of the top of the limestone near the river, the whole thickness of the latter, together with that of the Tonto (Silurian?) shales, being covered with the lava.

This lava capped hill was near the western end of a series of similar ones, which appeared to line the southern side of the cañon to the east; this side being generally higher than the northern side.

South of these hills the floor of the country is mostly of the vitreous sandstone, but covered with hills of the overlying shales, of which many are lava capped. Eastward this hilly character increases, but diminishes to the west, where the vitreous sandstone predominates, its surface being eroded into a beautiful rolling country, and having a strong, constant dip to the north and east. Down this slope the streams flow in characteristic box-cañons to join the Salt River.

This vitreous sandstone rises gradually toward the south for ten or twelve miles from the river, when it breaks off precipitously and forms a high wall or bluff, bounding the northeastern side of the San Carlos Valley. This abrupt mesa edge, standing probably 5,000 feet above the sea, and equalling in height the neighboring mountain masses, forms the southwestern boundary of those sedimentary rocks which compose the great Plateau System stretching northeastward to the Rocky Mountains.

FIG. 92.—Section across San Carlos Valley, Arizona.

To the northwest of the point on which we stood this edge was deeply cut by the lower cañon of Salt River, but rising again on the opposite side, it forms the Sierra Ancha, a massive, squarish, steep-sided mesa-mountain of the Tonto sandstone. To the southeast it swings to the eastward, widening the valley, but soon appears lost among masses of apparently plutonic and eruptive rocks. Below, it rests on granite, occasional abrupt detached outliers of sandstone-capped granite lining the edge, while similar isolated remnants appear on the flanks and top of the Apache Mountains on the opposite side of the valley. These also occur still farther south, and search would probably discover them even to the verge of the Gila Valley. They afford evidence of the former greater extent of the sedimentary rocks, and of the enormous erosion which must have taken place to have so effectually removed them. The southern masses of sandstone have been faulted down with respect to those lying north.

With the mesa is left a pleasant vegetation of pine groves and grassy glades. In descending into the San Carlos Valley, (see section,) the edge of the Tonto sandstone shows a thickness of several hundred feet. It rests directly upon a granite or granulitic rock, which consists nearly wholly of red orthoclase and some quartz, and which forms the base of several rugged hills capped with the sandstones. Lower down, darker colored rocks, resembling diorites, prevail, weathering characteristically in many small, sharp, irregular ridges. The detrital filling of the valley is soon encountered, descending in what, at a distance, appears a long even slope, but which is much cut up by ravines, many of which cut through it to the rock beneath. Naturally, it is mainly composed of *débris* from the Tonto sandstone with the other rocks of the valley. The lower part is well stratified, the surface generally less so, often not at all. Near the center of the valley, but most apparent in its southern side, a mass of basaltic lava lies under this alluvium, occasionally projecting above it, but mainly exposed by ravines.

Fig. 93.—Section across the Apache and Pinal Mountains.

In ascending the Apache Mountains, we passed directly from detritus, composed of Tonto sandstone, without seeing granite, on to the portion of the bed itself, which here forms the summits of the range, its whole thickness, with some of the overlying shales in places still remaining. A spur to the southeast of the line of section, but lying much below the summit, also appeared capped with the sandstone. The general dip was northeast, and the mass generally lay below the edge of the mesa, of which it was once a continuation, the displacement probably being due to a fault in the valley, the downthrow being on the southern side.

The southeastern end of the range appears to have less of the sandstone upon it, probably being composed of the underlying rocks.

Crossing the divide, there are found upon the southwestern slope of the Apache Mountains two or three lines of hills composed of the Tonto sandstone, each preserving a gentle northeastern dip and resting on granite, but faulted downward with respect to the summit mass. This system of faults seems to continue to the southwestern side of the Sierra Ancha, where several hills with precipitous southern sides, like others near the "Wheat-fields" of Pinal Creek, are visible.

The valley of Pinal Creek (see section) lies between the Apache Mountains on the northeast and the Pinal Mountains on the southwest. Where crossed, the main mass of the latter was of granite, but upon their northeast flanks is a long area of highly metamorphic rocks, consisting mostly of crystalline schists, micaceous, chloritic, and talcose, their erosion forming an intricate maze of small valleys, separated by sharp ridges, which present a strong contrast with the more massive features of the mountains. An adjacent spur of the Pinal Mountains seems still capped with Tonto sandstone, which dipped into the range at an angle of about 10°, the last recognized southwestern remnant of the Plateau beds. The northeastern flanks of the valley, where exposed, consisted of red granite and allied rocks.

Upon this side the detrital filling of the valley naturally consisted mostly of the *débris* of the Tonto sandstone, while upon the opposite (southwest) side granitic and metamorphic rocks prevailed. This detrital filling, as in the San Carlos Valley, is composed of two distinct parts, the lower, *b*, of stratified sands and gravels, having a gentle inclination toward the valley, and

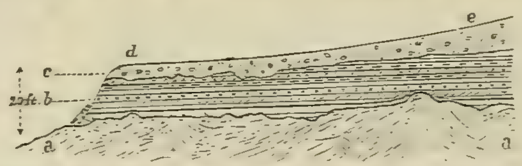

FIG. 94. To illustrate the detrital filling of Pinal Valley, (west branch Pinal Creek.)
d, e. Present surface slope, 4° to 7°.
c. Unstratified mass of more or less angular bowlders.
b. Stratified gravels and sands having gentle inclination toward the valley.
a, a. Crystalline schists.

resting upon the bed rock below, and an upper portion, *c*, mostly of angular bowlders, wholly unstratified and resting upon the irregular summit of the lower portion, its general surface inclining toward the valley at an angle of 4° to 7°, increasing toward the bounding ranges. These valleys present an interesting transition between the valleys of Nevada, which have long been free from water that their subaërial detritus largely predominates over, or wholly covers, any subaqueous filling which they may have contained, and the valleys of and near the Gila River, which are almost wholly occupied by nearly level subaqueous deposits, and in which subaërial action has as yet hardly had time to commence.

The main Pinal Creek, (so called, though perfectly dry,) where crossed, had not yet cut through the stratified material to the bed-rock below.

The Pinal Mountains were approached by ascending the west branch of Pinal Creek, which carried us across the zone of crystalline schists, and into the granite, which at this point forms the mass of the range. Gold quartz and copper ore were frequent in the stream bed. The granite is a handsome coarse-granular aggregate of quartz grains and orthoclase, large projecting crystals of the latter, which is mostly white, mottling the weathering rock, while the mica is subordinate, occurring in small black flakes. It is characteristically cut in deep and rugged ravines, and is at first strongly affected with joints having a southern trend, and inclined 60° to 80° eastward, with a subordinate system of east and west joints, dipping north, the two together tending to stud the surface with large tombstone-like slabs of rock. The first set of joints swings westward as the range is crossed.

In crossing the range this granite axis was found to extend continuously to Camp Pinal, and seemed to form nearly all of its northern and lower parts. To the southeast, however, the topography changes, the range rising in long, even slopes to three flatly conical, massive mountains, which form its highest points, and have the contour of rhyolite, of which they are probably composed.

At Camp Pinal a light pink rhyolitic lava is encountered bordering the range, and apparently derived from the higher points to the left, though now separated from them, I understand, by the cañon of Mineral Creek. The camp is situated in a narrow valley, which forms the line of demarkation between the granite and the bordering rhyolite; the junction northward along the range being more strongly marked by the cañon of Pinto Creek. This bordering rhyolite stands nearly as high as the main granite ridge where crossed, and, though having a rather undulating surface, its sides break down in most rugged palisades, whose precipitous faces overhang the cañons and rim the borders of the range with almost impassable cliffs. These form an abrupt termination to that mountainous country bordering the Plateau region through which we had passed, and, extending a long distance either way, look off at once upon the mountain-studded deserts of the great Gila Valley.

Immediately beneath these skirting rhyolitic cliffs, the sloping front of the range, at many points, and apparently for many miles, is composed of the upturned edges of a series of sedimentary rocks, which dip into the range at a high angle. At Surprise Valley, where this series was first encountered, a thickness of about 2,000 feet is thus exposed between the covering rhyolite and the dark plutonic, highly metamorphic rocks forming the base of the slope, and on which they rest, with an inclination toward the east-northeast of about 35°. The rocks first appearing beneath the rhyolite are here but little changed, soft, red, with some shaly, sandstones ; these are followed by partially metamorphosed and highly crystalline limestones or marbles, while nearly all the lower half of the series—not seen near by—appeared red, as if sandstones. At first there was much *débris* of limestone, lithologically the same as much of the carboniferous limestone of the Plateau series. Had opportunity offered, search would probably have been rewarded by fossils, but none were observed, and the rocks remain unrecognized. I am inclined to believe that they will prove to be a remnant of the Plateau series, and have so colored them on the map.

Near where the range was left, and below its more abrupt slopes and skirting foot-hills, are several groups of low scattered hills and occasional high table-topped buttes, which often rise precipitously from the rather flat border land of the valley, and which are apparently composed of rhyolite. A high butte called Tortilla is the most conspicuous of these.

Looking back, the mountain edge presented a formidable barrier, and, for many miles, above the foot-hills of plutonic rocks, presented its slopes of sedimentary strata capped with the lava palisades. In the far distance to the northwest, and near the border mountain region, stands the curious looking Superstition Mountain, showing nearly horizontal strata, apparently of lavas or perhaps sedimentary rocks.

At the few points observed the bed of the valley was of the ancient plutonic and metamorphic rocks similar to those of the foot-hills, but these soon passed under the continuous alluvium of the approaching plains, which descended with a gentle slope to the Gila River.

From here on our route remained constantly on the alluvial filling of the valleys of, and tributary to, the Gila, so that even hurried opportunities for observation here ceased, and the nature of the formations and ranges passed became a mere matter of speculation. The main physical features of this great region, however, though so often described by others, are of sufficient interest to warrant remention.

It is a great depressed mountainous region, deeply buried beneath the sediments which have been eroded from its own mountains by a surrounding sea. This action has filled the valleys, gradually covered the foot-hills, and, removing the *débris* from the mountain bases as fast as formed, has left their clean and sharp cut tops projecting above the surrounding plain without the usual accompaniment of foot-hills and border region which surround nearly all ranges, the changes on the contrary from mountain slope to the gentle incline of the plain being generally very abrupt. The mountains seem to be of ancient plutonic or metamorphic rocks, or else of lavas; the former more often forming ranges of which the majority trend about northwest and southeast; the latter more frequently occurring as striking isolated peaks. The detrital filling varies from gravels traceable to the rocks of adjacent hills to the finest of alluvium, the dust of which the winds often carry for miles into Northern Arizona. It is sparsely sprinkled with a dreary vegetation, composed principally of scattered individuals of many species of mimosæ and of cacti, the most striking of the latter being the tall and isolated *Cereus giganteus.*

To stand on the edge of the Pinal Mountains upon a quiet day, and look off upon these wonderfully silent and arid plains, with their innumerable "lost mountains" rising like precipitous islands from the sea, all bathed in most delicate tints, and lying death-like in the peculiar, intangible afternoon haze of this region, which seems to magnify distant details rather than to subdue them, impresses one most deeply. The wonderful monotony seems uninclosable by an horizon; and one imagines the scene to continue on the same and have no end. Though the gulf and ocean are three hundred miles away, yet here is the continent's real southwestern border.

Were the waters of the Gulf of California suddenly changed to gravel and sand, with its precipitous and rugged mountain islands left projecting from the surface as now, there would be so produced an excellent representation of these deserts, and, geologically speaking, it is but as yesterday that precisely the same action was going on over all this enormous area as is now in progress in the more confined region of the Gulf. The slow elevation which has in part probably caused the gradual receding of the waters may still be extending the area of our continent.


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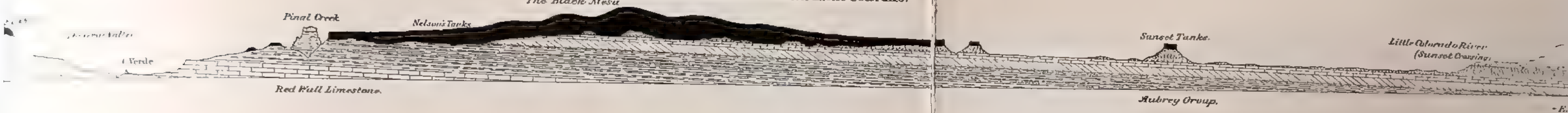
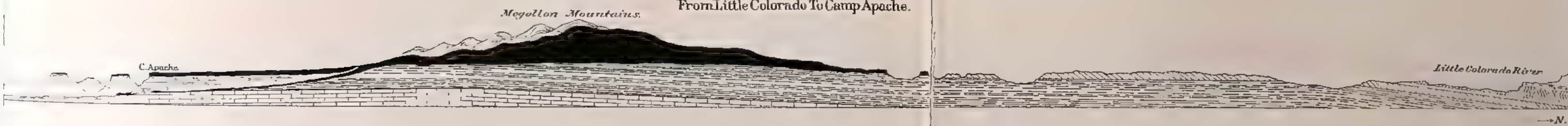
GEOLOGICAL SECTIONS
FROM THE
VERDE RIVER TO THE GILA RIVER, ARIZONA TER.
Along The Route Travelled By Party No 2 Of The Exploration of 1871.
To Accompany the Report of
ARCH. R. MARVINE.

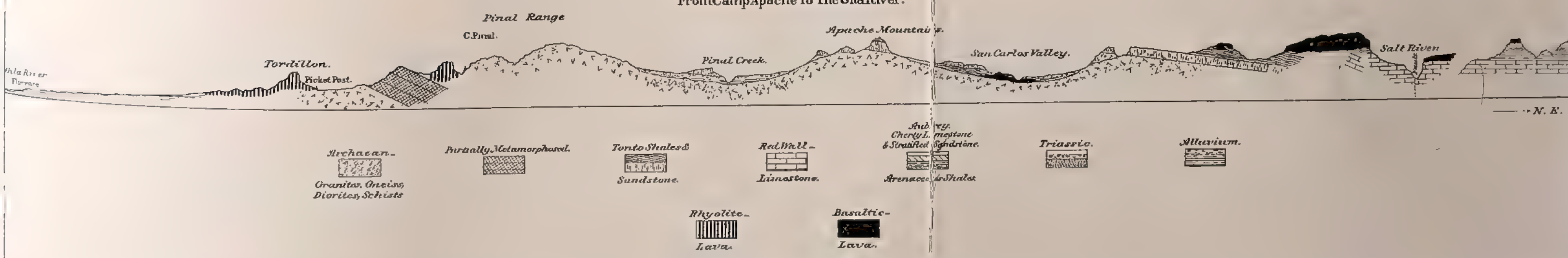
SEC. 1.
From Verde River to the Little Colorado.



SEC. 2.
From Little Colorado To Camp Apache.



SEC. 3.
From Camp Apache To The Gila River.



Horizontal Scale 8 miles - 1 in.

PART III.

REPORT

ON

THE GEOLOGY OF PORTIONS OF UTAH, NEVADA, ARIZONA, AND NEW MEXICO.

EXAMINED IN

THE YEARS 1872 AND 1873.

BY

EDWIN E. HOWELL.

COMPRISING

CHAPTER VIII.—THE BASIN RANGE SYSTEM OF SOUTHWESTERN UTAH;
IX.—PLATEAU SYSTEM OF PORTIONS OF EASTERN UTAH, NORTHERN ARIZONA, AND WESTERN CENTRAL NEW MEXICO.

UNITED STATES ENGINEER OFFICE,
GEOGRAPHICAL EXPLORATIONS AND SURVEYS
WEST OF THE ONE HUNDREDTH MERIDIAN,
WASHINGTON, D. C., *July* 1, 1874.

SIR: I have the honor to submit herewith a report upon the geological material gathered during my two years' connection with the survey under your charge.

In 1872, the route of the party to which I was attached traversed portions of the Sierra region of Western Utah and adjoining Nevada, and of the Plateau region of Central Utah.

In 1873, I once more entered the Plateau country in Utah, and continued upon it to Arizona and New Mexico, making in the latter Territory a detour southward among the Sierras. The entire data in regard to the plateaus I have found it convenient to combine in a single chapter. The description of the mountain ranges examined in Utah and Nevada constitutes another chapter; and my notes upon the Sierras of Southern New Mexico I have turned over to Mr. Gilbert, to be combined by him with the data he has gathered in an adjoining and nearly surrounding belt. The report gives the result of no detailed work, and I do not dare to hope that it will prove free from error, either of observation or of deduction. Probably the least unworthy contributions to the report relate to the distribution of the several geological formations, and to the description of the folds and faults of the Plateau System.

My especial thanks are due to Mr. Gilbert Thompson for assistance in the collection of geological facts and specimens. Despite his onerous duties as topographer, he gave untiring and intelligent attention to the subjects that occupied me, and his contributions were both numerous and valuable.

Very respectfully, your obedient servant,

EDWIN E. HOWELL,
Geological Assistant.

First Lieut. GEO. M. WHEELER,
Corps of Engineers, in Charge.

CHAPTER VIII.

THE BASIN RANGE SYSTEM OF SOUTHWESTERN UTAH AND SOUTHEASTERN NEVADA.

SECTION I.

MOUNTAIN RANGES: THEIR GEOLOGICAL STRUCTURE, AGE, THICKNESS, AND CHARACTER OF STRATA.

There is such a gradation of the range into the Plateau System, along their line of intersection in Southern Utah, that it is impossible to draw a line which shall have all range structure on one side, and all plateau on the other.

From the Uintah Mountains south to Mount Nebo, the eastern base of the Wahsatch, is a line of perfect separation; but south of this mountain the Wahsatch line of uplift drops down, and is soon lost beneath the Tertiary and Cretaceous beds of the Plateau System; and the division line is crowded westward to the next parallel line of uplift—the Pah-vant range—the western base of which Mr. Gilbert found to be an anticlinal, formed of Paleozoic rocks, overlaid on the east with Secondary and Tertiary beds This line may be followed south to Baldy Peak, where everything is buried beneath immense beds of lava.

A few miles farther south, this ridge flattens out and joins the Plateau System, and we are obliged once more to strike west or southwest from the neighborhood of Frémont's Pass to the Iron Mountains, which may be followed to Iron City and Pinto. At this point it becomes doubtful where the line should be drawn, but I believe fewer difficulties are encountered by continuing it in a southwest direction to the head of the Virgin range, which, from this point southward to the Colorado River, gives once more a well-marked line of separation.

This line separates two regions, that cannot be better contrasted than by the terms Sierra and Plateau. The first of these, which now claims attention, is characterized throughout Southwestern Utah and Eastern Nevada, as elsewhere, by nearly level arid plains, separated from each other by parallel mountain ranges, which occur at irregular intervals of fifteen to thirty miles, giving, on the average, a range of mountains every twenty miles, with a trend varying but little from north and south.

In structure these ranges are both anticlinal and monoclinal, the latter being the prevailing form, while pure anticlinals are seldom met with.

Very few ranges, however, have the same structure throughout their whole extent. Frequently, in tracing a monoclinal, we find it changing to an anticlinal, or more frequently to a faulted anticlinal—the axis of the anticlinal being at the same time the line of a fault, showing the beds on one side of the axis at a much lower level than the same beds on the opposite side. Further followed, the anticlinal would probably be found (after a cross-fault or disturbance) with the downthrow on the opposite side, which, still further followed, would give a monoclinal again, with the dip in the opposite direction from that first started with. Thus, not unfrequently, a great variety of mountain structures may be found represented in a single range.

These plains, or valleys, have an average height above sea-level of about 4,500 feet, while the height of the ranges above the plains varies from 3,000 to 6,000 feet.

If admitted that this section has been covered with the heavy beds of Triassic and Jurassic rocks, which are seen lying, conformable to the Carboniferous, on the borders of the system, and which Mr. Clarence King assures us in his Mining Industry, page 451, have capped the ranges of this same system a little farther to the north; and if we admitted, also, that the main folding was completed in late Jurassic times; then, before the erosion, which has gone on since the early Cretaceous, the height of the ranges above the then much lower valleys must have been truly wonderful. But in the region of our examination no evidence was found to warrant the assertion of such former extension of these beds. At only two localities, and both of these near the border of the system, have any beds been seen that could with propriety be referred to these horizons. The first of these localities is on the south end of the Mineral range, near Minersville, where some red beds, several hundred feet in thickness, were seen overlying a yellowish-gray limestone, which furnished fossils of Permian or Upper Carboniferous types. Overlying these red beds, and a little farther to the north, Jurassic fossils were found by Mr. Gilbert.

The second locality is a little west of Cedar Mountains, where there is an exposure of 2,000 feet or more of yellowish-brown *siliceous* limestone, which, although no fossils were seen, is probably of Triassic Age. Nowhere else inside the system have we seen any evidence of beds, other than the subaërial gravels and modern lake deposits, lying above the Carboniferous; the hard limestones of which now cap most of the ranges.

Omitting any further description of this region, the leading features of which have so often been described by others, let us now examine a little more in detail the different mountain ranges visited, and then call attention to some features which are common to all.

WAHSATCH RANGE.

The Wahsatch, as already stated the most easterly range of the system, is in the main monoclinal in structure, with an average dip to the east of 25° or 30°; but our observations extended only to the southern portion of the range—that which faces Utah and Juab Valleys. To the description as above given, Mount Nebo is an exception. It is set off to the west, so that its eastern base is in line with the western base of the range farther north, and appears to belong to the same line of fracture; the uplift in this case being to the west of the line, giving a western dip to the strata.

If we imagine a continuous anticlinal, with Nebo as the only remaining portion of the western half, opposite which the eastern side has been removed, it will give a correct idea of the relation which this mountain bears to the rest of the range. That the missing portions of the anticlinal never existed, there can be no question; the deposition of the later beds on the eastern base of Nebo being sufficient proof as regards that portion, and we are unable to conceive of a force which should remove the western portion, referred to, so completely, leaving the eastern side and Mount Nebo undisturbed.

To the west of Nebo, and running north for some distance, is another ridge, with a parallel strike, which dips to the east, making a synclinal fold with Nebo; but the structure is quite complicated at this point, and time did not permit to trace it out.

A section of the range made at Rock Cañon, near Provo (Fig. 95)

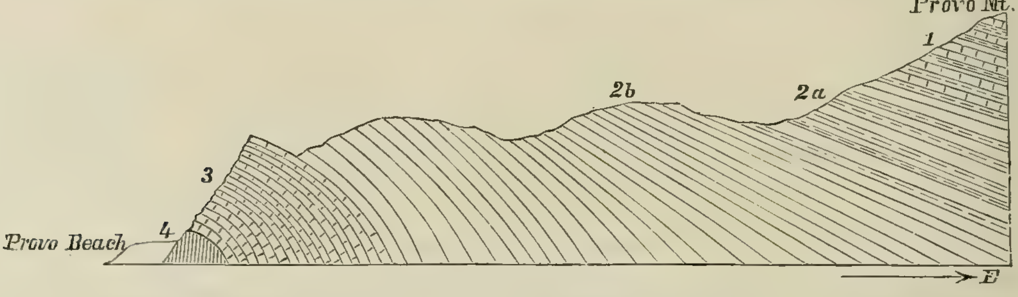


FIG. 95.—Section of Wahsatch range near Provo. 1, sandstone and limestone; 2*a*, shaly limestone; 2*b*, massive limestone; 3, quartzite; 4, chloritic schist.

represents an exposure of about 10,000 feet. Carboniferous fossils, *Athyris subtilita* and *Hemipronites*, were found almost at the top of the series. The conformable Triassic and Jurassic beds lie farther to the east, denudation having completely removed them from the summit of the range. Our section is—

1st. Seventeen hundred feet of sandstone, a large portion of it vitreous, and 600 feet of massive and shaly limestone, arranged in alternate layers with the sandstone, to the number of fifty, and containing *Athyris subtilita*, *Productus semireticulatus*, *Spiriferina*, *Hemipronites*, *Chaetetes*, *Discina*, &c., 2,300 feet.

2d. *a.* Two thousand feet of limestone, all more or less shaly, with some beds of calcareous shale. A mile or two north of where this section was measured, a thin stratum of clay slate was seen containing cubical crystals of iron pyrites. There is also a single layer of vitreous sandstone 10 feet thick. *b.* Four thousand feet of massive limestone, in the main highly metamorphic. The changes in this division from shaly to massive, and from slightly metamorphic to highly metamorphic are so gradual that any separation of them must be arbitrary. The fossils found in No. 1 were seen continuing down through this division until the rock became so much changed that organic remains could not be recognized, 6,000 feet.

3d. Hard, typical quartzite, pale flesh-color to nearly white, with a little pale-green, 1,500 feet.

4th. Nonconformable pebbly chloritic schist, 250 feet.

Prof. Frank H. Bradley found similar rock associated with the granite farther north, and could we have followed our section a little deeper, we should doubtless also have found granite.

Although no fossils were seen here or elsewhere on this range below the Carboniferous, when this section is compared with those made of other ranges farther to the west, as well as those made farther north on this same range by other geologists, I have no hesitancy in referring the heavy quartzite bed (No. 3) to the Lower Silurian, and a portion of the metamorphic limestone above it should probably be referred to the same Age, but how much, I am unable to say, as at no point was a marked change in the character of the rock noted. I was unable to make a satisfactory section of the Triassic and Jurassic formations, but Fig. 96, as seen in passing up Spanish Fork Cañon, may be considered as a fair continuation of Fig. 95, (1,) the lower beds in this section corresponding very closely to the upper beds in the first section. From Rock Cañon to Spanish Fork the strata dip very much to the south as well as to the east.

In passing up the cañon, above limestone containing Carboniferous fossils, I found a lighter colored, very hard siliceous limestone, some of which might, with more propriety, be called sandstone, or even quartzite, in which no fossils were seen, but from its position I am disposed to consider it as belonging to the Trias. This formation is of great thickness, probably 4,000 or 5,000 feet.

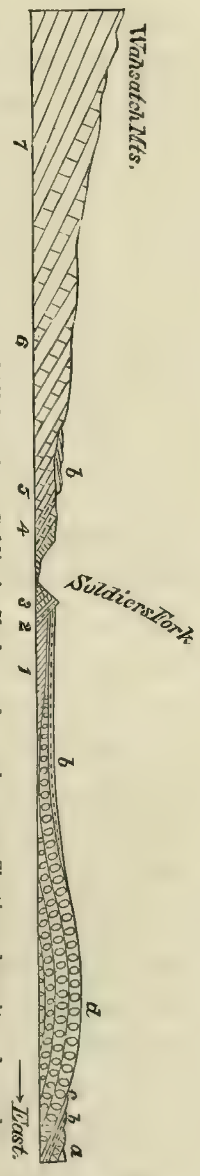


Fig. 96.—Section of western base of Wahsatch at Soldier's Fork; *a*, *b*, *c*, calcareous Tertiary deposits; *d*, conglomerate; 1, 2, 3, 4, 5, Jurassic shales and sandstones; 6, Trias siliceous limestone; 7, Carboniferous limestone.

1. Yellow and cream-colored sandstone, with occasional bands of gray conglomerate and sandstone, about4,000 feet.

2. Calcareous shale, light drab to slate-colored, 200 feet.

3. Red, cream, yellow, and buff cross-bedded sandstone with *Pentacrinites asteriscus*, 575 feet.

4. Red shaly sandstone, 500 to 1,000 feet.

5. Lying conformably above and dipping to the east-southeast at the same angle (25° to 30°) are sandstones more highly colored, (red, yellow, and buff,) very vitreous at the bottom, but becoming less so above, and containing fragments of characteristic Jurassic *Pentacrinus*, 1,000 to 3,000 feet.

While the upper portion of this division is undoubtedly Jurassic, the lower portion is probably Triassic, but the section was not well enough exposed to determine a line of separation.

This completes the exposure of from 6,000 to 8,000 feet of strata that must be classed as Jurassic. Lying nonconformably above, and jutting up against the Jurassic, as shown in section 2, is, first—

d. A thin bed of red conglomerate, which to the eastward increases rapidly in thickness to 2,000 feet, in a distance of three or four miles, and then dipping eastward is lost below more recent beds. This conglomerate is composed largely of quartzite, but limestone pebbles, in which Carboniferous fossils are not infrequent, are very abundant in the upper portion.

I was unable to determine the age of this conglomerate, and have not been able to discover its equivalent in other localities. It is overlaid with—

a, b, and c. Limestone marls and calcareous shales of Tertiary Age, which further up the mountain are in immediate contact with Jurassic and Triassic (?) beds. To the south of Mount Nebo, and along the western base of the ridge which separates Juab and Sam Pitch Valleys, the same being a continuation of the Wahsatch uplift, there are overlaid with red conglomerate—probably the same as the above—quite extensive beds of Jurassic Age, composed mainly of greenish gypsiferous shales with occasional layers of sandstone, which furnish *Pentacrinites asteriscus*, *Comptonectes*, *Trigonia*, and other fossils. These same beds appear again near Manti, and skirt along the western side of the valley nearly to Glencove.

In Salina Cañon, to the east, (above) the much distorted gypsiferous shales are 4,000 or 5,000 feet of strata, which doubtless correspond to Nos. 1 and 2 of Fig. 96, given above. Where these beds first make their appearance from below the overlying, nearly horizontal strata, they dip 25° to the east. Following westward down the cañon, we find them gradually increasing in dip, coming even to the vertical before the gypsiferous beds are reached. I was unable to trace a complete connection between the two formations, although such a connection doubtless exists. About 1,000 feet of the lower portion is gray and red freestone, with occasional beds of conglomerate toward the top, agreeing in this respect with No. 1, at Soldier's Fork, Fig. 96. The main mass above this is a yellowish, friable sandstone.

LAKE RANGE.

This range, just west of Utah Lake, is a low monoclinal ridge, the strata dipping to the east about 8°, and is composed entirely of the characteristic bluish-gray Carboniferous limestone. A few specimens of *Productus* and *Spirifer* were the only fossils obtained, owing partly to the highly metamorphic character of the rock. Mr. H. Engelmann, geologist of Captain Simpson's party, found in the limestone of this range the spiral axis of an *Archimedes*, together with some badly preserved Brachiopods. Messrs. Meek and Engelmann, in speaking of this,* say: "As the genus or subgenus *Archimedes* has not yet, so far as we know, been found as high in the Carboniferous System as the Coal Measures, and there are apparently no decided Coal Measure forms in the collection from this rock, we are inclined to regard it as belonging to the Lower Carboniferous series."

OQUIRRH RANGE.

The beds of this range are so much and so irregularly disturbed that I am unable to speak with any confidence in regard to its structure.

Data collected from several points indicate the axis of an anticlinal, with a strike north about 35° west, passing near Ophir and Lewistown; and another, nearly parallel, passing through Middle Cañon, and coming out not far from Cedar Fort; and that in a general way the northern end of the range is a continuation of the eastern side of this latter anticlinal.

The Carboniferous limestone is largely developed, and furnished fossils

*Proc. of the Acad. of Nat. Sci. of Phila., April, 1860, page, 127.

at the north end, near Great Salt Lake, Tooele, Ophir, Lewistown, and along the road leading from Fairfield to Rush Valley. In the lower part of the limestone at Ophir, not more than 300 or 400 feet below beds containing *Euomphalus*, *Conocardium*, *Hemipronites*, *Phillipsia*, *Athyris subtilita*, and other fossils, recognized by Mr. Meek as a Carboniferous fauna, were found some Primordial types, including *Dikellocephalus*. Mr. J. E. Clayton found below this limestone an exposure of partly calcareous and partly siliceous and micaceous shale, containing several species of trilobites and *Discina*, specimens of which he very kindly furnished. The Carboniferous and Lower Silurian fossils are found so near together, that I am led to believe that the two formations are in contact at this locality. All our evidence from other localities indicates that this relation is common to the whole region, and renders it improbable that the Devonian or Upper Silurian will be found in Southwestern Utah. To the west of this are some localities, discovered by Mr. H. Engelmann, and the survey of the Fortieth Parallel under Mr. Clarence King, which are pronounced Devonian by Mr. Meek,* and Professor Sanborne Turney has discovered two species of *Zaphrentis*, and one of *Syringopora* in the Wahsatch range, between Little and Big Cottonwood, which Mr. R. P. Whitfield refers to the horizon of the Upper Helderberg. That the limestone of this range corresponds in general to that of the Lake range, I think there can be no doubt, and not only are the Devonian and Upper Silurian formations wanting, but the Lower Carboniferous, as indicated by the *Archimedes* before mentioned, must be restricted to very narrow limits, unless we include in that division the beds (or at least the lower portion of them) which contain *Euomphalus*, *Phillipsia*, &c., a point that may be left to the paleontologist to decide.

ONAQUI AND STANSBURY RANGES.

Passing westward, the Onaqui range is found to be a monoclinal ridge, with the usual north and south trend, the strata dip to the west at an angle varying from 25° to 70°. Perhaps in this case the term "faulted anticlinal" might be used with more exactness, as there are a few hundred feet of very much disturbed limestone, but with a general dip to the east

* American Journal, 1873, page 139.

along its eastern base, which doubtless corresponds to the limestone that is seen on the western slope of the range, overlying the heavy bed of quartzite, which makes up the main mass of the mountain. The eastern base of the range marks the line of a fault, and the force which lifted the range to its present position tilted the beds east of the line of fracture to some extent, giving us a section like the following, (Fig. 97).

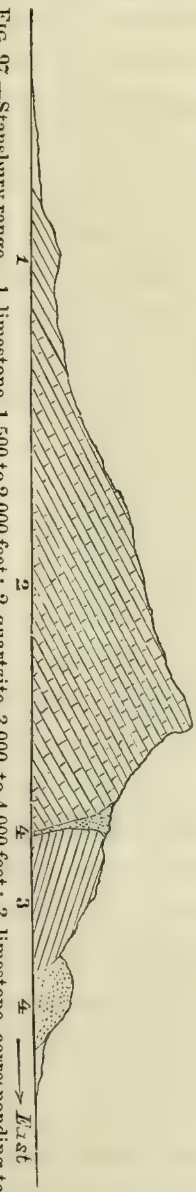


FIG. 97.—Stansbury range.—1, limestone, 1,500 to 2,000 feet; 2, quartzite, 3,000 to 4,000 feet; 3, limestone, corresponding to No. 1, much metamorphosed, but furnished a few fragments of fossils of Carboniferous Age; 4, trachyte, and occasionally a little basalt.

This lava can be seen stretching along the base of the range for a long distance. There appears also to have been a slight flow along the line of fracture between the quartzite and limestone, and it is not improbable that the mass along the base of the limestone came from this source. This range was crossed over a pass four or five miles south of Grantville, where there is a small cross-fault, with the downthrow to the south. These cross-faults are of common occurrence in the ranges of the Basin Range System, and frequently determine the position of mountain passes and cañons.

CEDAR MOUNTAINS.

From Beckwith's Spring north, as far as seen, Cedar range is a monoclinal ridge, with a dip to the west. At Beckwith's Spring, and southward for a short distance, it is an anticlinal, the western half being a continuation of the monoclinal, which changes its trend at this point from north and south to northeast by southwest. The completion here of the anticlinal expands the range to the east, and there appears to be another anticlinal to the southeast *en échelon*, but the whole soon flattens down into low hills. On the western side of the range were seen yellow sandstone and dark limestone, slightly bituminous, and somewhat shaly, containing Carboniferous fossils, *Fusulina cylindrica*, *Productus*, and *Rhynchonella*. The same forms were found on the eastern side, where the limestone is highly metamorphic. The relations of the sedimentary beds are very much masked here by trachyte. There are also one or two slight outbursts of basalt. A mile or two west of this range is a ridge, exposing 2,000 feet or more of yellowish-brown siliceous limestone, dipping to the northeast 25° or 30°. This limestone so closely resembles the beds referred to the Trias in the Wahsatch, that, in the absence of fossils, I am inclined to regard it as belonging to that formation.

GRANITE ROCK.

Granite Rock rises abruptly from the plain, and stands as an island in the desert, as it once stood an island in Lake Bonneville,* the old beach-lines of which are plainly seen surrounding it. The whole island is granite, save a little dark-colored rock along its western base, which appeared, although seen only from a distance, to be limestone. It is difficult to make out any bedding to the granite, yet all the evidence points to a north and south trend, with a high angle of dip (60° or 70°) to the west. The western side of the mountain is of a darker granite, and weathers more slowly than the eastern. Veins are abundant everywhere, but those crossing the darker granite are more numerous and larger, they intersect the rock in all directions, and are of all sizes, yet the most of them are confined to two systems. The first, which comprises a majority of all the veins, trends northeast by southwest, and dips northwest, conforming very nearly to the apparent bedding. The veins of the second system cross these at right angles, and, in general, appear to have been later formed. So far as I observed them, they consisted almost entirely of feldspar; some veins were five or six inches wide, with from one to two inches on either side coarsely crystalline, the center being formed of apparently the same material in a much finer state. The granite contains orthoclase in considerable excess, and much of it occurs in large crystals.

SNAKE RANGE.

Gosi-ute and Kern Mountains are included under this head, as they belong to the same line of uplift, and are in fact all parts of the same range. Structurally the range is in part anticlinal and in part monoclinal. At

* The old lake, which once covered so large a portion of Utah, and of which Great Salt Lake is the modern representative, has been described by Mr. Gilbert, in a previous chapter, under the name of Lake Bonneville.

Uiyabi Pass and northward, for some distance, the range is anticlinal, but from there southward to Pleasant Valley it is a monoclinal, dipping to the west. At Pleasant Valley the structure again changes, and Kern Mountains are anticlinal or quaquaversal. Thence southward to Sacramento Pass the range is monoclinal again, with the dip as before to the west. From the pass southward the rocks form an anticlinal fold, the axis of which rises to Wheeler's Peak, and then falls again, producing an elongated quaquaversal. A short distance south of the peak the western half of the anticlinal disappears, leaving the ridge a monoclinal, with its bluff face to the west. Thus it will be seen we have a series of anticlinals and monoclinals, following each other in quick succession. There is also in some places a local mingling of these and other systems, which it is not deemed advisable to note in a general description like the present. Patches of rock, sometimes of considerable extent, with a reverse dip, were seen along the bluff bases of the monoclinals, but they are small in amount and exceptional in character. The nucleus of the range is granite, which is exposed at many places, overlaid with quartzite, shale, and limestone. South of Wheeler's Peak there is an exposure of 4,000 or 5,000 feet of limestone of the usual bluish-gray color. Immediately under this comes quartzite, with thickness unknown, but probably not less than 1,000 feet. This forms the summit and slopes of the peak, but the deep cañons from the same penetrate the granite, as is shown by the bowlders brought down in the wash.

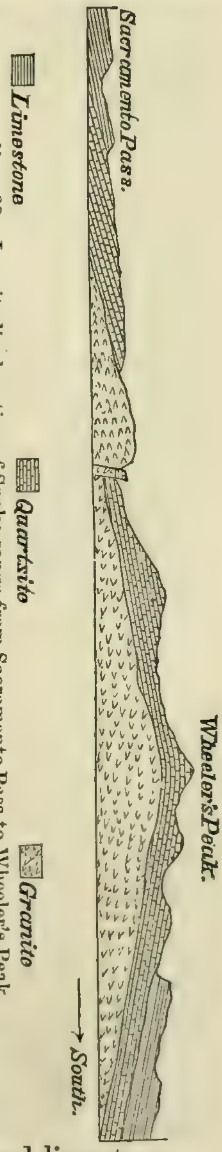


Fig. 98.—Longitudinal section of Snake range from Sacramento Pass to Wheeler's Peak.

Four to six miles north of the peak is a high pass—a depression in the profile of the mountain due to a cross-fault, with the downthrow to the south. Fig. 98 shows the structure at this point, the line of section being lengthwise of the range, and east of the axis of the anticlinal, so that the beds represented have an easterly as well as a westerly dip. This fault brings the granite well into view, and exhibits its relation to the overlying quartzite and limestone.

From Sacramento Pass northward to the Kern Mountains the bluff eastern side of the range presents limestone with fissile micaceous quartzite at the base. The whole central portion of Kern Mountains is granite, and is flanked on all sides with quartzite, shale, and limestone, which dip outward at a high angle.

From Pleasant Valley to Uiyabi Pass the base of the range is granite, overlaid and flanked on the west with quartzite and limestone, except at the head of Deep Creek, and northward for a few miles, where the limestone and quartzite have been worn away, leaving the bare granite. At Uiyabi Pass there are from 200 to 400 feet only of quartzite between the granite and limestone, which shows it much thinner than at Wheeler's Peak, and the little evidence collected indicates a gradual thinning of the quartzite on this range, from south to north. All of the limestone exposed doubtless belongs to the same bed. The order of superposition is always the same—limestone, frequently a little shale, quartzite, and granite. At Uiyabi Pass I estimated the thickness of limestone at 3,000 to 5,000 feet. At Pleasant Valley the same, while south of Wheeler's Peak, the exposure is apparently still greater. The prevailing color is bluish-gray. It is everywhere more or less changed, and much of it is very highly metamorphic. Only a few fossils were found, but all indicate Carboniferous Age, and at Uiyabi Pass *Fusulina cylindrica* was among the number.

SCHELL CREEK RANGE.

From Patterson, which is at the southern terminus of the range, northward for twenty-five or thirty miles, the rocks, as I saw them, appeared to dip toward the east at a high angle, while farther to the north they presented a bluff face, showing a westerly dip. At Patterson a heavy bed of quartzite is exposed, dipping east-southeast about 45°. A few miles farther north, this is covered with conformable bluish-gray limestone; limestone was also seen to the west of the quartzite at Patterson, apparently forming with it a faulted anticlinal. Ten or fifteen miles north there is a low limestone spur sent out from the range, which extends across to Fortification range, and separates Spring and Duck Valleys. In crossing this ridge, which I have considered as a spur of the Schell Creek range, I found a few crinoid stems in the hard limestone. The rocks of the range were touched at no other point, and the fossils found are not sufficient to determine their age, but as this limestone agrees lithologically with that of the Snake range to the east, and Highland range to the south, and is underlaid with a similar bed of quartzite, I think it should be classed with them as Carboniferous.

HIGHLAND RANGE.

Directly south of Schell Creek range, and apparently along the same line of uplift, comes Highland range, which continues south past Pioche, the mines of Ely district being in a spur which runs out southeast from this range. At the north end the dip is south at an angle of 8°, and 1,500 or 2,000 feet of limestone are exposed Following southward three or four miles we come to a pass, caused apparently by a cross-fault, beyond which the dip is 10° or 12° to the southwest. The total exposure here is 2,000 feet, consisting almost entirely of limestone containing well marked Carboniferous fossils—*Athyris subtilita*, *Spirifer cameratus*, *Spirifer*, *Spiriferina*, *Productus semireticulatus*, *P. punctatus*, *Hemipronites*, *Retzia*, and others. Below the limestone at this point, and apparently interbedded with it at the base, are some thin beds of quartzite. A few miles farther south is another depression in the range, and trachyte comes on the scene, masking all stratigraphical characters. Still farther south, at Bristol district, the general dip is 10° to 12° north-northeast, just the opposite of that observed twenty miles farther north, and quartzite was seen along the western base, the whole upper portion being highly metamorphic limestone.

At Pioche the spur of the range has a southeast by northwest trend, and in structure is a faulted anticlinal, to the peculiarities of which attention will be called in the fourth section of this chapter. There is here 400 feet of highly metamorphic limestone of the bluish-gray color, in which no fossils were found; but in the absence of proof to the contrary, I am disposed to consider it as of Carboniferous Age, and as belonging to the same bed which yielded fossils farther north. Immediately below the limestone comes about 400 feet of reddish cream-colored calcareous and siliceous shale, the lower portion being siliceous and also micaceous. This shale in places yields Lower Silurian fossils in abundance. Below this is quartzite to an unknown depth. This quartzite, as well as that seen farther north and on Snake range, corresponds, I believe, with that of the Onaqui and Wahsatch ranges. And I consider in like manner all the exposures of limestone as parts of one bed, once continuous from the Wahsatch to Nevada.

Glancing once more over the field to see how the facts will bear out this conclusion, there is everywhere the same sequence of limestone, shale, quartzite, and granite, with the lithological characters similar throughout. I find, first, a heavy bed of bluish-gray limestone of Carboniferous Age universal. On the Wahsatch this is overlaid with Triassic and Jurassic beds, but in the other ranges where it occurs it is the topmost rock. This bed has been identified by its fossils on the Wahsatch, Lake, and Oquirrh ranges, at numerous localities—Cedar Mountains, Snake range, at Uiyabi Pass and Pleasant Valley, and at Zion Mountain on the Highland range No fossils were found at Bristol district or Pioche, and only a few crinoid stems where the spur of the Schell Creek range was crossed, but the absence of fossils at these localities, or rather failure to find them in the very limited search made, is due no doubt in the main to the highly metamorphic character of the rock. Underlying this limestone is an equally universal bed of quartzite. At Uiyabi Pass this bed is only from 200 to 400 feet thick, but at no other locality have I seen it so thin. Usually it is not less than 1,000 or 1,200 feet, and frequently much more. Between this bed and the overlying limestone there is generally to be seen a thin layer or bed of arenaceous or calcareous shale, varying in thickness from a few feet to 400 feet at Pioche. Where this shale has been examined it is separated from the limestone by a more definite line than from the quartzite; still, occasional thin layers of limestone are seen interbedded with it near the top, but there is a much greater interbedding with the quartzite at the bottom of the shale. Mr. Watson, superintendent of the Newark shaft at Pioche, told me that in sinking through the lower shale he met five or six layers of quartzite, one of them being 11 feet in thickness with 137 feet of shale below it, and I learned from Mr. W. H. Clark, assistant superintendent of the Raymond and Ely mine, that in sinking the Lightner shaft he passed through 100 feet of shale before coming to the solid quartzite, but that in this one hundred there were fifteen or twenty layers of quartzite from 2 to 8 inches in thickness. I was also told that a stratum of shale 12 feet thick was met with in the Washington and Creole mine below 500 feet of quartzite.

Besides this alternation, of which more examples might be given, there is also a gradation of one into the other, showing that the shale is not an essential feature, and may be represented by quartzite, or even in part by limestone, in some localities.

Some of the more calcareous portions of this shale at Pioche furnished Primoridial fossils in great abundance.

Similar fossils, several species of which are identical, were found by Mr. Clayton in the shale below the limestone at Ophir, Oquirrh range. Mr. Gilbert also found Lower Silurian fossils in a dark shale on the House range, but in this case with a very considerable thickness (much greater than seen elsewhere) of limestone and calcareous shales below them. Wherever erosion or upheaval reveals the base of the quartzite, it is seen to rest upon granite.

I would also call attention to a few facts outside of this field, which confirm the position here taken, and show that the same generalization may be carried over a still larger area. Mr. S. F. Emmons gives a section of the Toyabe range and another of the Toquima range near Belmont, in each of which we find the same order of sequence—limestone, shale, quartzite, and granite. Mr. Emmons discovered *Fusulina cylindrica* in the limestone of the Toyabe range, and in 1871 Mr. Gilbert found graptolites of Lower Silurian type in the shale at Belmont. Thus we have not only the same lithological sequence which we find at Pioche and eastward, but the same geological horizons also. Prof. Frank H. Bradley gives some sections of the Wahsatch at Ogden and Little Cottonwood, which are also interesting to compare with our sections farther south and southwest.* On page 194 I find a section near Ogden with, 1st, 3,000 feet of limestone, "plainly of Carboniferous Age;" 2d, below this, from 2,000 feet to 2,500 feet of quartzite; 3d, nearly 2,000 feet of limestone; 4th, "something over 1,000 feet of gray calcareous shales;" 5th, 1,500 feet of quartzite which rests non-conformably on metamorphic rocks, which are "mostly hornblendic gneiss with some gran-

*See report of Frank H. Bradley, geologist of the Snake River division, in Sixth Annual Report of U. S. Geol. Surv. Territories, Washington, 1873.

ites, and occasionally chloritic and talc-mica schists. Professor Bradley found fossils in the upper limestone, which are, he says, "plainly of Carboniferous Age," and that in the lower quartzite bed are "indistinct fucoidal markings, resembling in general appearance the *Árthrophycus Harlani* of the Medina sandstone, but plainly not identical with it." (Fucoidal markings answering to this description were seen in the siliceous shales at Pioche.) Professor Bradley refers this quartzite, the shale, and the lower bed of limestone to the Silurian Age, leaving the upper quartzite bed only undisposed of.

On page 197 he tells us that at Little Cottonwood, about fifty miles farther south, he found, as at Ogden, a heavy mass of quartzite resting unconformably upon the granite; above this "lies a series of limestones, the lower part rather thin bedded, the upper part in heavier layers." This upper limestone he refers to the Carboniferous Age, and the lower to the Silurian, and considers it analogous to the lower limestone at Ogden. Thus the quartzite which separates the Silurian and Carboniferous limestones at Ogden is found disappearing southward, and the Silurian limestone, shale, and quartzite represented by a thin-bedded limestone and quartzite, which shows a rapid approximation to the sections farther south and west.

Some data have been collected from a number of ranges in Southern Utah which indicate that they have in general the same geological and lithological sequence and character, but the nature of the data is too fragmentary to be of much value in any attempt at generalization.

I have already mentioned the occurrence of Jurassic and Triassic beds near the south end of Mineral range, overlying cherty-gray limestone of Upper Carboniferous or Permian Age. This range, as seen to the north, has a granite nucleus, but the volcanic rock which forms the eastern and highest ridge at this point overlies everything to the south, and is followed to the southwest by low hills of the same material, which form the eastern boundary of Escalante Valley. The southern continuation of the Picacho Mountains, west of Hot Springs, gives an exposure of 4,000 to 6,000 feet of quartzite and sandstone, the upper 600 or 800 feet being quite friable. This is overlaid with about 2,500 feet of bluish-gray limestone, the whole dipping to the south at an angle of fifteen or twenty degrees. Overlying the limestone again is volcanic rock, and in passing along the southern ends of Hawahwah and Needle ranges to Desert Spring, and from Desert Spring northwest to Pioche, the same immense beds of lava are the only rock seen until the latter place is reached. Southward from Desert Spring to the Bull Valley Mountains the same thing occurs on every hand, and no sedimentary beds are seen until the Virgin range is reached. This range has nearly a north and south trend. Mr. A. R. Marvine crossed it near the northern end in 1871, and found it a moniclinal at that point, dipping to the east. The western base is formed of crystalline rocks, flanked on the east by heavy beds of quartzite and vitreous sandstone, and these in turn are overlaid with limestone of Carboniferous Age. In crossing the range near where the Virgin River cuts through it, I found it anticlinal, and the same structure could be seen continuing southward for many miles. I did not get below the Carboniferous limestone at this point, but a few miles to the north gneiss and sandstone were seen outcropping along the western base. Fig. 99 represents a section from this range to the Pine Mountains, about twenty miles distant, which gives an exposure of from 12,000 to 15,000 feet, reaching from the Archaean up to the Tertiary. Capping Pine Mountain appears—

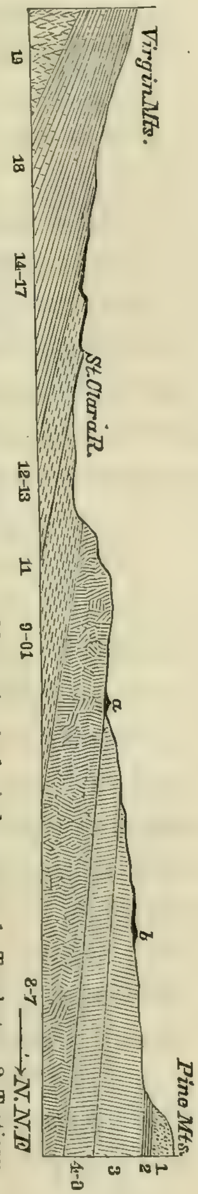


Fig. 99.—Section from the Virgin range to the Pine Valley Mountains: *a b*, cinder cones; 1, Trachyte; 2, Tertiary limestone; 3, Cretaceous sandstone and shale; 4–6, Jurassic sandstone and limestone; 7–8, cross-bedded Trias sandstone; 9–10, Trias shales and shaly sandstone; 11, Shinarump conglomerate; 12–13, Trias shales and marls; 14–17, Carboniferous limestone and sandstone; 18, quartzite and sandstone; 19, Gneiss.

No. 1. Trachyte, 1,700 feet.

No. 2. Red, mixed with some white and yellow, concretionary limestone—Tertiary—300 feet.

No. 3. Yellow, red, and white, mostly friable sandstone—Cretaceous—3,000 to 4,000 feet. This part of the section was not examined, and it is probable that a portion of No. 3 is Tertiary.

No. 4. Yellow massive sandstone—Jurassic (?)—500 feet.

No. 5. Buff and yellow oolitic limestone, alternating with red, calcareous, and gypsiferous sandstones—Jurassic—500 feet.

No. 6. Red and yellow shaly sandstone—Jurassic—200 feet.

No. 7 Buff cross-bedded massive sandstone—Trias—1,200 feet.

No. 8. Red cross-bedded massive sandstone—Trias—2,000 feet.

No. 9. Red shaly sandstone—Trias—400 feet.

No. 10. Purple and red gypsiferous shales—Trias—150 feet.

No. 11. Yellow conglomerate, with silicified wood, very abundant, (Shinarump conglomerate,)—Trias—100 feet.

No. 12. Chocolate-colored shales—Trias—300 feet.

No. 13. Slate-colored shales—Trias—500 feet.

No. 14. Mostly red, with some buff shales—Carboniferous?—800 feet.

No. 15. Same as 14, with occasional thin beds of limestone—Carboniferous—550 feet.

No. 16. Yellow, cross-bedded sandstone—Carboniferous—200 feet.

No. 17. Limestone, dirty-yellow above and pale-red below—Carboniferous—2,000 feet.

No. 18. Quartzite and sandstone.

No. 19. Gneiss.

a and *b*. Basalt.

The Iron Mountains are a very irregular low range, formed almost entirely of volcanic material. From Iron City a ridge runs north to Antelope Spring, which shows sedimentary beds below its capping of trachyte. At the Silver Bell mining-district quartzite and sandstone were seen, but no evidence was collected which throws any light upon their age.

SECTION II.

VALLEYS: THEIR RELATION TO GEOLOGICAL STRUCTURES.—LAKES: ANCIENT AND MODERN.—RIVERS: WATER SUPPLY.

The Basin Range System as seen in Southwestern Utah and Eastern Nevada has already been described as divided by mountain ranges into broad, arid plains or valleys, which conform to the lines of uplift, and have a north and south trend. Many of these valleys are inclosed basins, or are divided into a series of small basins separated from each other, sometimes by lava floods or other rocky ledges, but frequently by simple bars of detritus, through which a stream could easily cut a channel, if such a stream existed to perform the work; but the annual rain-fall is so light that these basins are, with few exceptions, left dry the greater part of the year. In some of these the water collects to a considerable depth during the rainy season, and in some cases the supply is sufficient to form permanent lakes or marshes, which are, as a matter of course, salt. The only exceptions that

I am aware of are Stockton Lake, and a lake or marsh near Fairfield, Cedar Valley. The first of these, it is known, did not exist ten or fifteen years ago, and the second is nearly dry now a part of the season, and its existence as a permanent marsh is doubtless of recent origin.

These valleys are filled to a great and unknown depth with the *débris* from the surrounding mountains in the form of gravels, sands, and marls, and their history shows, first, a long period of subaërial denudation, succeeded by a lake period, when these valleys were covered with water to a depth of several hundred feet, distributing and sorting to a considerable extent the accumulated material, leaving beds of sand and marl inclosing the records of fluvial and lacustrial life. This period was followed by the present, in which the lakes have mostly disappeared, leaving the arid plains before mentioned. The largest of these, called the Great Salt Lake Desert, has an altitude varying but little from that of Great Salt Lake, and stretches from Granite Rock, which has previously been described as an island in the desert, far northward beyond the region of this survey, and sending out its arms to the south, one of which, Snake Valley, reaches below the Thirty-ninth Parallel. Between Granite Rock and the Gosi-ute Mountains the desert for eighteen miles is almost a perfect level, with not a spear of vegetation of any kind to be seen, but, instead, a thin film or white incrustation of common salt, giving an appearance similar to that of a light fall of snow on a frozen pond. The smaller valleys of this region are not quite so barren, but over the greater portion of their surfaces little is seen excepting the inevitable sage-brush.

The whole western portion of this section is of very little value for agricultural purposes. Stock-raising can be and is carried on to some extent, the springs and small mountain streams, which sink as soon as they reach the loose gravelly deposits of the plains, furnishing water enough for that purpose, and the mountains themselves are usually well stocked with nutritive grasses.

A strip along the eastern border of the system, thirty to fifty miles in width, includes a series of valleys such as the Jordan, Utah, Juab, Cedar, Tooele, Rush, and others farther to the south, which are much better supplied with water than those to the west of them. Considerable portions of these are already under successful cultivation, and still larger portions are capable of being worked with profit. As examples, might be mentioned the old benches or deltas at the mouth of the Provo and Spanish Fork Cañons, containing in the aggregate not less than thirty thousand acres, all of which it is believed may be successfully irrigated by these streams.

During the lake period referred to, the major part of this whole area was covered by one immense sheet of fresh water, which rose to a height nearly 1,000 feet above the present level of Great Salt Lake, leaving many of its old beach-lines so plainly marked that they attract the attention of even the most common observer. This lake has been so fully described by Mr. Gilbert in another chapter under the name of Lake Bonneville, its extent marked out, and prominent beach-lines noted, and the evidence in regard to its history so thoroughly treated, that it hardly seems desirable to say anything further; yet a few additional notes in regard to some of the localities not visited by him may not be amiss.

Among the many beach lines that can be traced in favorable localities, two are so much more prominent than all others that they are scarce ever lost sight of, and have been deemed by him worthy of individual names. To the first, which is the highest of the whole series, he has given the name of Bonneville Beach, the same name as that attached to the lake which formed it, and to the other, 300 feet lower, Provo Beach, from its unusual development at the mouth of Provo Cañon. When the old lake stood at this level, the detritus brought down by Provo River formed a delta, covering at least twenty thousand acres. Another delta was formed at this time at the mouth of Spanish Fork Cañon, in the same valley, which covered an area of eight or ten thousand acres. The streams which formed these deltas have a rapid fall, and reach far back in the soft rocks of the Plateau System, which accounts for the large amount of detritus carried by them. They lowered their beds with the lowering of the lake, and have cut channels through these deltas, leaving them as elevated benches.

In Escalante Valley, which was the most southerly arm of this lake, the upper or Bonneville beach was traced to latitude 37° 45′, being only fifteen or twenty miles from the southern boundary of Utah. This bay was shallow, and left very indistinct beach-lines, which can only be traced in the most favorable localities. A broad arroyo at the southern extremity, near Desert Spring, suggested the possibility of an outlet in that direction to the Colorado. As this is the only point at which a southern outlet was possible, it is to be regretted that it could not have been relieved of all doubt; but it was impossible to make the desired examination. Information, however, which was obtained from different sources, and deemed trustworthy, confirmed my own suspicion that the head of this arroyo was in the Bull Valley Mountains, and was formed by water flowing into the valley, rather than out, and that there is a well marked divide between this and the drainage to the Colorado. Accepting this, it becomes necessary to look to the north for the outlet to the ancient lake, and one has been discovered, by Professor Marsh and Professor Ward, draining into the Snake River. Professor Bradley also reports three or four possible points of outlet in the same direction.

In the southern end of Snake Valley, where the water was shallow, the ancient beach-lines are also indistinctly seen, but farther to the north, where the bay was deeper and broader, they are preserved with wonderful clearness, and not only the more prominent beaches, but, in favorable localities, fifteen or twenty others can be distinctly traced. At Granite Rock, and on the north end of the Oquirrh range, the prominent beach-lines are marked by extensive deposits of calcareous tufa, which, like the marls in other localities, contain several modern species of fresh-water shells. The line of tufa marking the Provo beach at Granite Rock is 2 to 3 feet in thickness, and 20 or 30 feet in breadth, lying on the slope of the rock. The curious phenomenon of this granite island, surrounded by bands of calcareous tufa, is one not easily explained.

It has already been mentioned that Spanish Fork and Provo rivers drain portions of the Colorado Plateau System, and flow westward through the Wahsatch range, emptying their waters into the Great Basin. The interesting question may be asked, why did not these streams flow southeast into the Colorado, rather than force their way through a lofty barrier like the Wahsatch? That their courses through the range are along lines of weakness, is undoubtedly true; Provo River makes the axis of a synclinal, and at Spanish Fork there is probably a fault, and in a much disturbed region like that of the basin ranges it will be generally found that the larger cañons are formed along the axis of anticlinals or synclinals, or lines of fracture. But this only illustrates the tendency of eroding water to attack the weakest points, and while it serves to explain the selection of these particular lines for crossing, it leaves untouched the question why the streams crossed the range at all, instead of escaping to the eastward over the lower barriers, which in that direction limit their basins. The most plausible answer to this question is, that the cañons through the range existed previous to the establishment of the present drainage, and this assumption shifts the inquiry to the manner of their formation. When the Cretaceous and Tertiary seas covered the present Plateau region, the Great Basin, as it is now called, was the continent which furnished the material for the heavy beds of rock which were then deposited, and we believe the formation of Provo and Spanish Fork cañons was begun by streams which carried the *débris* from this ancient continent down to these ancient seas. When the sea-bottom was lifted slowly to form the present plateau, overlooking the area from which it had derived its sediments, the channels of those former streams served as convenient gate-ways for drainage in the opposite direction.*

The Tertiary and Cretaceous conglomerates, made up of quartzite and limestone, point with sufficient clearness to the Great Basin as their source. I have already spoken of limestone bowlders in the conglomerate on Soldier's Fork, containing Carboniferous fossils identical with those found on the Wahsatch and elsewhere. And the fact that this bed of conglomerate, which has a thickness here of 2,000 feet, is not recognized, and apparently has no representative, farther to the east and southeast, would argue that it was formed at the mouth of a rapid stream, and was similar in character to the old deltas before referred to in the Utah Valley. Whether the conglomerate of Echo Cañon is likewise a local phenomenon, and had a similar origin, I cannot say.

When the first cañons were carved through this range it was not the lofty ridge that it is now, for the uplift of the plateau has been accompanied, at least to a great extent, by the elevation of the range—the line between the

*All these remarks apply with equal force to Weber River, and probably to Bear River also.

comparatively stationary Basin Range System and the upraised plateau being along its *western* base. This will help to explain its great elevation above the neighboring ranges of the same system. Had it been lifted above its companions at the main folding of the Range System, greater denudation would have been the necessary result; whereas the contrary seems to have been the case, more recent beds being found upon its summit than in the ranges to the west. The position of the Tertiary and Cretaceous beds on the eastern flank, as represented in Fig. 96, shows that the two have moved together. South of Nebo, the Tertiary and Cretaceous beds, which covered the old line of uplift, have been severed by the more recent movement and carried up, exposing a bluff face to the west. A few miles to the east of the Wahsatch is another line of uplift, and along these two lines have been the main movements which have reversed the positions of the two systems; placing the plateau above the plains of the Basin Range System.

SECTION III.

VOLCANIC PHENOMENA.—LITHOLOGICAL CHARACTER AND DISTRIBUTION OF VOLCANIC ROCKS AND MODE OF OCCURRENCE.—THERMAL SPRINGS.

It is not deemed practicable to attempt the separation of trachyte and rhyolite, owing to the impossibility of limiting the area occupied by each, and the difficulty, frequently encountered, of distinguishing one from the other, and in giving the distribution of volcanic rocks only two divisions will be made. First, basalt; second, trachyte and rhyolite. No volcanic rock older than trachyte was met with, except in a few doubtful cases.

1st. *Basalt.*—This rock is not very abundant, and occurs mostly in the form of massive eruptions; craters being seldom seen until we enter the borders of the Plateau System, when they become quite frequent. It generally occurs in connection with trachyte and rhyolite, but is seldom, as remarked by Baron Richtofen, seen overlying them, yet that it is more recent in age there can be no question. Great erosion has occurred in many places after the trachytic and rhyolitic flows and before those of basalt. This, as

I shall have occasion to note in another chapter, is notably the case in the Plateau region, where also are found numerous instances of faulting and folding having occurred between the deposition of the two rocks.

At the south end of the lake range a thin sheet of basalt covers some of the low foot-hills. It is very limited in extent, and appears to be entirely independent of any older lavas. It also occurs in connection with trachyte along the eastern base of the Onaqui range, and to the west of Cedar Mountains a small jet was seen in the center of a mass only a few rods in extent, and evidently of very recent age. No basalt is seen farther west until near the southern boundary of Utah. On the west side of Escalante's Valley, four or five miles north of Desert Spring, a small area is covered with this rock, while the higher hills and range beyond are composed of, or covered with, rhyolite and trachyte. Another similar area is seen a few miles north of Sulphur Spring.

Near Adamsville, along the east base of Mineral range, it forms a ridge of considerable height for a short distance, rising above, and overlapping, rhyolite, which is exposed to the west of it. It is, however, developed on a much larger scale to the north of the range, where a large area, visited by Mr. Gilbert, is covered with a sheet of basaltic lava, and numerous craters have been formed. It is also seen at a few places farther south, but not until the neighborhood of Pine Mountains is reached are any developments worthy of note met with. These mountains, which owe their existence to a heavy bed of trachyte that protected them while the surrounding country was denuded away, are flanked on the west, south, and east, by a belt of basaltic craters, the latest of which are perfect in form, although made up of loose scoriaceous materials, and are as yet uncovered with vegetation. One of the most recent is in Diamond Valley, just south of the mountains. It is a perfect cinder cone, 300 or 400 feet in height, and about 400 feet in diameter at the top, with a regularly formed crater, 75 feet to 100 feet deep. A few small streams of lava have issued from the same vent, but none have extended more than a quarter of a mile. The valley of the Santa Clara has been flooded with basaltic lava for eight or ten miles below Pine Valley settlement, filling up the channel of the river, which has carved for itself a new course, partly by the side of the lava stream, and partly

CLEAVAGE IN LAVA, MEADOW CREEK CAÑON, NEVADA.

cañoning through it. Farther down the Santa Clara another stream of lava has flowed from the southern end of *Diamond Valley*, nearly to Saint George. Over the vent from which this issued another fine cinder cone has been formed.

Trachyte and rhyolite.—Trachyte is seen in connection with basalt along the eastern base of the Onaqui range, and just south of Beckwith's Spring, on the Cedar range, it is piled up into some quite prominent peaks. Its limits north and south were not determined, but its greatest development is near the divide southwest of the spring. On the western side of Snake range, at the head of Pleasant Valley, this rock makes its appearance again in considerable force. It was not observed at any point farther north on the range, but it spreads out southward, and a low ridge, running westward to the next range, is apparently formed of the same material. North of this the valley of Deep Creek has been flooded from the west with a light-colored loose textured rhyolite.

Fortification range was not visited, but is composed in the main, if not entirely, of trachyte or rhyolite. On the Highland range, from Pony Spring southward nearly to Fifteen-Mile station, the range is low, and trachyte was the only rock seen.

In going from Pioche across to Desert Spring, the only rocks met with are trachyte and rhyolite.

At Rose Valley and westward for a few miles are numerous light-colored water rhyolites, of open texture, nicely stratified, and alternating with darker and more compact varieties. East of this, to Desert Spring, the whole mass is trachyte. From this point northward, along the southern ends of Needle and Hawahwah ranges to the Picacho Mountains, rhyolite, with the exception of the basalt before noted, was the only rock observed.

As far as seen, Bull Valley Mountains are composed entirely of trachyte and rhyolite, with one exception. In a deep cañon near the head of Beaver-Dam Creek, a dark green, compact, porphyritic rock was seen, overlaid with trachyte and rhyolite, crystals of green fibrous hornblende and feldspar, probably oligoclase, are imbedded in a greenish-gray matrix, composed apparently of the same minerals. Pyrite is also present in considerable quantities, together with fine particles of a dark mineral, which is probably magnetic or titanic iron. Its resemblance to prophylite, as described by Baron Richtofen, together with its undoubted basal position, appear to justify the belief that it is a true prophylite.

These mountains have the appearance of a vast irregular mass rather than a mountain range, and a careful study would probably reveal a series of eruptions, reaching from the early prophylite period to the later rhyolite. On the trip from Beaver-Dam Creek to Hebron, compact varieties of trachyte were seen, but just before reaching that town some light-colored water rhyolites were observed, which extend eastward in the direction of Mountain Meadow; but northward to Iron City nearly everything is trachyte again. At this point it is joined by the belt capping Pine Valley Mountains, and continues northward, capping Iron and Antelope Mountains, to Minersville. North of Beaver River a sheet of rhyolite is seen partly covered with basalt, but the greatest development of rhyolite is seen at Baldy Peak, near Beaver, where the whole mountain, as well as the range north and south for some miles, is entirely made up of, or covered with, this rock; near the summit, cañons 2,000 feet deep failed to reveal any other material, but trachyte was observed in great abundance fifteen or twenty miles farther south on the same range.

THERMAL SPRINGS.

The most interesting group of thermal springs seen on the trip is located near the town of Midway, on Provo River. A large area, a mile or two in extent, is covered to a depth of several feet with a deposit of calcareous tufa. Springs are frequent over this whole area, and the majority have built for themselves quite extensive craters of the same material. Time permitted us to visit but few of these, the largest of which, and probably the largest of the whole group, has a crater 65 feet high, and from 150 to 200 feet broad at its base. Copious streams of water, having a temperature of 108° F., were flowing over the sides in several places, and it may be remarked, in passing, that, as far as observation extended, the temperature of the water from the different springs was in proportion to the amount escaping. Some springs were seen in which the water did not come up to the top of the crater, and no outlets were visible; but the warmth of the water, and the slowly escaping gas showed that circulation was still going on. Still other craters were observed entirely dry, the streams that formed them having found some other exit. The interiors of these were cone-shaped, like the exteriors, and a section across one of them would be like the following figure: (Fig. 100.)

Another group of hot springs, not quite so extensive, but having a greater temperature, is located in the north end of Escalante Valley, sixteen miles west of Minersville. These springs are situated in the open desert, on two parallel ridges having a north and south trend, placed *en échelon*, about twenty rods apart, each eight or ten rods in width and 20 feet high, with a total length of about one and a half miles. These ridges have been formed mainly by the drifting sand, held together by the moisture and consequent vegetation, as no sinter nor tufa seems to be deposited by the springs. The highest temperature noted was 185°. The only other warm springs seen on the trip were in Jordan Valley, and a single one on Spanish Fork; temperature not noted.

FIG. 100.—Extinct crater of hot spring near Midway, Utah.

SECTION IV.

ECONOMIC GEOLOGY.

Under this heading it is proposed to call attention to some of the more prominent and valuable mineral and ore deposits of the region under consideration. A discussion of the character and distribution of the precious metals will be found in Vol. I, and these remarks will be confined to some notes upon the geology of Ely Mining District. This district, second in importance to no other silver-mining district on our western coast, save that made famous by the Comstock Lode, is located on a spur of the Highland range, in Eastern Nevada. The mines of the district occur in quartzite of Lower Silurian Age. The principal vein, worked by the Raymond & Ely and Meadow Valley Companies, and called the Pioche, has a nearly east and west trend, with a dip of about 70° to the south, and is an undoubted fissure-vein. This vein has been severed in two or three places, and thrown some distance laterally as well as vertically, by fissures and faults of more recent origin, which serve well to show the much disturbed condition of the rocks in this part of the district. The formation of this fissure may also have been accompanied by a considerable throw. The vein worked by the Newark Company, as I learned from Mr. Watson, the superintendent, has a similar trend and dip, and on the side of the hanging wall there is a thickness of 35 feet of crushed rock, a quartzite breccia. Such an amount of crushed material would indicate considerable movement. The thickness of the quartzite bed at this locality is unknown; an increase in thickness is seen in passing southward on the Snake range. If the same increase continues to this point, the thickness must be very great, but in regard to that it is impossible to say, as no exposure of the base of the quartzite was noted in this neighborhood. There is no reason to expect any great change in the character of the ore while the vein remains in the present rock, but what will be the result when the granite is reached, which will probably be found here as elsewhere underlying the quartzite, it is difficult to predict. A study of the veins in the granite of Eagle District might give some data for an opinion. Overlying the quartzite are about 400 feet of arenaceous and calcareous shales of a reddish-yellow color, containing in the more calcareous portions several types of Primordial fossils in great abundance. Capping the shale and forming the crest of the ridge to the westward is a bluish-gray limestone of Carboniferous Age.

Sheet No. 50, of the atlas to accompany this report, shows the topography of the district, as well as the relation to each other of the different geological formations. The accompanying Fig. 101 will serve partially to illustrate the same thing, while giving a ground-plan of the faults, sections, and the Pioche vein. The trend of this spur or ridge is northwest by southeast, (true,) and is structurally, as shown in Figs. 102, 103, and 104, a faulted anticlinal. The structure, however, is complicated by a number of cross-faults. In addition to the main fault referred to, which marks the line of separation between the shale and quartzite, there is another to the northeast, running parallel to it, marking the line between the quartzite and two limestone hills, north and east of the town, which are intersected by sections 102 and 103. I have indicated this limestone as dipping to the southwest.

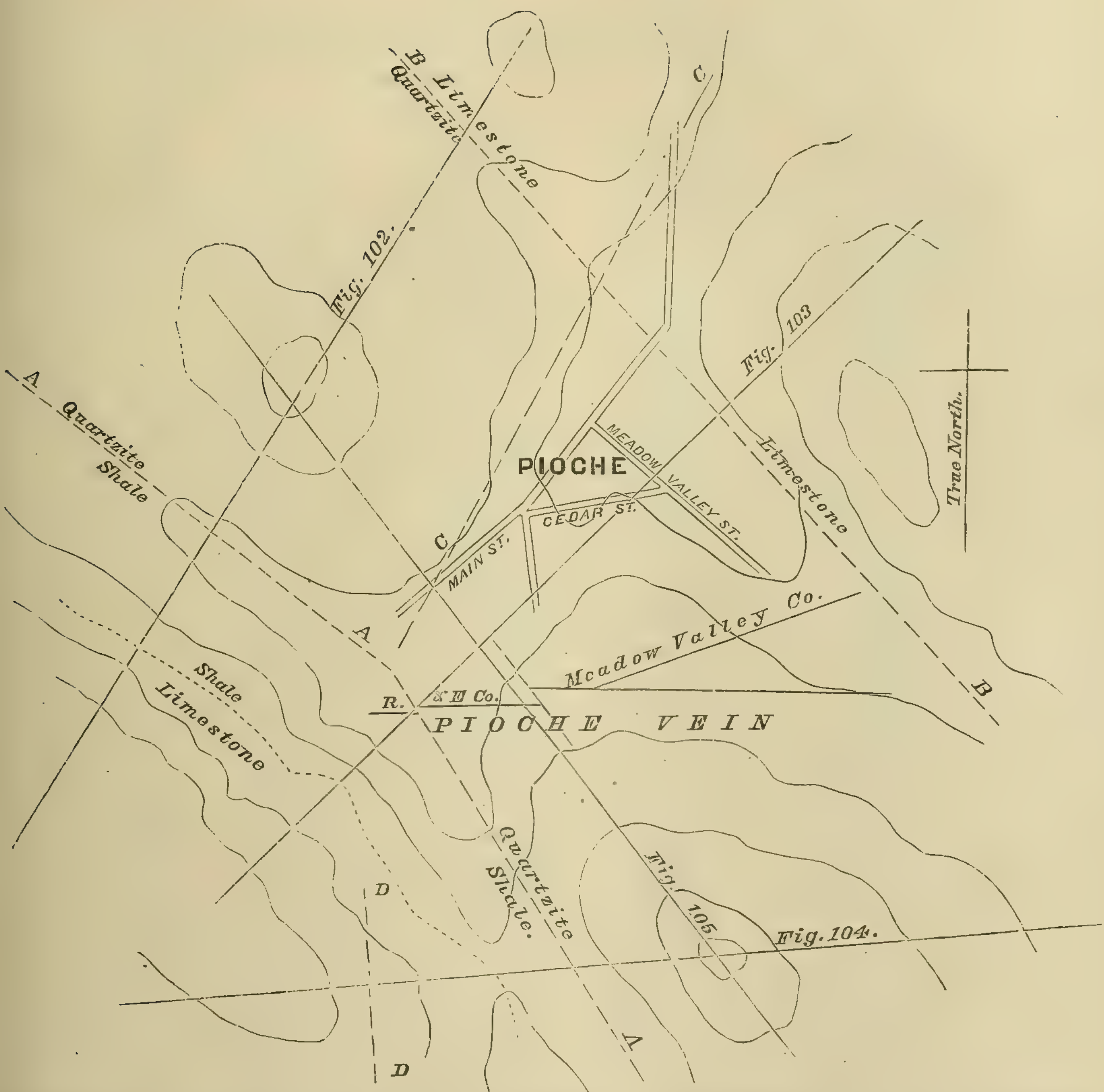


FIG. 101.—Chart of Pioche, showing lines of sections, (Figs. 102, 103, 104, 105,) and Pioche vein in full lines; faults, in broken lines; and base of western limestone, with dotted line. The topography is indicated by rough contours.

To arrive at certainty on this point is very difficult, owing to the metamorphic character of the rock. The evidence was such, however, that I was unwillingly led to this conclusion. Mr. Gilbert visited Pioche in 1871, and

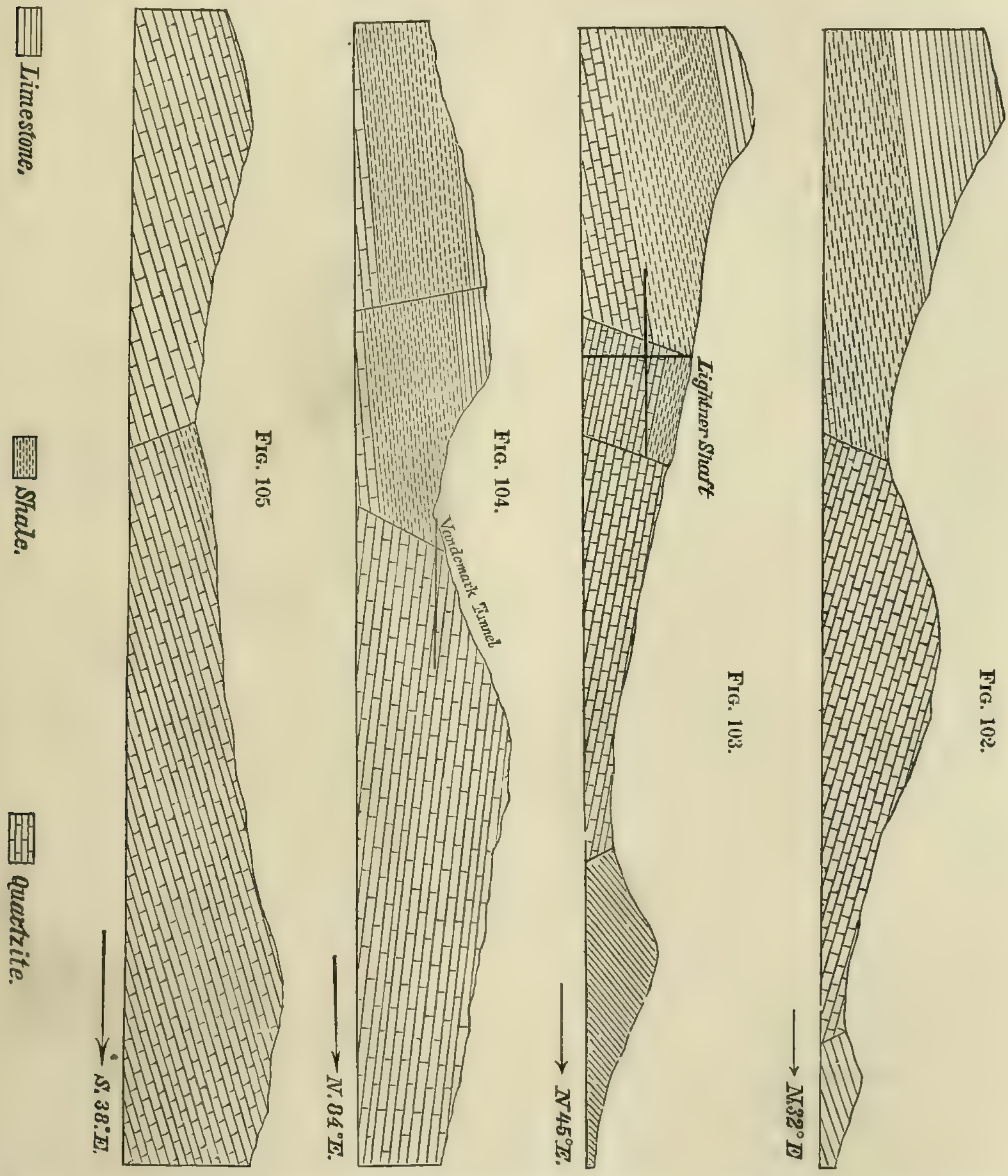


FIG. 105

FIG. 104.

FIG. 103.

FIG. 102.

I am pleased to find that our observations agree on this point. The limestone and quartzite, notwithstanding the *débris*, are seen to approach each other near enough in places to demonstrate the existence of a fault, and Mr.

Gilbert was fortunate enough at the time of his visit to see a shaft sunk on the contact vein of this fault, which clearly revealed the relation of the two formations.

To explain the existence of the shale, pierced by the shafts of the Raymond & Ely, Newark, and other companies in that immediate vicinity, it is necessary to suppose another fault, running through the town nearly on a line with Main street. (See Fig. 105 and *c c*, Fig. 101.) The Newark shaft was sunk through 365 feet of shale, which lay conformable to the quartzite below and dipped about 10° to the northeast. The Lightner shaft of the Raymond & Ely Company was sunk through 100 feet of shale, which dipped with the quartzite 15° to 20° to the northeast. As shown in Fig. 103, the main fault is a little to the west of this point, and beyond the fault the dip is to the northwest. The different levels run west from this shaft, cross this line of fracture. The third level was run west of this line, 35 feet through quartzite, to the conformable shale above, which dips to the northwest, as before stated, 10° to 15°. The position of this level is shown in Fig. 103. Unless the shale on the northeast of this fault is considered as interbedded with the quartzite, and passing under the hill northwest of the town, a highly improbable assumption, it seems to me, the existence of the cross-fault *c c*, must be admitted. The difference of throw along the main fault, as illustrated in Figs. 102 and 103, (assuming the shale on both sides as parts of the same bed,) is in harmony with this supposition. The throw illustrated in Fig. 102 is not less than 600 feet, while in Fig. 103 it is only 100. If there are no other faults the difference of throw at these two points should be equal to the throw of the cross-fault, and this is nearly as I make it. And farther, it seems to me that erosion is not sufficient to account for the topography at this point. Following the main fault southeast to the divide, I find the throw (see Fig. 104) as great perhaps as at the point represented in Fig. 102. This would seem to militate against previous conclusions, but I think we need not be troubled on that score when the disturbed condition of the rocks in the neighborhood of the Raymond and Ely and Newark mines is considered. And in following along the line of this section a little farther to the west, another fault (D D, Fig. 101) with a north and south trend is discovered, and with a throw of 100 feet to the east. This may be a continuation of the fault running near Main street, with a smaller throw at this point, or it may be an entirely independent fault. The throw of the main fault being to the southwest, and the dip of the Pioche vein where worked by the Raymond & Ely Company 70° south, it might be expected that the vein west of this fault would be thrown to the north, but on the contrary it is found to the south, which fact can only be explained by a horizontal throw. Five hundred and seventy feet east of this is another parallel fault dipping 70° southwest, and the same vein worked by the Meadow Valley Company to the east of this fault, is found over 100 feet to the north. To account for this, another lateral throw must be supposed, as the downthrow has been as before, to the west; or as usual, on the side of the hanging wall. It is obvious that the effect of the vertical faults—the vein dipping south and the throw being to the west—would be to carry the outcrop of the vein west of the fault to the north, but as it is found carried to the south in both cases, the evidence of lateral faulting must be admitted.

Owing to the greater resistance to erosion exerted by the quartzite, the valley separating it from the shale along the line of the main fault is being continually crowded over farther into the latter. The Vandemark tunnel afforded an opportunity of measuring the amount at that point. This tunnel (see Fig. 104) was run 75 feet through loose material, mostly quartzite, which served for a protection to the shale below it, and then 185 feet through shale before the line of fracture and the quartzite were reached. As the mouth of the tunnel was about 40 feet from the lowest point, 300 feet appears as the total amount of crowding.

The shale at this point appears to dip nearly north 15° to 20°, and the quartzite on the other side of the fault dips about 20° north-northeast. The dip of the fault here is 60° to the west. Next the quartzite, which has a tolerably clean face, there are 6 inches or 8 inches of finely pulverized material, then 10 or 12 feet of broken and ground shale, after which comes the solid shale which is unusually hard and vitreous for a few feet.

IRON.

An excellent quality of magnetite is found near Iron City in Southwestern Utah—very easy of access, and in quantity practically inexhaustible. There is one butte of solid ore 500 or 600 feet in length by about 200 in breadth and 150 feet in height. But this is not all; Mr. Thompson noted dike-like masses occurring a mile or so to the northeast of this, and also near Iron Spring about twenty miles to the northeast. Lieutenant Dinwiddie visited some mines at this latter place, and collected specimens of both magnetite and hematite. About three-fourths of a mile west of the "Iron Butte," and considerably lower, geologically as well as topographically, is a bed of hematite which covers the southeast slope of a ridge, and from a hasty examination seemed to be a bed 5 or 10 feet in thickness, inclosed in limestone and siliceous limestone, having a dip of 10° or 12° to the southeast. The surrounding country is so completely covered with Trachyte that the sedimentary rocks are but little seen, and their age was not determined.

The following analyses, made by Capt. C. E. Dutton, of the Ordnance Corps, U. S. A., show the extreme richness of the ore, but since it is very refractory the difficulty in its reduction will be to obtain sufficient heat.

This region is so sparsely wooded that a permanent supply of charcoal cannot be expected, but some experiments made with an open fire to produce coke from coal, which is said to be abundant in the Cretaceous rocks, ten or twelve miles to the southeast, give fair promise that the element needed may be derived from that source.

Analyses by Capt. C. E. Dutton, United States Army.

Red hematite ore:

By decimal parts:

Insoluble residue, (silica and silicates)	3.34
Magnetic oxide of iron, ($Fe_3 O_4$)	5.64
Peroxide of iron, ($Fe_2 O_3$)	82.97
Water	6.06
Alumina	1.35
Sulphur	.06
Phosphoric acid	.19
Lime	.33
	99.94

By elements:

Metallic iron	62.16
Phosphorus	.00
Sulphur	.06

Magnetic ore:

Insoluble residue	3.81
Peroxide of iron	28.00
Magnetic oxide of iron	67.68
Alumina	.38
Water	.10
Manganese	Trace.
Sulphur	None detected.
Phosphorus	None detected.
	99.97
Metallic iron	68.61

Both of these ores show very well indeed—some of the best I have ever seen. The pig-iron made from them, if it could be obtained, would give by analysis a better criterion of their precise value, as some elements, which are insoluble in the ore, become soluble in the pig-iron, *e. g.*, phosphorus.

Very truly, yours,

C. E. DUTTON.

KAOLIN.

Near Gunnison are some quite extensive beds of kaolin. The following analysis, by Dr. O. Loew, of a yellowish variety, indicates the presence of considerable iron; some of it, however, is free from this mineral, and is pure enough for the manufacture of porcelain. The major part has probably quite an excess of silica. Located as these beds are on the banks of the Sam Pitch Creek, within easy reach of coal, there seems to be no reason why they should not be turned to good account in the manufacture of fire-brick, &c., for the use of the neighboring mining regions.

Analysis of Kaolin, by Dr. O. Loew.

$Si\ O_3$	46.79
$Al_2\ O_3$	34.17
$Fe\ O_3$	5.04
$H\ O$	14.00
	100.00

SALT.

Salt of a good quality is found abundant in many localities. In the summer and fall, during the time of low water, hundreds of tons are gathered along the shore of Great Salt Lake; also at Little Salt Lake, south of

Beaver, and from the salt marshes in Snake Valley. It is also found in apparently inexhaustible quantities in a red clay of Jurassic age, near Mount Nebo on Salt Creek, on the west side of the Sevier Valley, between Gunnison and Salina, a few miles south of Salina, and in Salina Cañon. These salt deposits are all of excellent quality, being remarkably free from sulphates and from the other chlorides.

GYPSUM.

The Jurassic rocks are everywhere found to be very gypsiferous, and in some places good workable beds of gypsum are seen. One of these beds occurs on Salt Creek near Nephi, and another on the east side of the valley near Gunnison, and others are found in the plateaus of the southern part of the Territory. Mr. Thompson brought in some fine selenite crystals from the Salt Mountains, just south of Salina. Good plaster of Paris can be made from this gypsum, in quantities sufficient to supply all demands.

CHAPTER IX.

PLATEAU SYSTEM OF PORTIONS OF EASTERN UTAH, NORTHERN ARIZONA, AND WESTERN CENTRAL NEW MEXICO.

SECTION I.—STRATIGRAPHY.
SECTION II.—FOLDS AND FAULTS.
SECTION III.—VOLCANIC ROCKS.
SECTION IV.—GLACIAL PHENOMENA.

The main topographical features of this country are the results of erosion, aided and modified by faults and folds, to which volcanic rocks have added many interesting features, mainly by the resistance which they offer to denudation. The climatic conditions are such that the rocks are carried away as fast as disintegrated, which gives the harder rocks an unusual advantage over the softer in resisting erosion, and cliffs are the natural result. And as the streams are cutting down their channels more rapidly than the surrounding country is being degraded, a region of deep cañons, cliffs, and plateaus is found—the delight of the geologist and the wonder of all beholders.

SECTION I.

STRATIGRAPHY—TERTIARY.

The Tertiary formations of this region are confined to the northwestern portion—in Eastern Utah—and to some fresh-water beds in the valley of the Rio Grande. As these latter were passed over in a snow-storm, and partially in the night, I will omit any discussion of them, merely remarking that in some places they have yielded, in considerable numbers, mammalian bones, recognized by Professor Marsh as Pliocene, and they are believed by him to be the equivalents of the Niobrara Pliocene deposits.

The Tertiary beds of Utah are also all fresh water, or fresh and brackish water, deposits. These are bounded on the southeast by Castle Valley, where they form a line of cliffs running south-southwest, and overlooking the valley nearly all the way from Price River to the Last Bluff. From the Last Bluff their outcrop forms what are known as the Pink Cliffs, and continues to the southwest and west in a very irregular line, reaching, at a point near the north fork of the Virgin, as far south as 37° 25′, when it turns again to the northward, and is lost somewhere near the head of that stream. Farther to the west an arm or island of Tertiary extends as far south as Pine Valley Mountains, where it has been protected from erosion by the overlying trachyte. From this point northward to the Uintah Mountains, the western boundary of this Tertiary formation, is the line separating the Basin Range and Plateau Systems.

These boundary-lines so completely define the limits of the formation, that one instance only is known to me of its overstepping them. From the Last Bluff, the Tertiary extends to the southeast ten or twelve miles, in the shelter of a synclinal. On the other hand, throughout this Tertiary area, but few exposures of older rocks are met with. It may also be stated that south of Salina Creek, or south of latitude 38° 50′, this region is so completely covered with volcanic rocks, that sedimentary beds of any kind are only occasionally seen, except along the line of cliffs referred to. These Tertiary beds are so extremely variable in lithological character and thickness, that it is difficult to correlate sections, even when taken only a few miles apart, save in a very general way. This is especially noticeable in comparing sections near the western boundary of the system with each other, or with sections to the east, while the eastern sections show more uniformity in character. These facts are consistent with what might be expected, when we consider that the Basin Range System was the ancient continent, which furnished the sediments for these beds, and we find their variability such as is usually noted in off-shore deposits. To the north these beds are mostly soft calcareous shale and marls, with only a few sandstones and hard limestones. Southward there is an increase in the limestone, and at the most southeastern exposure, the Last Bluff, there are over 1,200 feet of more or less compact limestone. The fossils from this series have not yet been carefully studied. However, the major part of it, if not the whole, may be referred with considerable confidence to the Eocene, and perhaps the Lower

Eocene, and it is by no means impossible that the Cretaceous may eventually be moved up so as to include the lowest member.

Unimportant seams of lignite were noted in several places at the north, and in the vicinity of Sam Pitch Valley are coal beds of excellent quality and of considerable extent. Yet, notwithstanding the flattering prospects of this locality, these coal beds will doubtless prove of limited extent when compared with other coal fields, and are certainly far less extensive than those found lower down in the Cretaceous.

The mines on the west side of the valley at Wales were visited by Mr. Gilbert, and a section at that point will be found in chapter VII, section I, of this volume. The mines on the east side of the valley, at Fairview, were visited, and some fossils collected, by Lieutenant Wheeler, among which *Goniobasis* and *Unios* were abundant, but nothing more definite can be said about them, as the box in which they were shipped was, unfortunately, lost. In the section which I examined at Manti, the coal horizon furnishes only carbonaceous shales, with perhaps a few inches of very impure lignite, and is as follows: (Fig. 106.)

Section near Manti, east side of Sam Pitch Valley.

1. Calcareous, argillaceous, and marly fresh-water beds of various colors, containing *Planorbis*, *Physa*, *Goniobasis*, *Viviparus*, and fish-remains.

Feet.

(Thicknesses are measured in part and in part estimated.)

a. Reddish-yellow shale, with ferruginous concretions, 5 feet.
b. Yellowish-white limestone, 50 feet.
c. Greenish-white, soft, shaly limestone, 100 feet.
d. Green and red shaly marl, 150 feet.
e. Gray sandstone, 10 feet.
f. Red, yellow, and purple shales, 60 feet.
g. Grayish-white, changing to yellow, purple, and red shaly marls, 70 feet.
h. Yellowish-gray, soft, calcareous sandstone, 20 feet.
i. Greenish-gray, shaly sandstone, 40 feet.
j. Yellow sandstone, 30 feet.
k. Light, red, and purple shale, 30 feet.

} 565

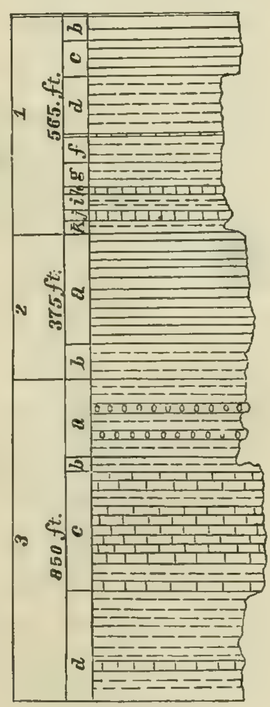


FIG. 106.

2. Light, gray, shaly, fresh-water limestone, with *Goniobasis*, *Physa*, *Viviparus*, and *Unio*:

	Feet.
a. Light yellowish-gray limestone, 300 (?) feet. *b.* Greenish-white, shaly, arenaceous limestone, with beds of dark carbonaceous shale, 75 feet. (This bed furnishes coal at Fairview and Wales (?).	375

3. Red, yellow, purple, and gray calcareous marls and sandstone.

a. Red and purple marls, with some gray conglomerate, 200 feet. *b.* Purple marls, 30 feet. *c.* Soft, light-yellow, shaly sandstone, 320 feet. *d.* Purple, red, and gray marls, with a little sandstone, (base not seen,) 300 feet.	850

By comparing this section with Mr. Gilbert's, just referred to, from Wales, it will be seen that my No. 1 and No. 2 *a*, correspond lithologically, as a whole, very nearly with his No. 1, and my 2 *b* with his No. 2, although in minor details they are very different. The same variability was observed in passing over No. 1, less than a mile from where the above section was taken; while the general character was the same, the details in regard to color, &c., were quite different. The evidence derived from the fossils, although by no means conclusive, favors this correlation of the two sections.

About twenty miles to the east of Joe's Valley, to the topmost rock exposed, is apparently analogous to No. 3, and a section at this point is as follows:

Section east of Joe's Valley, Fig. 107.

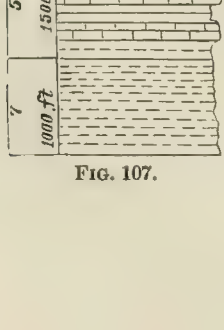


Fig. 107.

Thicknesses measured by aneroid barometer, except No. 6 and the lower part of No. 5.

	Feet.
No. 3. Blue limestone and red marls, which give to the whole a pink color, contains *Viviparus trochiformis* and *Unio vetustus* (?)	175
No. 4. Cream, cross-bedded, calcareous sandstone, interbedded with dark shale and thin layers of limestone, not well exposed, contains *Physa*, *Goniobasis*, *Nebrascensis*, *Unio vetustus*, *Viviparus*, and seeds of *Chara*	650

Feet.

Nos. 5 and 6. Cream, cross-bedded, more or less calcareous sandstone, becoming shaly lower down, and interbedded with dark shales toward the base; contains fragments of leaves, and, a little farther south, beds of coal, about 1,500

No. 7. Dark-gray arenaceous shale, with leaves and *Inoceramus*, about 1,000

The data for a satisfactory determination of the line between the Tertiary and Cretaceous were not obtained, but it is believed that the Cretaceous begins with No. 5. We shall have occasion to refer to this point further on.

For convenience of reference, the same numbers have been applied to what are believed to be the same beds throughout all the sections of this chapter.

In our next section, (Fig. 108,) on Price River, we find the Tertiary beds over 4,000 feet thick. This is the largest exposure examined by me. They thin out gradually to the south and west, but are seen in still greater force to the northeast.

Section near the junction of the north and south forks of Price River, (*Fig.* 108.)

(Thicknesses roughly measured and estimated.)

No. 1. Pale green to gray calcareous shales, with thin layers of limestone, containing turtle and fish remains, with *Unio*, *Planorbis*, and *Goniobasis*.

Feet.

a. Pale, reddish-yellow, soft limestone, 600 feet.
b. Pale green, calcareous shales, with thin layers of limestone, 1,000 feet. } 1,600

No. 2. Brown carbonaceous shales, with thin layers of gray and cream limestone and sandstone, containing fresh-water fossils only, such as *Unio*, *Planorbis*, *Goniobasis*, and *Viviparus*. Some thin layers of limestone are made up almost entirely of *Goniobasis* and *Unio*. Two or three thin seams of lignite were seen 850

No. 3. Red marls, with occasional thin beds of cream sandstone, and more frequent beds of blue limestone, which thicken toward the base. The last two or three hundred feet are mainly blue lime stone, but the red marl gives a pink color to the whole series. Fossils: *Unio*, *Viviparus*, *Physa*, and *Trionyx* 1,200

No. 4. Mainly cream, cross-bedded and shaly sandstones, (connection with No. 5 not seen) .... 400 to 600

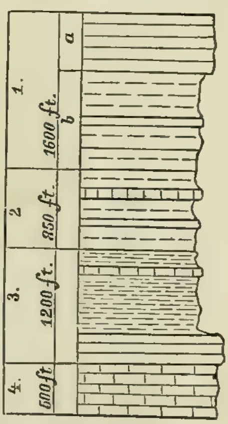


FIG. 108.—Section near the junction of the north and south forks of Price River.

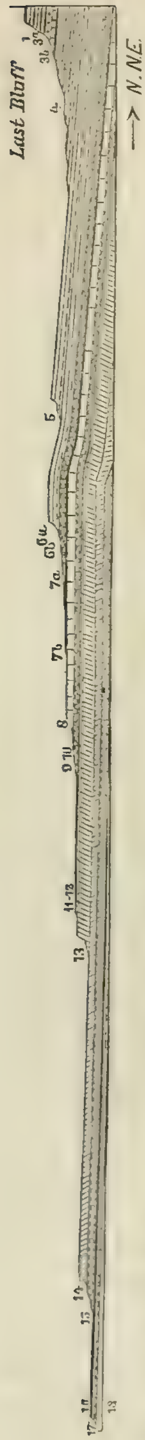


FIG. 109.—Horizontal section: 1 inch = 5 miles, or 1 : 300000; vertical section: 1 inch = 12,000 feet. Section from the base of the Trias formation, a few miles west of Paria Settlement, Utah, to the top of the Tertiary at the Last Bluff. 1, 3 *a*, 3 *b*. Mainly fresh-water Tertiary limestone; 4. Lower Tertiary shales. 5. 6 *a*, 6 *b*. Cream sandstones and dark shales, (Cretaceous;) 7 *a*. Argillaceous shales, (Cretaceous;) 7 *b*, Coal series, (Cretaceous;) 8. Massive sandstones, (Cretaceous;) 9, 10. Sandstone and gypsiferous shales, (Jurassic;) 11, 12. Hard calcareous sandstone and shales, (Jurassic;) 13. Buff, massive, cross-bedded sandstones, (Trias;) 14. Vermillion, massive, cross-bedded sandstone, (Trias;) 15. Variegated marl series, (Trias;) 16. Shinarump conglomerate, (Trias;) 17. Chocolate and light-colored shales, (Trias;) 18. Upper Carboniferous.

The materials comprised in this series are so largely marls and shales, which form gentle slopes and mark all minor features, that it is impossible to make detailed sections in traveling rapidly through the country, but the general characters are well marked, and could usually be followed with comparative ease and certainty.

One or two seams of coal 8 or 10 inches in thickness were noticed in No. 2. There are probably others that were not seen, as the soft, shaly material is well calculated to hide beds of that nature; but coal having economic value will probably not be found at this locality, although there can be but little question that it is the same horizon which furnishes the coal of Sam Pitch Valley.

In the southern portion of the Territory no coal of Tertiary Age has been observed, and, if I am correct in the correlation, the coal horizon is either absent, or is represented by a soft, massive limestone at the Last Bluff, where the following section was measured in part, and in part estimated. This section reaches from the top of the Tertiary to the base of the Trias, and will be constantly referred to throughout this chapter.

Section from the Last Bluff, south-southwest thirty-six miles, to a point a little west of Paria Settlement, (*Fig.* 109.)

	Feet.
No. 1. White to gray fresh-water limestone, containing *Helix* and *Physa Bridgerensis*	500
This is apparently No. 1 of the sections to the northward, but whether No. 2 is also represented, it is not so easy to say. It is one homogeneous mass at this point, and is separated from the limestone below only by color.	
No. 3. *a*. Pink fresh-water limestone, with bands of blue toward the base, containing *Physa*	850

	Feet.
b. Purple and light-colored marls, with conglomerate toward the base	300 to 600
No. 4. Gray arenaceous (and argillaceous) shales, containing an elongated form of *Physa*.	
a. Limea and two species of *Viviparus*, a single specimen of a small oyster, were seen, and some small fragments of large bones	1,200 to 1,500
Total thickness of Tertiary beds	2,850 to 3,450
No. 5. Cream sandstones and shales, with much dark shale and some coal	700 to 800
No. 6. Same as No. 5. Contains *Cardium*, *Corbula*, *Inoceramus*, *Neritina*, (*Dostia*,?) crocodile's tooth, &c.	
a. Cream sandstone, with some fine conglomerate and a little dark shale	200
b. Cream shales, and sandstones and dark carbonaceous shales and coal	500
No. 7. *a.* Dark argillaceous shale, with *Hamites*, *Baculites anceps*, *Ancyloceras*, *Ammonites percarinatus*, *Turritella*, *Cardium*, *Inoceramus problematicus*, *Lima*, *Ostrea congesta*, *Corbicula*, *Lucina*, and many other fossils	500
b. Coal series: Mainly dark carbonaceous shale, with coal, but containing some cream sandstone and shale, the whole capped with an oyster-bed, which varies in thickness from 1 foot to 5 or 6 feet, but is never absent, and is usually one complete mass of shells of several species, one of which is hardly distinguishable from the common edible oyster, (*Ostrea Virginiana.*) *Exogyra ponderosa*, and *Gryphæa Pitcheri* are also very common, and *Turritella* and *Ammonites* are occasionally seen	150
No. 8. Light-colored conglomerate and sandstone above, changing to red below, with banded red and slate-colored shales at base. A few leaves and one cast of gasteropod were found near the top, and on the Dirty Devil River Saurian bones were seen.	

a. Light-gray sandstone or fine conglomerate, changing gradually to a pale-red sandstone	250 feet.	500
b. Gray sandstone	5 feet.	
c. Dark-chocolate sandstone	1 foot.	
d. Pale-red sandstone	100 feet.	
e. Slate-colored shale	20 feet.	
f. Chocolate, red and slate-colored banded shales and sandstones	125 feet.	

Total Cretaceous	2,550 to 2,650
No. 9. Pale-red, massive, cross-bedded sandstone	125
No. 10. Variegated gypsiferous shales, with green and slate-colors at the top	175
Near the Dirty Devil River this bed contains *Camptonectes*, *Trigonia*, *Aviculopecten*, and *Gryphæa*. (?)	
No. 11. Pale-yellow, cross-bedded, calcareous sandstone	75
No. 12. Red, yellow, purple, and gray marly shales and sandstones	125
Total thickness of Jurassic beds	500

	Feet.
No. 13. Buff, massive, cross-bedded sandstone	800
No. 14. Pale-vermillion, massive, cross-bedded sandstone	600
No. 15. Variegated gypsiferous marls, containing silicified wood	400
No. 16. Shinarump conglomerate—a gray conglomerate, with large quantities of silicified wood	50
No. 17. Chocolate, arenaceous, and gypsiferous shales and marls	400
Total thickness of Trias	2,250

There can be little doubt that No. 1 of this section is the equivalent of No. 1 in the sections near Manti, and on Price River, (Figs. 106 and 108,) and it probably includes No. 2, also, of those sections. This bed caps Moo-se-ne-ah Peak, and all the adjoining Plateau. From the last bluff it extends to the west and southwest, blending more or less with the pink limestone below, (No. 3,) and with it forming the cap to the line of Pink Cliffs before mentioned.

Mr. Gilbert gives a section of the rocks exposed on the North Fork of the Virgin River, (chapter VII, section III,) which includes these beds, and illustrates what has before been remarked, that the beds near the old shore-line are more variable, and are now composed less of limestone, than those deposited at a greater distance from here in still water.* No. 1 is represented on the east flank of Pine Mountains by a few patches of soft, marly, white limestone, (3 *a*, Fig. 110,) in which were found the same species of *Physa* and *Planorbis*, (*Physa Bridgerensis* and *Planorbis* ———,) as at the Last Bluff and on Soldiers' Fork. These patches are little islands that have been protected from erosion by overlying trachyte. The trachyte covering the summit of Pine Mountains is also underlaid with about 300 feet of red and yellow concretionary limestone, which is probably Tertiary, and the equivalent of No. 3, (3*b*, Fig. 110, and No. 2, Fig. 99.) No. 4 is well exposed at Last Bluff, but it is difficult to correlate it with No. 4 of Figs. 107 and 108, one hundred and twenty-five to one hundred and fifty miles to the north. Its position, however, is defined by its relation to the beds above and below it, and a somewhat intermediate lithological condition is given in Mr. Gilbert's section, just referred to, fifty miles to the west. It is represented at

*No. 1 of Mr. Gilbert's section is the equivalent of 1 and 3 of mine; and No. 2 of his is the equivalent of No. 4 of mine; while 5 and 6 of my section are represented by No. 3 in his, with perhaps some of the upper portion of 4; and my 7 and 8 equal the remainder of his No. 4.

Pine Valley Mountains, (the upper part of No. 4, Fig. 110, and the upper part of 3, Fig. 99,) by rocks bearing a close resemblance to those seen to the north.

The fossils found in this bed, both at the north and at the south, indicate that it is the equivalent if the Upper Missouri lignite formation, but the fact that oysters were seen near the Last Bluff, and by Mr. Gilbert on the North Fork of the Virgin, show that it was deposited, partially at least, in brackish water, and suggests that it may prove to be the equivalent of the Bitter Creek series, and the Bear River brackish water deposits, which would make it doubtfully Lower Eocene or Upper Cretaceous; but for the present I shall consider it Lower Eocene.

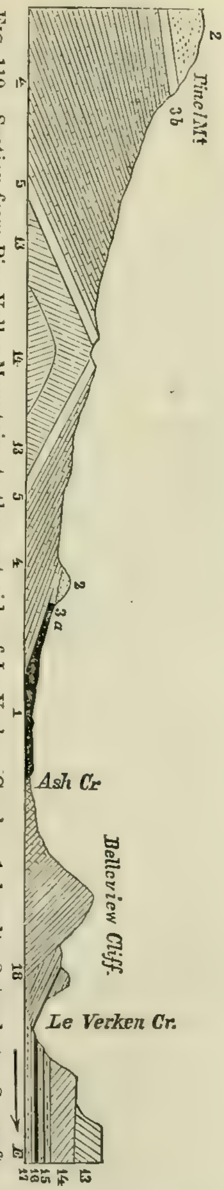


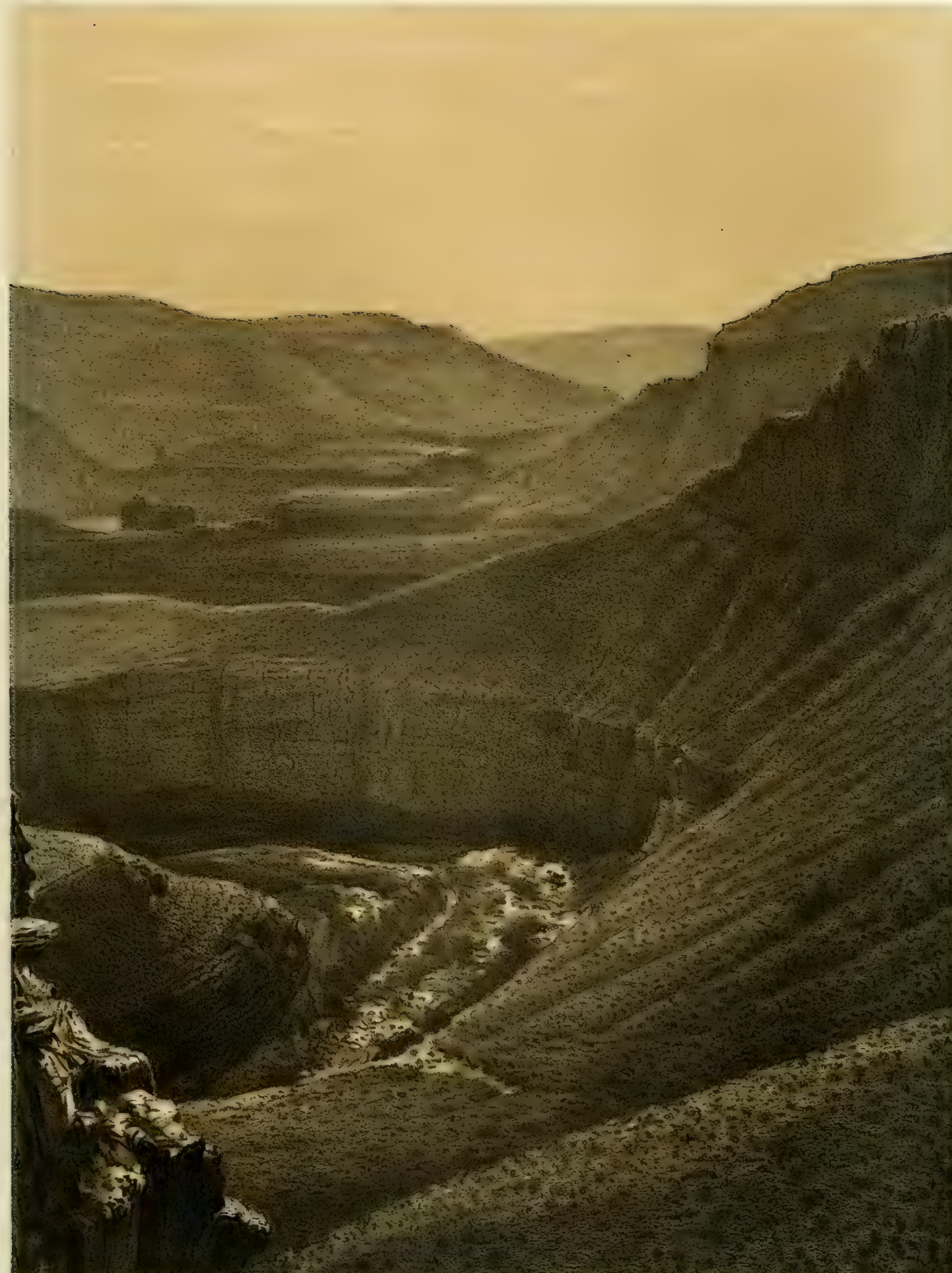
Fig. 110.—Section from Pine Valley Mountains to the east side of Le Verken Creek. 1, basalt; 2, trachyte; 3 *a*, soft-gray limestone, (No. 1, Tertiary;) 3 *b*, pale-red concretionary limestone, (No. 3? Tertiary;) 4, mainly Cretaceous sandstones, with No. 4? (Tertiary) at the top, and probably some Jurassic at the base; 5, Jurassic; 13–14, cross-bedded sandstone, (Trias;) 15, variegated marl series, (Trias;) 16, Shinarump conglomerate, (Trias;) 17, Lower Trias shales; 18, Carboniferous limestone and sandstone.

In the section previously given, on Soldiers' Fork, (Fig. 96,) *a* equals No. 2 of the general section; *b* and *c* may be parts of the same, but are probably the equivalents of the lower beds. The heavy bed of conglomerate (*d*) apparently has no representative to the east or southeast; at least I have not been able to recognize any. A little to the north, on North Fork, it rests nonconformably upon red sandstone. Near the north end of the Sam Pitch range there is a similar conglomerate resting apparently upon the upturned edges of Jurassic rocks. Another exposure of conglomerate, similar in appearance, and probably connected with the last, is seen at the lower end of the Sam Pitch Valley, overlying pure red sandstone, of which 200 to 400 feet are exposed. Above the conglomerate is a series of calcareous and argillaceous beds, to which belong the kaoline deposits near Gunnison. The colors are mostly green and yellowish-white, with a little red near the base. This whole series probably corresponds to No. 1. Farther to the north there appeared to be a non-conformity between these beds and the conglomerate, but the distance was so great as to leave this point uncertain. As these three are the only localities where we have seen this conglomerate, although our exposures, a few miles to the east, should have revealed it, did it exist, I am led to believe that it is extremely local. The two last-mentioned exposures are probably parts of the same bed, but I think it doubtful if they have any connection with the bed on Soldiers' Fork. This latter, I have before suggested, might be an old delta, and the bed to the south may have been formed in a similar manner. I know of no facts that will determine whether this conglomerate is Tertiary or Cretaceous.

CRETACEOUS.

Whether the entire area embraced in this chapter was ever covered with Tertiary rocks may be doubted, but that the Cretaceous beds were once universal admits of no question. There are many places where older rocks are now exposed over large areas, but the evidence is conclusive that these exposures are from subsequent erosion, and not from lack of deposition.

The boundaries of this formation cannot be so easily described as those of the Tertiary, and the reader is referred to the colored atlas for that information; but in a general way it may be defined as underlying the Tertiary of Utah, where its presence is occasionally revealed by folds and cañons, and forming a border fifteen or twenty miles in width outside the Tertiary cliffs on the south and east. There is another strip of about equal width lying to the west of the Henry Mountains, in the trough of a synclinal which trends about north-northwest by south-southeast. The same Cretaceous beds are again found in Northeastern Arizona. Beginning in a narrow strip near the Colorado River, south of the San Juan, they spread out rapidly to the eastward, and continue with few interruptions to the Rio Grande. West of Fort Defiance there is an anticlinal fold, which has so hastened the erosion that the Cretaceous rocks have been carried away from a strip thirty miles in width. At the Zuni Mountains the same thing has been repeated, and on a much smaller scale in a few other places. The



A CAÑON WITHIN A CAÑON,
In basin of the
COLORADO RIVER.

southern limits of the Cretaceous in Arizona may be very closely defined by a line run westward from the Fort Defiance anticlinal in latitude 35° 40′ as far as the Moqui towns, and from there due northwest to the Colorado River.

These beds are composed mainly of soft, more or less calcareous, cream-colored sandstones and dark, argillaceous and carbonaceous shales, containing extensive beds of coal, with almost an entire absence of limestone.

The most satisfactory examination of the whole series was made near the Last Bluff, in Utah. A section at this point (see Fig. 109) gives about 2,600 feet as the total thickness of the beds which we have called Cretaceous; but neither the upper nor lower limits of this formation have been determined as definitely as could be desired. The reasons for placing No. 5 with the Cretaceous are based upon lithological considerations entirely, as I was not fortunate enough to secure any fossils from this bed. It differs materially from No. 4, but agrees very closely with No. 6 (which is unquestionably Cretaceous) in color and texture. These beds are naturally separated from each other at this point, for the reason that the lower part of each is softer than the upper portion, which results in the formation of two distinct lines of cliffs; but to the northward no such division was seen, and I was not able to separate the two. No. 5, and the greater portion of No. 6, also, are wanting in the portion of Arizona visited; but in New Mexico, between Fort Defiance and the Rio Grande, both beds are apparently present, though no separation of the two could be made that would hold good for any great distance. Although many minor divisions could be made at any one place, they would not correspond to, and could not be correlated with, those made at another; yet, taken as a whole, the series everywhere presents the same appearance. As there is no evidence to the contrary, I think the intimate relation which exists between the two beds justifies placing them in the same formation.

Fossils are not very abundant in No. 6, but enough were collected to determine its geological horizon.

Professor Meek recognized, in a hasty examination, *Inoceramus*, *Cardium*, *Corbicula*, and *Neritina Dostia* (?) like those found by him at Coalville, on the Union Pacific Railroad, and assigns to it a position in his Coalville series so far below the summit of the Cretaceous that there is ample room for No. 5 in the same formation, and a lithological comparison of sections from the two localities favors that idea. And, as before intimated, it may even be questioned whether No. 4 also should not be placed in the Cretaceous series.

The same difficulty is met with in attempting to separate the Cretaceous from the Jurassic, as no fossils were found in No. 9, and only a few in the upper part of No. 8, and the division between the two is not a marked and constant one. A slight non-conformity by erosion was noted in one instance near the Paria; but a similar non-conformity was seen between 9 and 10, fifty miles to the northeast, in Water Pocket Cañon. While No. 10 is Jurassic, there can be very little doubt that No. 8 is Cretaceous, (at least the upper portion,) and the difficulty arises in disposing of No. 9. My reasons for placing it in the Jurassic with No. 10 are, first, the fact that at Soldiers' Fork and Salina Cañon there is a heavy bed of Jurassic sandstone not very unlike this in texture, lying immediately above the green gypsiferous shales, which shales are apparently the equivalent of the No. 10, and I think the inference is fair that the overlying sandstones are also equivalents. Second, I find, in going to the eastward, that while No. 8 is constant, the whole Jurassic series, including No. 9, thins out rapidly, and finally disappears in Eastern Arizona and New Mexico, leaving No. 8 resting immediately upon 13. As this is a variable bed and disappears with the known Jurassic, while the Cretaceous above and Trias below are constant, there seems to be a propriety in placing it with that formation. Still, it must be admitted that, so far as observed by us, it was more fully separated from No. 10 than from No. 8, and more careful study may show that it should be placed with the Cretaceous.

The main divisions of the Cretaceous retain their distinctive characters throughout, although subject to considerable variation in color, texture, and thickness.

Attention has already been called to the intimate relation which exists between 5 and 6. They have the same general appearance in New Mexico as in Utah, although containing apparently a little more dark shale, and perhaps, also, more coal; but it would require more careful examination to decide this latter point. Several exposures of coal were noted between Fort Defiance and the Rio Grande, and also in Southern Utah, and as far north in Castle Valley as Muddy Creek. The coal of the Placer Mountains near Santa Fé, judging from the accounts given of it, probably belongs to this horizon. No attempt was made to trace these coal exposures, but enough was seen to indicate that some of the beds will prove to be of considerable economic value.

As before stated, only the lower part of No. 6 is present in Northeastern Arizona, and this was not seen along the line of march more than twenty or twenty-five miles west of Oraybe, but it was seen in greater thickness far away to the north, northwest, and northeast, and it is probable that not only the whole of No. 6, but No. 5, also, is there represented.

The whole region in the neighborhood of the Moqui towns consists of broken mesas, capped with from 100 to 300 feet of cream sandstone and dark shale, the lower part of No. 6. Below this are the dark argillaceous and carbonaceous shales of No. 7, from 300 to 500 feet in thickness, while at the base of the mesas, and forming the floors of the valleys, may be seen the soft, yellowish-white sandstone of No. 9.

The Moqui towns are all built on the salient angles or peninsulas of these mesas. At the town of Oraybe, No. 6 has a thickness of 150 to 200 feet. Five miles to the northeast it is considerably thicker. A section, beginning at the top, is as follows:

	Feet.
a. Almost white, coarse sandstone, estimated	70
b. Cream sandstones and shales	60
c. Dark carbonaceous shale	35
d. Cream to white sandstone	30
e. Dark and cream shale	35
f. Hard cream sandstone	30
	260

No. 7 shows throughout a great degree of constancy in its general character. Although cream shales and sandstones are always present in variable quantities, the general appearance is everywhere that of a dark-gray shale.

The thickness of this bed, in New Mexico, Arizona, and Southern Utah, is usually from 400 to 700 feet, but in the northern part of Castle

Valley it attains a thickness of 1,000 or 1,200 feet. Professor Meek recognizes the fossils collected from this bed in Utah, Arizona, and New Mexico as the same that are characteristic of No. 2, or Nos. 2 and 3, of Meek's Nebraska Cretaceous. The determination of this horizon is especially interesting from the fact that it is pre-eminently the coal formation of the area embraced in this chapter, and probably of the whole Colorado Plateau System.

I have already mentioned the occurrence of coal in the Tertiary beds in the vicinity of Sam Pitch Valley, of excellent quality, but of limited extent, and also a second horizon in the Upper Cretaceous (Nos. 5 and 6) of Utah and New Mexico, but the lowest and most important of all is now reached. The data collected indicate that the coal bed or beds of this horizon have extended, with but little, if any, interruption, from the western border of the plateau, near Cedar City and Kanara in Utah, to the Rio Grande in New Mexico, a distance of over five hundred miles.

Mr. F. Klett, of our party, brought in some very fine-looking specimens of coal, collected from the summit of the bluff just east of Kanara. His section at this point is:

1st. Black soil capping the bluff.
2d. "Shell-bed," (the only fossils recognized by Mr. Meek are, *Corbicula* and *Corbula* of Cretaceous types.)
3d. Coal and carbonaceous shale, 18 feet.
4th. Red sandstone, 2,000 feet.

The fossils collected were merely enough to show it to be of Cretaceous Age, but the fact that all below the coal is called "red sandstone" indicates that it is near the base of the Cretaceous; and evidence from other sources goes to prove that only the lower part of the Cretaceous is present at this point. The shell-bed above, and the dark soil, (shale?) indicate, moreover, that the horizon is the equivalent of our No. 7, *b*. And, still further, *Turritella* and oyster-shells were brought in by other members of the party from the same plateau, a little farther to the east, and probably from the same shell-bed.

It will be seen from Mr. Gilbert's section on the North Fork of the Virgin, that he met with coal there at the same horizon. I would also call attention to his section on the West Fork of the Paria for the details of the coal series at that locality. Another section, which I saw near the town of Paria, is as follows:

	Feet.
a. Oyster-bed, of light-cream color	4
b. Pink sandstone	3
c. Argillaceous, carbonaceous, and cream shales, with some coal	40
d. Cream shale	10
e. Argillaceous and carbonaceous shales, with coal; one vein of good quality, 12 inches thick	10
f. Yellow and cream sandstone	4
g. Argillaceous and carbonaceous shales, with coal; one vein 18 inches thick	20
h. Cream sandstone	10
i. Cream shale and green argillaceous shale	10
j. Argillaceous and carbonaceous shales, with some coal	20
k. Argillaceous shale, with selenite	10
l. Brownish-gray conglomerate and sandstone, upper part of No. 8.	

In some parts of Arizona the coal is confined to fewer beds, and seems to be present in much greater quantity. Near the head of a little cañon, twenty-five miles northwest of Oraybe, one bed of very pure coal, $8\frac{1}{2}$ feet thick, was seen and measured. A little farther down the cañon a lower bed was seen, 4 or 5 feet in thickness, while two or three miles to the north only one bed was seen, which had a thickness not far from 25 feet. This is probably the same bed which Dr. Newberry mentions as 30 to 50 feet thick, farther to the north, on the San Juan.*

To the eastward coal was not seen in such thickness, and it probably does not exist, although the loose, shaly rock weathers in a way well calculated to conceal the coal at this horizon, but exposures were seen at various localities near the Moqui towns, and east of Mount Taylor, enough to indicate that the bed continues with greater or less thickness to the valley of the Rio Grande. And the coal mentioned by Dr. John L. Leconte,† near San Antonio, is probably from the same horizon. This coal horizon in Utah extends far northward in Castle Valley, and just outside the limits of our survey, on the Muddy and San Rafael, are coal-beds, reported by the Mormon explorers to be of great thickness.

If the thick beds of Lower Cretaceous coal reported by Dr. Newberry, as occurring in the San Juan region, do indeed belong to this same horizon,

* Am. Journal of Science, April, 1873.

† Notes on geology, from Smoky Hill River, Kansas, to the Rio Grande.

then this Lower Cretaceous coal horizon of the Colorado Plateau System is one of the most extensive known.

The bed of sandstone, No. 8, immediately below the coal series, shows considerable variability in texture and color, as well as thickness. In making a section near Paria, I found it 500 feet thick, but the greatest thickness was seen fifty miles to the east of this, near the Colorado, where it is about 800 feet, and much of the upper portion is made by a fine conglomerate of gray or cream color. No. 9 also attains its greatest thickness at this point, and is but little thinner than No. 8. There is a gradual thinning of both beds toward the north, and on the Dirty Devil River No. 8 is about 300 feet thick, with much the same lithological appearance, except that the conglomerate of the upper part is a little coarser.

To the eastward, in Arizona, it has a thickness in places of at least 500 feet, and its usual color is a greenish or yellowish white, sometimes becoming nearly a pure white, with streaks of red or pink toward the base, which frequently extend well up. It is granular in texture, very soft and friable, but farther to the east becomes thinner and harder again, more nearly resembling its appearance in Utah. I had an excellent opportunity for observing and measuring this bed at the Zuni Buttes, four miles northwest of Zuni, where I found it 130 feet in thickness, cross-bedded, of a reddish-buff color, and resting immediately upon No. 13, which it resembles perfectly in color and texture, and from which it is separated only by a small fissure or crack, which could be plainly traced in the adjoining buttes also. A similar separation is seen at Inscription Rock, where No. 8 is not more than 75 feet thick. When the rocks are soft there is no fissure or crack showing, and it is frequently impossible to separate the two beds, but usually No. 8 is redder than No. 13.

JURASSIC.

Considering the thinness of the Jurassic formation, its outcrop occupies considerable space in the western part of our area, and this space is covered mainly by the lower two members of the series, and is due to the fact that No. 11 is a much harder bed, and weathers far slower than the upper beds and the Cretaceous series, and so forms a thin capping for a part of the

Trias over considerable areas. The formation, throughout, is characterized by large quantities of gypsum, and in some parts of Utah by extensive salt deposits. It is somewhat interesting to note that the limestone of the formation frequently corresponds in its oolitic character to rocks of the same age in Europe.

The most northern point in the plateau country, where the series was examined, is on the Dirty Devil River, where the estimated thickness is about 800 feet, divided as follows:

	Feet.
No. 9. Soft, pale-red, gypsiferous sandstone	500
No. 10. Green, gypsiferous shale, hardening toward the base into soft limestone, containing *Camptonectes*, *Trigonia*, *Aviculopecten*, and *Gryphæa?*	250
No. 11. Pale yellow, cross-bedded, calcareous sandstone	20
No. 12. Red marl and shale	10
Total	780

On the southwest side of Escalante River, sixty miles farther south, the series is from 200 to 400 feet thicker, and contains much more gypsum in the lower part, where workable beds 8 or 10 feet in thickness were seen.

In the section on the Paria (Fig. 109) I found the Jurassic only 500 feet thick, but seventy miles to the westward, near St. George, it has a thickness more than double this, (see Fig. 99,) and this thickness is small compared to the 6,000 or 8,000 feet noted along the east base of the Wahsatch. To the eastward it thins out rapidly, until, in Eastern Arizona and in New Mexico it probably disappears entirely. Beds evidently belonging to this series were seen near the Moencopie, but no definite idea of their thickness could be obtained. Between White Rock Spring and the Pueblo Colorado, 20 or 30 feet of red marl were seen lying just above No. 13, which are believed to represent the Jurassic series. South and east of Mount Taylor a series of beds having a thickness of about 125 feet were seen, holding the proper position, and closely resembling the Jurassic as seen in Utah, but no fossils could be found. Mr. Gilbert found a *Camptonectes*, fifty miles north of Camp Apache, closely resembling, if not identical with, the species found in the Jurassic of Utah; but the associated fossils indicate Cretaceous Age, and the question of its age is an open one, as is the whole question whether there is any Jurassic in Eastern Arizona and Western New Mexico. That the Jurassic is absent in some localities there can be no doubt, unless a portion of the so-called Trias is of that age. This is proved by what has already been said in relation to the Zuni Buttes and Inscription Rock. Where Nos. 8 and 13 are in contact and resemble each other so closely as these two beds frequently do, it is not an easy matter to separate the Cretaceous from the Triassic ; and I find that Dr. Newberry has classed all below the lower coal at the Moqui towns in one series.* As the Lower Cretaceous and Triassic are both unusually soft and marly in this region, it would probably be impossible to draw the line between them, even for one whose previous observations had convinced him that two distinct formations were there represented. That two such formations are there represented I can hardly doubt, as in no single instance where a section could be made out satisfactorily did I fail to find a bed of sandstone (No. 8) interposed between the coal series and the Trias; this is separated from the Trias in Utah by beds 500 to 1,000 feet in thickness, which thin out to the eastward, and finally disappear entirely in parts of Arizona and New Mexico, leaving only a fissure or crack to represent them, or mark their place, where the rocks are hard; and where soft, nothing whatever.

TRIAS.

Nos. 13 to 17, (inclusive,) of Fig. 109, give a typical section of the most characteristic group of rocks found in this plateau country. This group, by the common consent of geologists, has been called Trias, although as yet it has furnished no fossils to satisfactorily establish this conclusion. This formation, like those above, terminates to the southward in abrupt cliffs. These cliffs, usually two in number, and sometimes three, as seen in Fig. 109, run from Southwestern Utah, near St. George, in a very irregular line to the Colorado River near the mouth of the Paria, and then southeast to the head-waters of the Little Colorado. East of the Colorado, they conform very closely to the axis of a monoclinal fold, and form a tolerably straight line, but to the westward they are crossed at right angles by folds and faults, and as the beds thrown down by these movements weather more slowly than those retained at a higher elevation, they are left behind in the

* Ives Report.

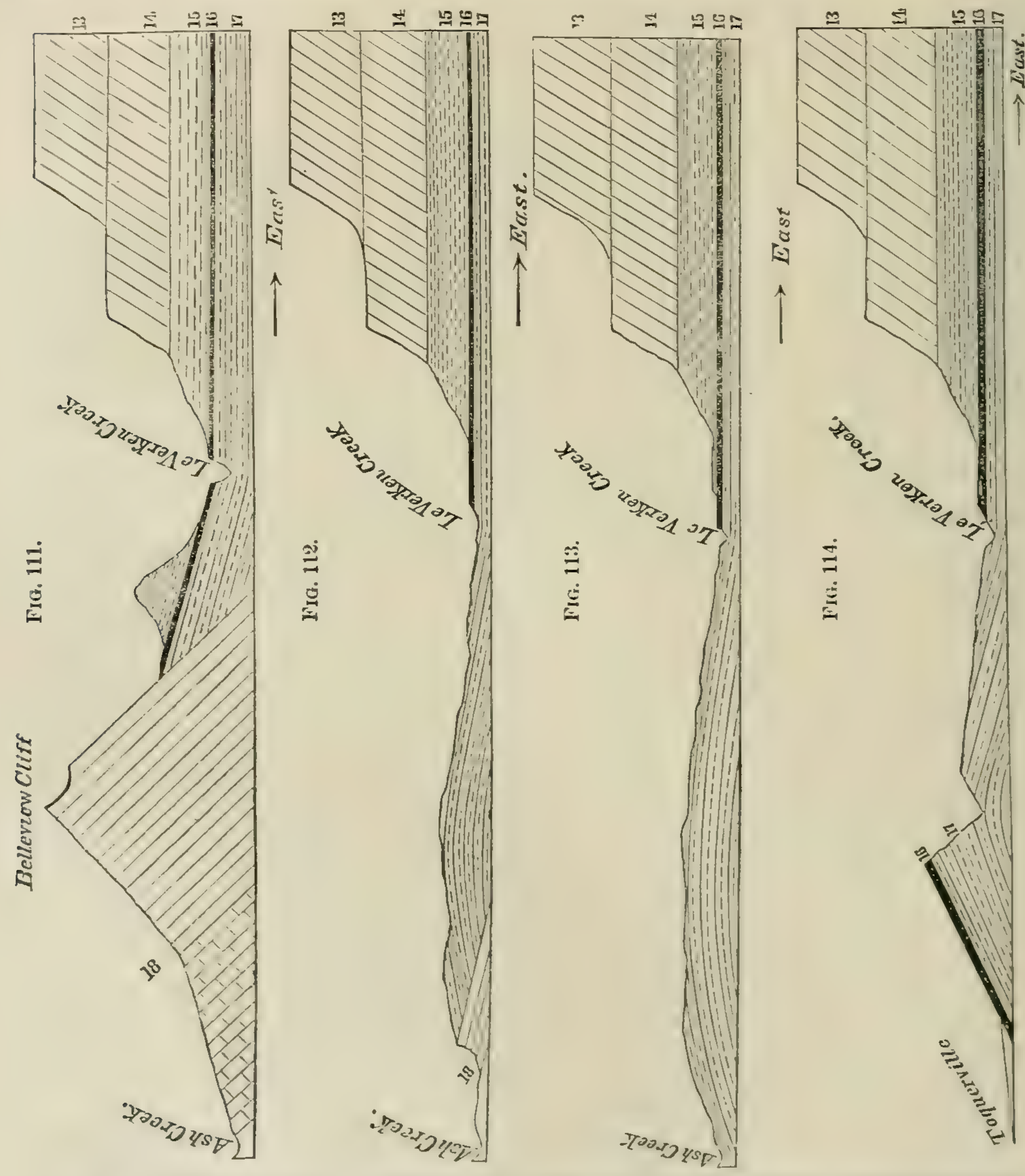
northward retreat, and a very irregular line of cliffs is the result. The plateau south of this extended line of cliffs is capped with rocks of Upper Carboniferous Age, while to the northward the lowest exposures are usually Triassic. The most important exception to this in the area embraced in this report is the Zuni Mountains, which are composed of Carboniferous rocks with a crystalline nucleus, exposed near their southeastern extremity, while the range is wholly surrounded by Trias cliffs, similar to those described above, (see Figs. 115 and 116.) The thickness of this Triassic series in New Mexico and Eastern Arizona is from 1,200 to 1,800 feet. This gradually increases to the westward, until in the section near Paria (Fig. 109) it is estimated at 2,250 feet. Ninety miles to the northeast, on the Dirty Devil River, 1,700 to 1,900 feet is found, while at the extreme western point examined, near St. George, the same series is estimated at between 5,000 and 6,000 feet, (see Fig. 99.) This is perhaps an overestimate, but the thickness of the series is undoubtedly much greater here than anywhere to the eastward.

The two upper members of this series (Nos. 13 and 14) are usually soft, massive, cross-bedded sandstone. The color of the upper member is generally pale-yellow or buff, while that of the next is some shade of red; but this division is not a constant one, and to the eastward any attempt to separate the two becomes impracticable. Moreover, the division, which is usually very well marked in Utah, between these beds and the variegated marls below, is also very indefinite, as the base of 14 becomes soft and shaly, making an easy gradation from the marls below to the sandstone above. The whole upper part of the series is much softer in Eastern Arizona than it is either to the west or east, much the same character being seen in New Mexico as in Utah.

Considerable limestone was seen in the variegated marls series (No. 15) in Arizona and New Mexico, and east of the Colorado, for a distance of fifty or sixty miles, the series has a thickness of 500 or 600 feet.

The conglomerate bed, No. 16, to which Mr. Powell has given the Indian name, Shinarump, is a very singular formation. Having a maximum thickness at St. George of 100 feet, it seldom exceeds 40 or 50 to the east, but is co-extensive, so far as I know, with the Trias of the Colorado

Plateau. Occasionally it is little more than a coarse sandstone, and sometimes thins out to 8 or 10 feet, but never have I passed that horizon without seeing it. One of its constant features, almost as constant as its existence, is the great amount of silicified wood which it contains.



Figs. 111–114 are sections near Toquerville, Utah, showing a non-conformity between the Trias and Carbonif-rous; 13–14, cross-bedded sandstone, (Trias); 15, variegated marl series, (Trias); 16, Shinarump conglomerate, (Trias); 17, shales, (Trias); 16, limestone and sandstone, (Carboniferous.)

Being harder than the beds above and below it, this caps a line of cliffs, which are the second or lower line of Trias cliff, previously referred to.

Just below this line of cliffs, near Toquerville, in Southwestern Utah, a few fragments of lamelle branch shells were seen. Although too indefinite for determination, they indicate that more careful search will yet procure the evidence needed for determining the age of these beds with certainty.

A very interesting instance of non-conformity between the Trias and Carboniferous was seen a little north of this town. Fig. 111 shows this non-conformity as it appeared at a distance of two or three miles. Later experience and more careful examination of the weathered exposures along monoclinal folds have had a tendency to throw doubt on this as a true case of non-conformity, but I am still disposed to think that the relation of the beds was correctly seen.

The Carboniferous limestone, forming the Belleview Cliffs, a little south of the line of this section, makes a twist, and the western edge dips rapidly to the south, and soon assumes a nearly horizontal position, as seen in Fig. 112, one and a half miles farther south. It is soon after buried beneath the Triassic rocks.

Fig. 113 is a section half a mile south of the point represented in Fig. 112, and in Fig. 114, one mile farther, we find the Shinarump conglomerates capping the cliff just east of Toquerville. If this be, as I believe it is, a true case of non-conformity between the Trias and Carboniferous, it is the only one of which I am aware, and deserves more careful study.

CARBONIFEROUS.

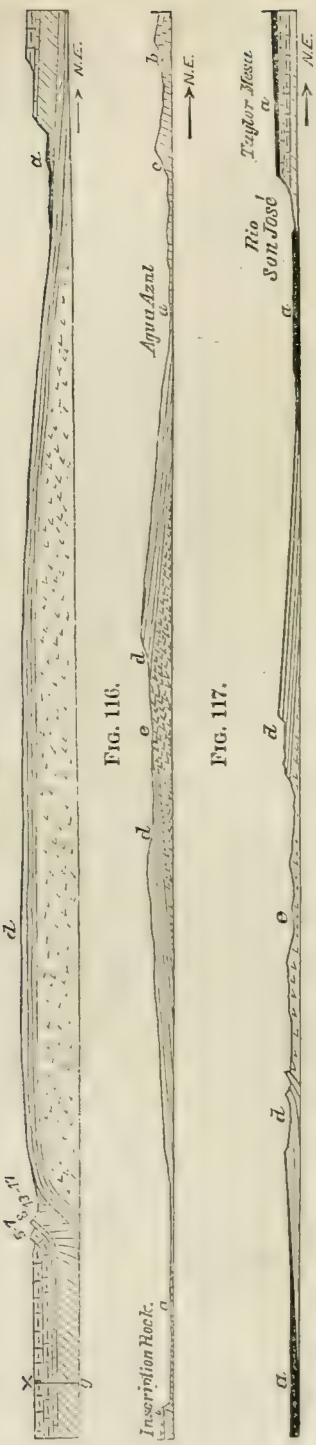
I have before stated that the plateau country south of the great line of Trias cliffs is capped with rocks of Upper Carboniferous Age, but my work southward ended at the base of the Trias, and only at a few places did I enter the Carboniferous at all; so that no facts were gathered except in regard to its geographical distribution.

About 2,000 feet of yellowish-gray limestone and sandstone, belonging to these series, are revealed by the Hurricane fault, near Belleview, in Southwestern Utah, as shown in Fig. 110.

Fig. 115.

Fig. 116.

Fig. 117.



Figs. 115–117.—Sections of the Zuni Mountains. *a*, Basalt; *b*, Cretaceous; *c*, Trias; *d*, Carboniferous; *e*, Granite. Scale of Fig. 115: 1 inch = 215,000 feet approximately; scale of Figs. 116 and 117: 1 inch = 18,000 feet.

A gray calcareous sandstone, probably of Carboniferous Age, was seen at the base of the Trias, between the Dirty Devil and Escalante rivers, and a few other cases were met with where the rocks were doubtfully of Upper Carboniferous or Lower Triassic Age. The whole crest of the Fort Defiance anticlinal is so near the base of the Trias, that a cañon anywhere, a few hundred feet deep, would expose the Carboniferous.

The Zuni Mountains have a trend northwest by southeast, and are an elongated quaquaversal, from which all the rocks above the Carboniferous have been denuded, but the Trias and Cretaceous are seen in bold cliffs facing the mountains on all sides, as shown in Figs. 115 and 116. Here and in the Fort Defiance anticlinal are two fine illustrations of the more rapid denudation which results from an increase in elevation. Fig. 115 is a section across the range at the north and near Fort Wingate.* Fig. 116 shows a section twenty or twenty-five miles farther southeast, while Fig. 117 is a section at the southeastern extremity, where the erosion has revealed the crystalline nucleus. This nucleus, however, is probably only a highly metamorphic condition of the Carboniferous rocks, and a very easy gradation can be traced from red siliceous sandstone, through sectile quartzite, still retaining some of its red color, and showing small rounded

* A section of the western Zuni fold, twenty or twenty-five miles to the north of this, is shown in Fig. 123.

crystals or crystalline grains of quartz, into rocks showing a less perfect bedding, but more highly crystalline structure, which, with an increased development of feldspar and mica, merges into a rock, that in selected hand specimens no one could hesitate to call granite.

Immediately above these rocks are:

	Feet.
f. Pink and red sandstone	500 or 600
e. Pink to gray limestone	75 to 100
d. Red sandstone again	50 to 100
c. Blue to gray limestone	100 to 150
b. Pale red sandstone	150 to 200
a. Gray sandstone (?) limestone (?)	150

Then comes an interval where no sedimentary beds are seen, and the first rocks outside of this are Upper Trias. The nature and thickness of the intervening beds were not determined, and unless it is admitted that the crystalline rocks are of Carboniferous Age, the thickness of this formation here is far below the minimum usually assigned to it in the west. The most common fossil seen in these beds is the *Productus costatus.* Some specimens of *P. semireticulatus*, *Athyris subtilita*, (?) and *Bellerophon crassus* (?) were also collected.

From a glance at the sections here given, it will be readily seen that the main, if not the entire, elevation of this range was after the deposition of the Cretaceous beds, which are now seen only at its base, but folded, as illustrated in Fig. 115, in such a manner as to show that they took part in the uplift. In many places, however, erosion has progressed so far that no folded Cretaceous rocks remain, (see Fig. 116, at the left,) and it will be readily perceived that if the Cretaceous beds represented in Fig. 115 were carried back a few hundred feet, or to the line, *y*, no evidence of their ever having been folded would remain.

GENERAL SECTIONS.

A few general sections are added here to give the reader at a glance some of the leading geological features of this country. The first, (Fig. 118,) crosses the Zuni Mountains, and runs in a southwestern direction to Zuni, and shows the line of cliffs which extends northward to Fort Defiance, and is the same (?) that is shown just east of the Fort in Fig. 121.

Fig. 118.

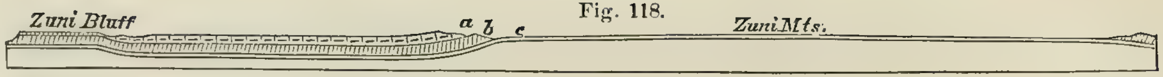


Fig. 119.

Fig. 120.

Fig. 121.

Fig. 122.

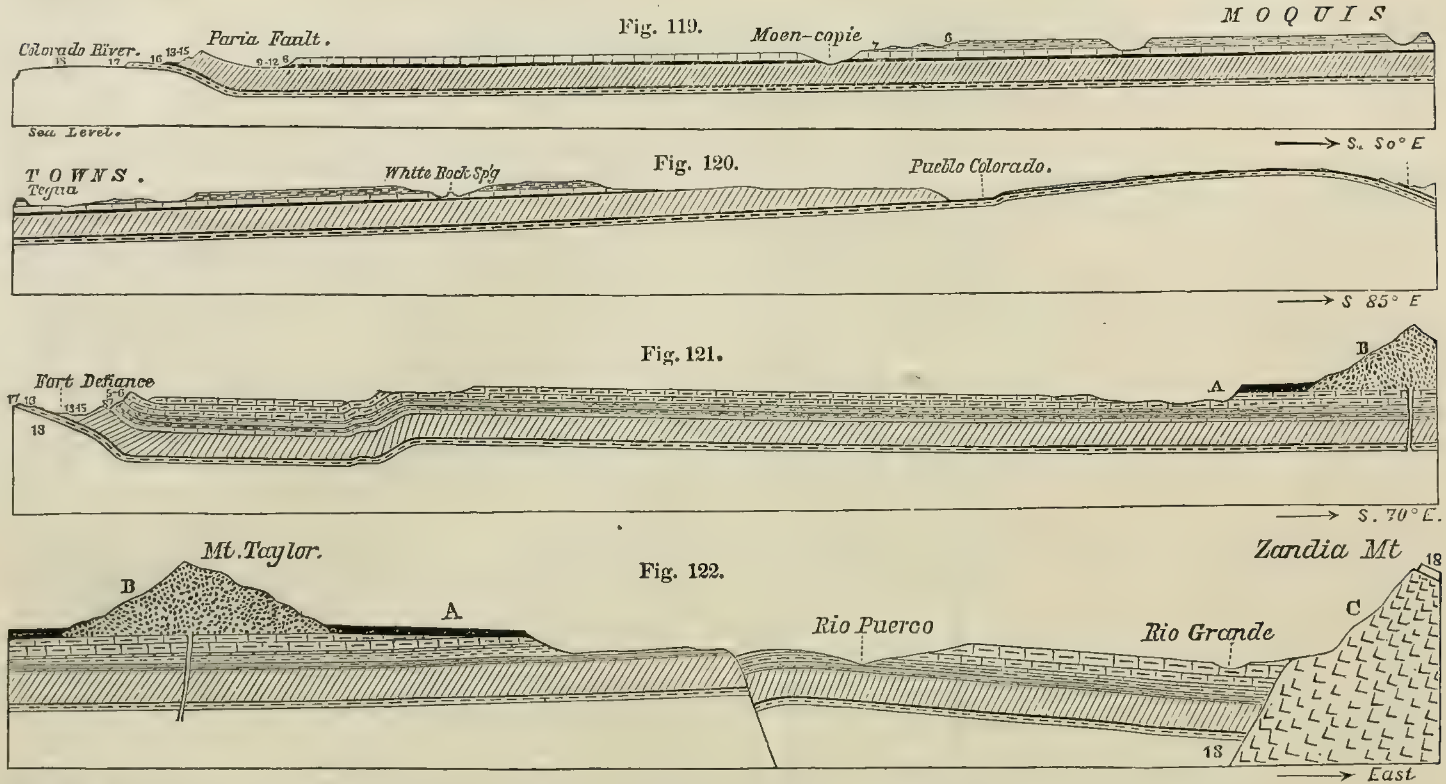


FIG. 118.—Section from near Zuni, to east side of Zuni Mountains, near Fort Wingate. *a*, Cretaceous; *b*, Trias; *c*, Carboniferous.

FIGS. 119 to 122.—Continuous section from Colorado River to Rio Grande. The strata are numbered, corresponding to the analytical section in the text, 5 to 8, Cretaceous; 13 to 17, Trias; 18, Carboniferous; *A*, Basalt; *B*, Trachyte; *C*, Granite. Scale: horizontal, 1 inch = 10 miles; vertical, 1 inch = 10.000 feet.

Figs. 119, 120, 121, and 122 represent a continuous section running from the Colorado River, a little below the mouth of the Paria, southeast to the eastern of the Moquis towns, then nearly due east past Fort Defiance, and then southeast again *via* Mount Taylor to the Rio Grande and Zandia Mountains.

SECTION II.

FOLDS AND FAULTS.

The Colorado Plateau region is traversed by folds and faults having a general north and south trend. Much the greater number of these belong to the class called monoclinal or uniclinal folds, which, however, generally are replaced by plain faults throughout parts of their courses. Comparatively few typical anticlinals are met with. The most important of these in the region examined is the Fort Defiance anticlinal, which has a trend near Fort Defiance, where crossed, a little east of north. I have no knowledge of its northern and southern limits. From the section of it in Figs. 120 and 121, it will be seen that there is a slight monoclinal on either side, showing a combination of the two classes, which, as will presently be seen, is not an uncommon occurrence.

The Zuni Mountains, which have already been described, may perhaps be considered more as anticlinal than monoclinal in character, and, in the sequel, I shall have occasion to refer to two or three typical anticlinals which were traced some distance in Utah.

The valley of the Rio Grande marks the line of a fault having a downthrow of many thousand feet to the west. In Fig. 122 is shown a section of this as it is seen at the Zandia Mountains. In the same figure is a section of a fault west of the Rio Puerco, where there is a drop of about 1,000 feet to the east. This fault was crossed at only one place, but its course could be traced to the north and south for several miles. The trend is north-northwest.

The next great fault to the westward is the one forming the southwestern and western boundary of the Zuni Mountains, of which several sections have already been given, (see Figs 115 and 116.) This, at the farthest point north at which it was seen, was bearing about due north, and was diminishing rapidly in force.

So far as I am aware, this is a true monoclinal fold throughout its entire course; but it combines with another monoclinal fold in such a manner as to form an anticlinal or elongated quaquaversal throughout the length of the Zuni range.

A section about eight miles north of Stinking Spring, which is at the north end of Zuni range, is shown in Fig. 121. Fig. 123 is a section only

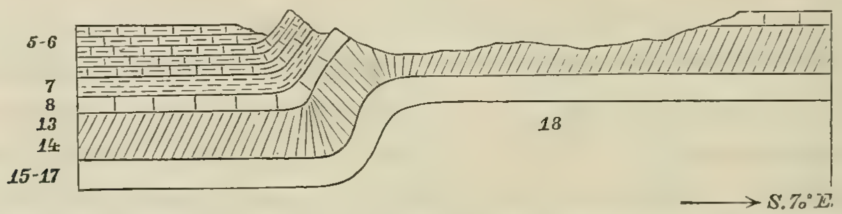


FIG. 123.—Section of fold half a mile north of Stinking Spring, New Mexico; 5–8, Cretaceous; Trias; 13–17,18, Carboniferous.

about half a mile north of the spring, where the erosion is much greater, and its monoclinal character not quite so apparent.

The total displacement at this point is about 2,000 feet. This, as before stated, decreases in amount toward the north; but twenty or twenty-five miles to the south-southeast, near Nutria, the maximum is reached, and the drop at that point must be at least 5,000 feet. About two miles west of this the section crosses another small fold, with the downthrow of only 200 or 300 feet in the same direction.

Going southward from Zuni, by different routes, Mr. Gilbert and I both passed from horizontal beds of Lower Trias a few miles over an open country to beds of Cretaceous Age.

The circumstances were such that we were compelled to assume the existence of a fault between the two exposures, but there was no evidence then of its direction. Thirty miles to the east, however, I saw, afterward, a fault trending westward, and with a throw to the south, and it is probable that the two are identical. If this is so, the line of the fault is followed very closely by a lava stream, which has run from the volcanic region lying to the east to Deer Spring.

West of the Fort Defiance anticlinal the country for a long distance is remarkably free from disturbances of any kind, as may be seen from the section across the Colorado, (Figs. 119 and 120,) but just before reaching the river it crosses a monoclinal fold, (the Paria fold,) with an easterly downthrow. This fold crosses the Colorado at the mouth of the Paria, and runs in a north-northwest direction to the Last Bluff, keeping a little to the west of that point, and extending, apparently, but little farther in that direction. When last seen, the throw was only a few hundred feet, and was diminishing rapidly. A section south of the Last Bluff is shown in Fig. 109. The same fold keeps a south-southeast direction from the Colorado River to the Little Colorado, and follows that stream for a long distance. A partial section of it near Big Dry Fork is given by Dr. Newberry in Ives's Report, page 77. This point is over two hundred miles from the Last Bluff, but how much farther the fold may continue, I know not. Mr. Marvine crossed it fifteen or twenty miles farther to the southeast in 1871, and gives a section as seen by him in Plate IV of this volume. This section, like the one given by Dr. Newberry, would show the true character of the fold better if continued a little farther. This is a more recent fold than the Eastern Kaibab, as is shown by its crossing and displacing the latter on the East Fork of the Paria.

The Eastern Kaibab fault follows the eastern side of the Kaibab Plateau, and northward from Paria bears a little to the east. It was last seen a few miles to the east of the Last Bluff, and evidently does not extend much farther in that direction. Its drop at Paria is not far from 3,500 feet.

About twenty miles to the west of Paria there is a small fault with the drop to the west. This is probably the continuation of the western Kaibab fault.

Between the Last Bluff and the Henry Mountains the rocks are folded and thrown into waves on a greater scale than elsewhere seen. This excessive corrugation is especially shown in Figs. 129 and 130. East of Thousand Lake Mountain, which is a lava capped mesa butte, is a monoclinal fold, which shows as a fault in some parts of its course, with the drop to the west. And two are so near each other, that they might, taken together, be called an anticlinal with a flattened top. A section of this mountain is

FIG. 124.

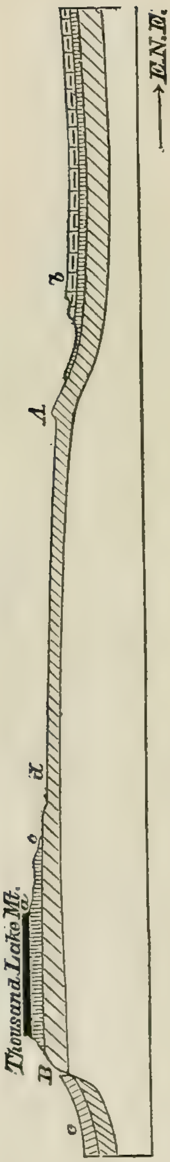
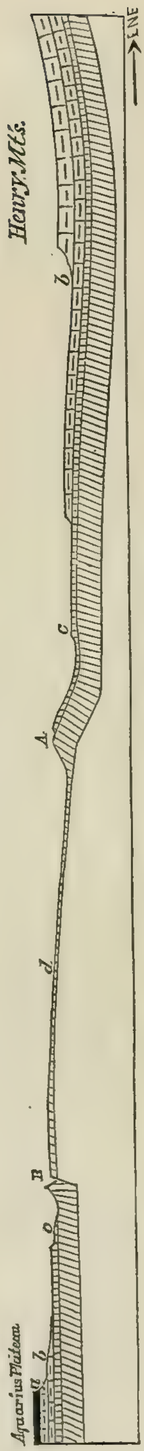
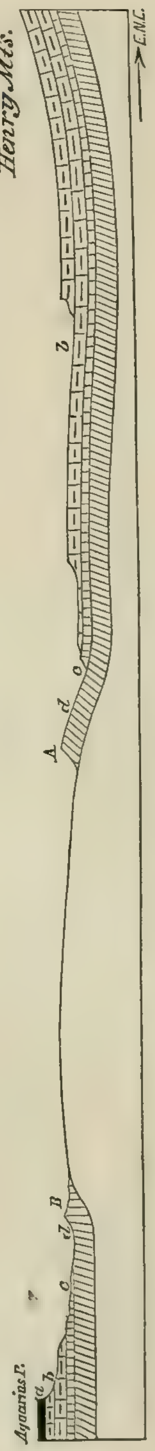


FIG. 125.



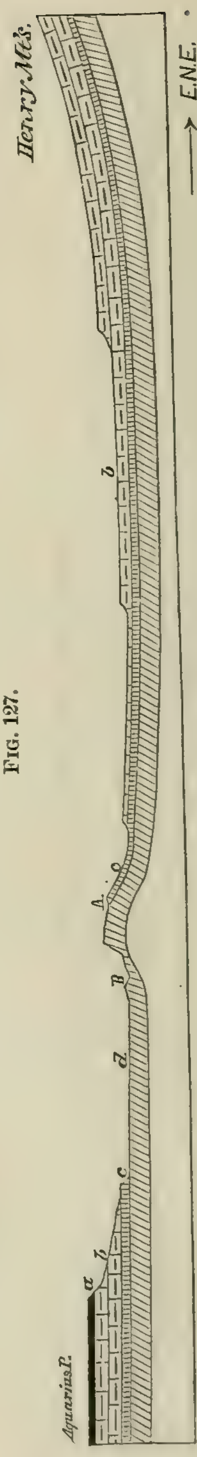
Scale: 1 inch = 225,000 feet, (approximate.)

FIG. 126.



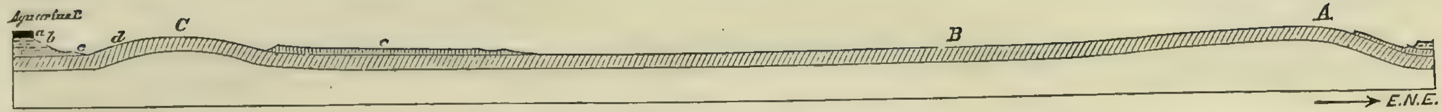
Scale: 1 inch = 225,000 feet, (approximate.)

FIG. 127.



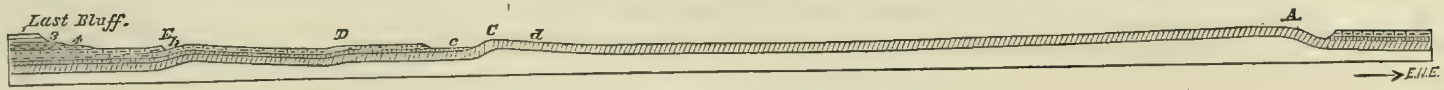
Scale: 1 inch = 240,000 feet, (approximate.)

FIG. 128.



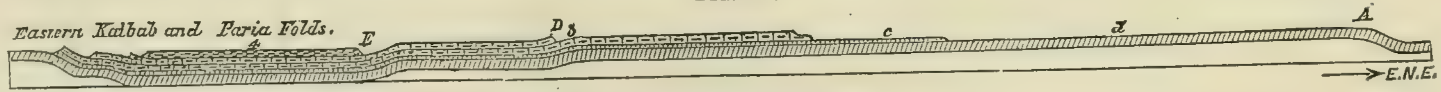
Scale: 1 inch = 300,000 feet, (approximate.)

FIG. 129.



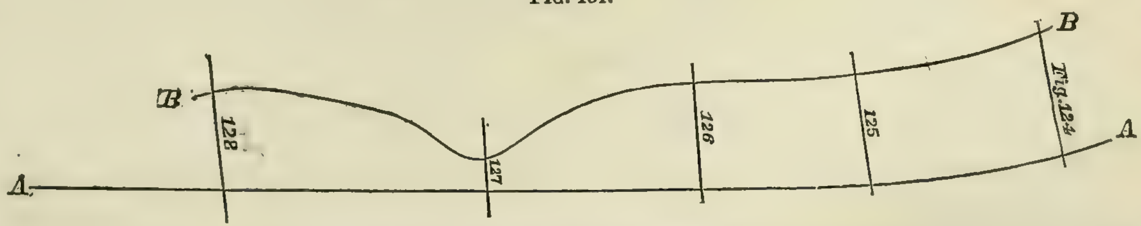
Scale: 1 inch = 475,000 feet, (approximate.)

FIG. 130.



Scale: 1 inch = 400,000 feet, (approximate.)

FIG. 131.



FIGS. 124–130 are sections exhibiting the dislocation of the strata chiefly in the southern end of Castle Valley, east of the Last Bluff and Aquarius Plateau, and are arranged in order from north to south. Fig. 131 is a diagram showing the courses of the folds A and B, and the points at which the different sections intersect them. A, B, C, D, E: Folds, *a*, Trachyte; *b*, Cretaceous; *c*, Jurassic; *d*, Trias 1–3, Tertiary limestone; 4, Tertiary shales.

represented in Fig. 124, and the eastern and western folds are designated by the letters A and B in this and the following sections, (Figs. 124 to 130, inclusive.)

The eastern fold, A, trends south-southeast, keeping an approximately straight course for one hundred miles to the Colorado River and Navajo Mountain. The other, as may be seen from the sections, is very irregular. The lines A A and B B, in Fig. 131, represent the courses of the two folds, and illustrate this point still better. The points at which the different sections cross the folds is shown in the same figure.

The fold B approaches the fold A in one place so closely, that the two form a perfect anticlinal, (see Fig. 127.) It spreads out rapidly again to the southward, and soon afterward flattens out and disappears.

To the west of this is a typical anticlical, of which C, in Fig. 128, shows a section; as it is seen at the southern end of the Aquarius Plateau. It trends to the southeast, but does not run far before the eastern side begins to flatten out, as seen in Fig. 129, and finally, as it nears the fold A, the whole anticlinal gradually spreads out and disappears, leaving a gentle slope to the west of 3° or 4°, as shown in Fig. 130.

What becomes of this fold to the northward is not certainly known, but from the facts obtained I am strongly led to suspect that it continues in a northwest direction to Grass Valley, and then turning to the northward, probably as a plain fault, forms the cliffs on the east side of that valley. From this point its course is more plainly marked, as it keeps on past Moo-se-me-ah Peak, up the eastern side of Sam Pitch Valley, and across Soldiers' and North Forks, where it becomes anticlinal in caharcter, and greatly diminished in force. Beyond this point it has not been traced. The appearance of this fold along the lower end of Sam Pitch Valley, and south as far as Salina, is very peculiar. Fig. 132 represents a section of it as it appears at Moo-se-me-ah Peak. Instead of a plain fault or monoclinal fold, is seen a curious compromise of the two.

Going west from the fold C, near the mouth of Birch Creek to the Last Bluff, two other folds are crossed. The first of these, D, Fig. 129, is a monoclinal, with a throw of a few hundred feet only to the west. From this fold the beds rise at an angle of from 2° to 4° to the west-southwest, until the

GRAND CAÑON.

COLORADO RIVER

point E is reached, when they dip suddenly to the west again, at an angle as high in some places as 30°. After dropping about 1,500 feet, they assume a nearly horizontal position, and apparently continue to the Last Bluff with no further disturbance. These folds are both monoclinals, although from the summit of each the beds dip, at a low angle to the east. The dip, as we have seen in the case of the fold E, is 2° to 4°, and some might prefer to call it an anticlinal, with the angle of dip on one-side 25° or 30°, while that of the other is only from 2° to 4°.

This fold was crossed six miles to the north-northwest, where the throw was considerably less, and the highest angle of dip about 13°.

To the southward neither of these folds were crossed, but were traced for twenty or thirty miles; and another approximate section of them is given in Fig. 130.

The next folds to the westward are the Paria and Eastern Kaibab, sections of which are given in the same figure, just a little south of their point of intersection, where the combined throw of the two folds is about 4,000 feet.

It will be observed that 1,000, or more, feet of Lower Tertiary rocks are preserved in the shelter of the synclinal between these two folds, and those to the eastward, D and E.

To the east of the fold A, and lying between it and the Henry Mountains, there is another deep, broad synclinal, as shown in Figs. 125, 126, and 127.

From a point a few miles north of Thousand Lake Mountain, a large anticlinal was seen bearing off to the north-northeast. This could be traced in the distance for fifty miles, without showing any diminution in force. What becomes of this fold and the folds A and B when they meet to the northwest of Thousand Lake Mountain is not known. A section about thirty-five miles north-northeast of this point is given in Fig. 132.

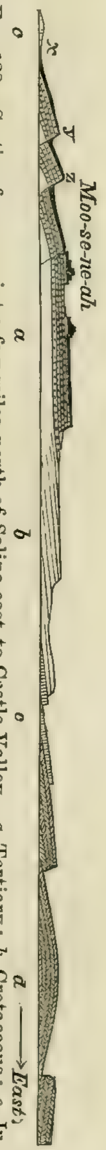


Fig. 132.—Section from a point a few miles north of Salina east to Castle Valley. a, Tertiary; b, Cretaceous; c, Jurassic; d, Triassic.

The occurrence of the Jurassic along the eastern side of the lower ends of Sam Pitch and Sevier Valleys, as shown in this figure, is a curious phenomenon.

The only explanation to suggest is, that at the point x there has been a drop, similar to those at *y* and *z*, deep enough to expose the Jurassic beds, which seem never to have been covered very deeply at this point, as the Cretaceous and Lower Tertiary are apparently absent at this locality. A little north of Salina we find the upper beds of the Tertiary series lying outside and apparently immediately above the Jurassic. Fig. 133 is an approximate section from this point to Moo-see-ne-ah Peak.

Fig. 133.—Section from near Salina, Utah, to Mos-se-ne-ah Peak. *a*, Tetiary limestone; *c*, Jurassic shales.

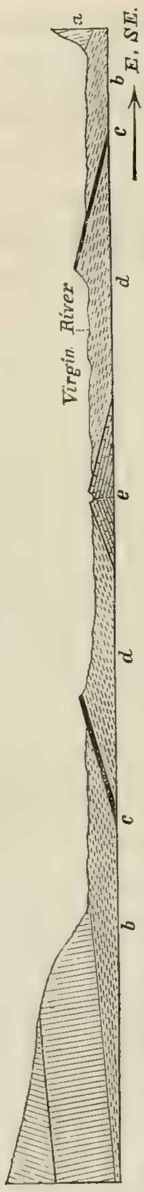


Fig. 134.—Section of anticlinal near Washington, Utah: *a*, Trias, (Nor. 13, 14;) *b*, Trias, (No. 15; *c*, Trias, (No. 16;) Trias, (No. 17;) *e*, Carboniferous.

The Jurassic is much corrugated, and probably existed as islands or high hills during the deposition of the Cretaceous and Lower Tertiary beds.

The Salt Mountains, south of Salina, were not visited, but enough was seen to show that they are formed of the same Jurassic rocks, which probably have not been covered by the Cretaceous or Tertiary.

Southward from Glencove, past Monroe, and all the way up the east side of the Sevier Valley is a fault with the throw to the west. This has been traced nearly to the Colorado River. To the northward it has been traced but a short distance beyond Glencove, and it is possible that it soon disappears, as the amount of drop was seen to diminish rapidly from a point a few miles north of Monroe.

West of the Sevier fault is another, with the downthrow likewise to the west. This runs along the western edge of Pahvant, Beaver, and Parowan ranges, past Kanara and Belleview, to Toquerville. A section of this fault north of Toquerville is shown in Figs. 110, 111, and 112. Fig. 110 also shows a section of an anticlinal which was crossed at only this one point, and of which nothing more is known. Another small anticlinal, having a north-northeast trend, was crossed on the Rio Virgen, a few miles north of Washington. Fig. 134 is a section at this point. The little anticlinal showing in Figs. 112, 113, and 114 is probably the northern extremity of this same fold. Its course to the southward beyond Washington is not known, but a little below this point an anticlinal was seen by Mr. Thompson, bearing to the southeast, and it may be the same fold, with a change in the trend.

A few other folds and faults were met with, but they are either too small in amount, or too little is known in regard to them to deserve mention in this connection.

SECTION III.

VOLCANIC ROCKS.

The distribution of the volcanic rocks will be shown on the geological maps, and I shall attempt to add but little to the information there given.

Thirty-five or forty miles southwest of Mount Taylor, in New Mexico, is the center of an ancient volcanic region, from which large streams of lava have been sent out in all directions. One of these runs nearly due west to Deer Spring, a distance of fully fifty miles.

Another of nearly equal length runs northwest to Pescado Spring, and then, according to Mr. Marcou, west to Zuni. And still another, somewhat more recent than the others, runs north-northeast, past the south end of the Zuni Mountains, to the Rio San José, and down that stream for six or eight miles. This latter is the one described by Dr. Newberry in Ives's Report, page 97.

The valley between Inscription Rock and the Zuni Mountains has been flooded from the same source.

This region is covered with great numbers of ancient cinder cones. The largest of the group was climbed, and found to be 800 feet high. Its form is still that of a nearly perfect crater, although so ancient that pine trees 12 and 14 inches in diameter are growing on it. At the north end of the group, near the Zuni Mountains, are some craters of much more recent formation.

Eight or ten miles south of the large crater are two prominent buttes, which were evidently formed by massive basaltic eruptions. Ten miles to the south of these a dike was crossed, 10 to 15 feet thick, with a north and south trend, and this has afforded so great a protection to the adjoining sandstone, that a ridge 200 to 300 feet high has survived the denudation of the surrounding country.

The large mesa southeast of Zuni Mountains, Mesa de Acoma, is capped with 100 or 200 feet of dark volcanic rock, probably basalt, the same as the Mount Taylor mesa to the north of it. This latter mesa is capped with from 100 to 400 feet of dark, massive olivine basalt, which extends south and southwest of Mount Taylor eight to ten miles, and to the east and northeast twelve to fifteen miles. This rests, non-conformably, not only upon the Cretaceous beds of the mesa, but upon the trachyte of Mount Taylor proper, as shown in Fig. 122. The source of the basalt was not discovered, but from the fact that its greatest thickness is near Mount Taylor, from which it thins out in all directions, it seems probable that it found exit somewhere near the base of that mountain.

The rock forming the main mountain we have called trachyte, but it is a somewhat peculiar lava, holding an intermediate position between trachyte and basalt, both lithologically and geologically. It is usually of a dark or reddish-brown color, and greatly resembles basalt in its habit, but in its texture and mineral composition resembles trachyte much more closely than basalt or rhyolite, and we have used the term trachyte when speaking of it.

Two or three miles north of Covero is a basaltic butte, and four or five miles north of Moquino are two others. Six or eight miles farther to the northeast a line of similar buttes commences, and bears in a north-northeast direction to the Cabezon, which forms one of the line. These buttes are all massive basaltic eruptions. The fact that they are in line indicates a continuous dike, and the buttes mark points of eruption along its course.

In this connection I would add, that a dike 10 feet in width was seen directly in the line of these buttes, about two miles southwest of Moquino, and it is perhaps also worthy of note that this same line, continued to the southwest, would intersect the volcanic region south of Zuni Mountains.

Forty miles southwest of this latter region are a number of cinder cones, and basaltic lava covers nearly all the country between them and the Escadillo Mountain. The only other volcanic rocks encountered by us in the Plateau region of New Mexico are some sheets of basalt, along the valley of the Rio Grande, which have been described by Mr. Marcou, (Geology of North America, page 22,) and some basaltic buttes, near Fort Defiance, mentioned by Dr. Newberry, on page 92 of Ives's Report.

In Arizona, at Moencopie, we saw a dike with a north and south trend, and fifteen miles to the northward a cinder cone, and to the westward two others. Between this point and the volcanic peak of San Francisco Mountain great numbers of ancient craters were seen.

Attention has already been called to the fact that the high Plateau region of Utah, south of Salina Cañon, is almost entirely covered with volcanic rock. This is in the main trachytic, and lies conformable to the sedimentary beds below, over which it was spread before the disturbances referred to in the last section. The thickness reached in some places, on what is called the Sevier range, cannot be less than 1,500 feet, while on the Thousand Lake Mountain and Aquarius Plateau it is from 100 to 300 or 400 feet, and is the same variety of trachyte as that which occurs at Mount Taylor, in New Mexico.

Since these sheets of trachyte were poured out, and the folding had been carried to considerable extent, or completed, other eruptions have occurred, one of which, a massive eruption of basalt, has built a peak north of Fish Lake, and just east of Summit Valley, 11,575 feet high.

There are a number of comparatively recent cinder cones south and east of Toquerville, and on the southern slope of Pine Valley Mountain. Another group of craters was seen by Mr. Gilbert on the plateau north of Toquerville, and this extends nearly as far north as Parowan. But to the north and east of this point the entire absence of craters is very noticeable.

SECTION IV.

GLACIAL PHENOMENA.

The most important and clearly-marked evidence of glacial action met with is at Fish Lake, in Central Utah. This lake has an altitude above sea-level of 8,830 feet, and is located in a narrow north-and-south valley about one mile in width. The volcanic ridge to the east rises 500 to 800 feet above the lake, while the volcanic-capped mesa on the west has an elevation fully double this. And the snow which lingers on its summit late into the summer is the source of the water-supply for the lake.

The lake-basin is caused by the terminal moraine of a former glacier, which stretches across the valley, making a dam 30 or 40 feet high. Another moraine of equal or greater altitude stretches across the valley at the south end of the lake, making another basin, where, however, the water accumulating is only sufficient to form a marsh. Between these two moraines, and below the first, are several remnants of other moraines, which doubtless also once stretched from ridge to ridge.

Some volcanic bowlders were seen, bearing upon their surfaces undoubted glacial scratches.

Running along the shore of the broader, shallower portion of the lake, on the southwest, is a ridge formed of heterogeneous materials, and having a uniform height of 3 to 4 feet, (see Fig. 135.) This is believed also to be the work of ice. During the cold winters at this high elevation, the shallower portions of the lake, at least, must become one solid mass of ice, which, under the influence of heat and cold, expands, pushing the loose material before it, up the easy-sloping shore, so as to form the ridge as described.

FIG. 135.—Section showing raised beach around Fish Lake, Utah.

The evidences of glacial action, on a small scale, are to be seen in many places in this high plateau region. Moraines and remnants of moraines were seen in Summit Valley, north of Fish Lake, and many of the lakelets on Thousand Lake Mountain are glacial.

Twelve or fifteen miles to the northward, on the same mesa ridge, another lakelet of the same character was seen, and the high valley to the west contains some very well marked terminal and lateral moraines.

On the high plateau ridge west of Grass Valley, called the Sevier range, other glacial lakelets were seen.

In many cases the work has been performed on so small a scale that it is doubtful whether it should be referred to a glacier or a snow-bank, and if a distinction is made, much of it must be credited to the latter.

PART IV.

REPORT

ON

THE GEOLOGY OF A PORTION OF COLORADO.

EXAMINED IN

1873.

BY

PROF. JOHN J. STEVENSON.

COMPRISING

UNIVERSITY, NEW YORK, *June* 8, 1874.

SIR: I have the honor to submit herewith a report upon observations made in Colorado during the season of 1873.

As the main object of the exploration was to obtain material for a topographical atlas, and the area was large, it was found necessary to move with such rapidity that detailed work in geology could not be performed. Under the circumstances the duties of the geologist were the more arduous, as, unlike the mountains of Utah and Nevada, the region examined during 1873 is for the most part densely wooded on the slopes to an altitude of from 10,000 to 12,000 feet. At the same time I trust that the accompanying report will be found, as far as it goes, an acceptable contribution toward the elucidation of the general structure of the region.

I am under obligation to Mr. J. J. Young, the excellent topographer of the party, for many favors. The illustrations are from sketches made by him in the field, and afterward drawn on the wood by him. To Lieutenant Marshall, who commanded the party, I am indebted because of his constant endeavor to aid me.

Very respectfully, your obedient servant,

JNO. J. STEVENSON.

Lieut. G. M. WHEELER,

Corps of Engineers, in Charge.

CHAPTER X.

GENERAL PHYSICAL FEATURES.

SECTION I.—TOPOGRAPHY.
SECTION II.—CLIMATE AND AGRICULTURAL RESOURCES.

SECTION I.

TOPOGRAPHY.

The area examined during the season of 1873 is embraced between the meridians of 105° and 107° west from Greenwich, and between north latitude 39° 45′ and the southern boundary of Colorado, giving a length of one hundred and ninety miles, and a breadth of about one hundred and six. Besides this rectangle there was explored a smaller one at the west, reaching almost to west longitude 108°, and extending from the southern boundary of Colorado, northward to the Rio Grande. The number of square miles included in the whole area is not far from twenty-two thousand, of which barely three thousand were not visited or examined to some extent by the main division of the party.

Excepting only a narrow strip, reaching ten to fifteen miles west from the one hundred and fifth meridian, and the plains known as South Park and San Luis Valley, the whole region covered by our observations is mountainous, exhibiting, perhaps, the grandest development of the Rocky Mountains to be found within the United States. The ranges are more massive, more sharply defined, and the average elevation is much greater than in any other portion of the chain.

The district thus brought under our notice includes portions of five

NOTE.—The altitudes given were obtained by the field parties under the charge of Lieutenant Marshall, Corps of Engineers, from barometric observations computed at the office of the survey in Washington, D. C.

great drainage areas, whose chief rivers, with one exception, find their source within it. These are the *South Platte* area, the *Arkansas* area, the *Rio Grande* area, the *San Juan* area, and the area of the *Grand* and *Gunnison.* The first three are east from the great water-shed, and are drained into the Gulf of Mexico, while the other two are merely portions of the widely extended area of the Colorado River, which empties finally into the Gulf of California.

The area of the South Platte occupies the northeastern part of our district, embracing South Park, Clear Creek County, and the plains east from the mountains as far as, say, fifty miles south from Denver. The Arkansas area is irregular in outline. Its upper portion, which is exceedingly narrow, lies directly west from South Park; the next division lies directly south from the Park, and extends for more than fifty miles in a north and south line; the third division lies east from the mountains, and reaches southward to beyond the southern boundary of Colorado. Of the Great Rio Grande area but little lies within our borders. From the head of the river, a narrow cañon, opening here and there into insignificant parks, extends for about eighty miles, in a rudely east and west direction, like an enormous tongue separating the San Juan from the Grand and Gunnison. At the mouth of the cañon we have the extensive park of San Luis Valley, embracing the counties of Costilla and Saguache, with a portion of Conejos, and reaching far beyond the Colorado border into New Mexico. This area lies west and south from that of the Arkansas. Still less of the San Juan area comes under our notice, as the greater portion of it is in New Mexico, or in Colorado, beyond our extreme western limit. It occupies the southwest corner of our district, embracing the most of Conejos County. The Grand and Gunnison area is of enormous extent, embracing all the northwestern portion of Colorado, but not more than nine thousand square miles fall within our limits. To the geologist this region will prove most interesting, owing to the strangely complicated stratification. A thorough study of this area will afford the solution of many perplexing problems in dynamical geology.

THE DIVIDES.—*The Main Divide.*—Of the numerous divides, the great water-shed between the Atlantic and Pacific first claims our attention.

Beginning at our northern line, about forty-four miles west from Denver, its trend is south and west of southwest to the head of Tennessee Creek, the West Fork of the Arkansas describing a curve, whose convexity is toward the southeast. From the head of Tennessee Creek, the course is east of south to the head of the South Arkansas River, a distance of sixty-nine miles. Thence the direction is rudely south of southwest to the cañon of the Rio Grande, about thirty miles above its mouth. There it bends abruptly westward to the head of that river, about fifty miles, to 107° 30′ west longitude, where it turns sharply upon itself and follows an easterly course for fifty miles. These two divisions form the walls of the great cañon of the Rio Grande. At the head of the South Fork of the Rio Grande it takes a southerly direction, which it maintains until it crosses the line into New Mexico, after which the course is changed to south of southwest. The divide then is made up of six divisions, well marked by variation in the trend. As a whole, this main divide, though not coinciding with the geological arrangement of the axes, is the most imposing portion of our mountain series. Its greatest development is seen in the first two divisions and in the fourth and fifth, the third and sixth being of comparative insignificance, owing, however, only to the gigantic dimensions of the others.

Near the northern extremity of the first division, as included in our district, are seen the Twin Peaks of Gray and Torrey, both reaching to a height of more than 14,000 feet, and distinguishable for many miles. Southward from these are numerous peaks without fixed names, whose synonymy would fill a page. Near the extreme eastern projection of this curved division is a massive group, in the vicinity of Evans and Rosalia Peaks, which are among the highest yet measured. These rise nearly 3,000 feet above the timber-line, and retain throughout the year immense masses of snow. Following the ridge westward, we reach Gilpin's Pillars. These twin mountains, whose altitude is about 13,500 feet, are enormous knife-edges, with smoothly planed abrupt slopes on the west, but jagged and torn by huge chasms on the east. Viewed from the south, their resemblance to each other is not striking, but their northern presentation is such that, seen separately, it would be hard to determine which one is under observation. Farther westward is Mount Morton, locally known as "Silverheels," similar in outline to those just mentioned, and having an elongate crest running rudely northeast and southwest. Its eastern slope is scarred by an immense excavation, which always contains more or less snow. This peak has an altitude of 14,044 feet. A few miles farther west is Mount Lincoln, with its mate, Mount Bross, together an enormous, almost characterless mass, reaching to 14,300 feet above the sea. It is almost wholly separated from the main divide by immense gorges, in which rise the South Platte, Arkansas, and Blue Rivers. The main divide here is a narrow precipitous wall, so narrow, indeed, that, standing on its crest, one might with equal ease throw a stone into the waters of the Pacific or into those of the Atlantic slope.

The passes of this division are by no means devoid of interest. At the extreme north is Berthoud's Pass, leading from Clear Creek into Middle Park; a pass of comparatively easy grade, and the main line of travel over the range to the park. It has been supposed by many that a narrow-gauge railway might be constructed by this route, but the grade is too sharp to admit of it without extraordinary outlay. The "Argentine," or "Grizzly Bear," Pass leads from Georgetown to the Peru Fork of Snake River, and crosses the range in a saddle between Gray's Peak and the McClellan Mountain. The approaches are very difficult on each side, and the summit, which is at an altitude of 13,283 feet, is exceedingly narrow. This pass is choked with snow for from five to seven months each year, and is little used, except for passage of pack animals. A wagon-road has been constructed, but, notwithstanding its numerous windings, is so steep as to be almost unavailable. A similar pass exists near Montezuma, at the head of the other fork of Snake River.

The old Georgia, or Jefferson Pass, from Buffalo Flats, on Swan River, a tributary of the Blue, to the town of Jefferson, and thence to South Park, leads across the divide east from the easterly one of Gilpin's Pillars. Until within half a mile of the summit, the approach from the Blue River side is very gradual, but beyond that it is abrupt. On the other side, the grade is equally abrupt near the summit, but diminishes rapidly below, and near the opening into the park is comparatively slight. The altitude of the summit is 11,776 feet.

It is a narrow trough between high peaks, and is apt to choke with snow, so that it may remain closed for seven or eight months in the year. Though formerly used as a wagon-road, it has been little traveled since the town of Jefferson was deserted. Adjoining it is the Frenchman's or French Gulch Pass, reaching over 12,000 feet. Like the last, it remains closed until late in the summer, and is no longer used.

The Hamilton Pass, between Gilpin's Pillars and Mount Morton, leads from Hamilton, in South Park, to Breckenridge, on the Blue, and is the regular road for stage-coaches. Though nearly as high as the Georgia Pass, it is much more available, as the grade throughout is quite easy, and the broad, open summit permits early melting of the snow. Indeed, there is no reason why this pass should not be kept open during the whole year without serious difficulty. As matters now stand, it is the best in the region.

The Hoosier Pass, crossing from Breckenridge to Montgomery, on the headwaters of the South Platte, is, however, the one most likely to prove available for all purposes, though the present direction of the wagon-road is contradictory to any such conclusion. From Breckenridge, the road follows the Blue to near its source, when, turning off somewhat sharply, it ascends the mountain with an unnecessarily abrupt grade. The summit, which has an altitude of 11,600 feet, lies between Mounts Lincoln and Quandary on the one side and Mount Morton on the other, three of the grandest peaks in the whole Rocky Mountain chain. On the Platte side the road descends with painful grade to the now almost deserted village of Montgomery. This direction was chosen from necessity, as, when the road was constructed, Montgomery was an important center of mining operations. A much better, though somewhat longer, route would be to carry the road along the easterly side of the cañon from the summit to Fairplay, about eleven miles away. The grade then would be little more than 100 feet per mile. An equally favorable grade can be obtained on the Blue River side, at comparatively small expense. Under such conditions, the pass would be available for railroad purposes.

The Arkansas Pass leads from the head of the Arkansas to the head of Ten-Mile Creek, a tributary of the Blue. On the southerly side the approach is very gradual, and a wagon-road could be constructed without difficulty and at little expense. The summit has an elevation of only 11,500 feet, and, if necessary, could be kept open during the winter. It is doubtful whether the descent on the opposite side can be utilized, as the drainage is exceedingly bad, inducing a marsh which stretches entirely across the summit and extends for miles down the stream, involving the hill-sides, and rendering passage hard even for pack-animals.

The second section of the divide, beginning at the head of Tennessee Creek, separates the waters of the Grand and Gunnison Rivers from those of the Arkansas. It is by far the finest portion of the divide. Standing on the west side of the Arkansas River for sixty miles, an unbroken wall of magnificent mountains, deeply cut, with harsh, rugged outlines, and reaching far above timber-line, its naked peaks fully equal one's ideal of the Rocky Mountains. It shows no airy pinnacles, no slender needles ornamenting its crest; everywhere it is massive; imposing because of bulk, and not because of eccentric outline. The average height of the whole division falls little below 13,000 feet, and few of the peaks are less than 13,500, while many reach even to 14,000. At the head of Tennessee Creek is the Homestake group, 13,000 feet high, with a remarkable series of glacial cavities on the eastern slope, and a similar series scarcely less wonderful on the western side. South from this in close succession are Massive Mountain, Mounts Elbert, Harvard, Yale, Pisgah, and Usher, and Hunt's Peak, with many other peaks of almost equal importance, but still unnamed. The only depression falling below 12,000 feet, and extending for any considerable distance, is at Colorado Gulch, about ten miles south from the head of Tennessee Creek. No similar break occurs elsewhere in the whole division.

The passes are few, and, with the exception of that near the head of Tennessee Creek, are wholly unworthy of the name. The Tennessee Pass belongs, indeed, properly to the first division, but for the sake of convenience is described in connection with the second. It crosses the divide at the head of a small tributary of Tennessee, and leads to the Eagle River, a tributary of the Grand. It is low, barely 10,681 feet at the summit, where it is covered by a dense forest of pine and spruce. The approach from the Arkansas is exceedingly gradual, and the summit is broad and easily drained. On the Eagle the grade is somewhat sharper for a short distance, but can be overcome with little difficulty. The natural drainage on this side is more imperfect than on the other, and can be remedied only by careful working. The low elevation of this pass and the ease of its approaches have made it a favorite with railroad engineers. Its main drawback is, that the region of the Upper Arkansas, for fifteen miles below the pass, is completely closed by snow early in the winter, and so remains until late in spring.

Trails cross the divide at the heads of Lake, Cottonwood, and Chalk, as well as of several other creeks. These can hardly be called passes. They owe their origin to mountain sheep, and have been used to some extent by the Indians. At the three localities given above, one can cross without much risk to life and limbs, and, this being possible at few points in this division, they are regarded by prospectors and explorers as quite feasible passes. The crossing at Lake Creek is reached with some difficulty through a bad morass on the Arkansas side, and is so abrupt near the summit that a pack-mule with a light load can climb it only by painful effort. On the opposite side it leads, with a grade almost impracticable for horse and rider, to a tributary of Taylor River, the chief fork of the Gunnison. The trail is so difficult and abrupt that to construct a wagon-road seems almost impossible. At the summit, which has an elevation of 12,237 feet, the divide is exceedingly narrow. The source of Lake Creek is a little pond, with, in August, an area of about fifty square yards, which is separated by a wall of rock, about 5 feet high and 20 feet wide, from a similar pond which is drained into Taylor River. It is quite probable that these ponds, greatly enlarged by the melting of the snows, communicate with each other during June by means of numerous fissures in the rocky wall which separates them. The so-called passes of Chalk and Cottonwood creeks are wholly undeserving of notice, being almost impracticable for foot-passengers. The summit of the Cottonwood trail is nearly 13,000 feet above the sea, and that at the head of Chalk Creek but little superior to it.

The third division consists of irregular, comparatively low mountains, seldom attaining an altitude of more than 12,000 feet. It separates the waters of the Gunnison from those of San Luis Lake or Swamp, which in a previous epoch was undoubtedly connected with the Rio Grande. This portion of the divide, as seen from the west, shows an evenness of crest, quite remarkable in the Rocky Mountains, and reminds one of the Appalachian ridges in the Alleghany division. The mountains may be crossed without much difficulty at many points, but the only pass employed is the Cochetopa, leading from a tributary of Saguache Creek to Pass Creek, which empties into the Gunnison River, through Cochetopa and Tomidgee Creeks. It is very low, having an altitude at the summit of little more than 10,000 feet, and is open throughout the year. The approaches are exceedingly gradual, there being abrupt grades in no part, and in this respect it is superior to any pass yet referred to. Except the Hoosier and Hamilton, it is the only pass with easy grade really available for a wagon-road, as it reaches into an extensive district of open country, practicable for wagons. Through this pass the Gunnison wagon-road was run in the year 1853.

The fourth division extends westward as the north wall of the Rio Grande Cañon, and as a divide is very narrow. Until near the head of the river the crest is quite regular, much torn by erosion, but easily accessible at very many localities from the north side. Its altitude is very great, there being at the head of Cochetopa and Lime Creeks a group of high peaks, among which a rounded knob with an elongate summit reaches to 13,700 feet, and others more peaked, farther west, reach 14,000 feet, while at the head of the Rio Grande, Middle Fork, there are several jagged peaks rising to an altitude of not less than 13,500 feet, and to the north and south some miles, groups reaching 14,000 feet. As by far the greater portion of this division lies within the Indian reservation, no passes other than trails exist. There is, however, a well-marked Indian trail leading from the agency across the divide to Antelope Park, on the Rio Grande, fifty miles above the city of Del Norte, situated at the mouth of the cañon. This is not difficult for pack-animals, and was formerly an important trail leading from the Gunnison River to the Rio los Pinos and the Pagosa Hot Spring in the San Juan area. At the head of the Rio Grande, Middle Fork, and at the end of this division, is the wagon-road pass now followed to the San Juan mining district. The summit has an altitude of 12,400 feet, rendering this one of the highest passes in the Rocky Mountains. Indeed, nothing but dire necessity leads to its use, for it is closed by snow from the beginning of November until late in June. From the Rio Grande it is reached by very difficult approaches, continuing for several miles; so difficult that, if one may judge from the numerous wrecks by the way, they are almost impracticable for wagons. On the western slope, leading to the Rio de las Animas, a tributary of the Rio San Juan, the condition is still worse, for the road descends more than 2,000 feet within one mile from the summit. Wagons are let down by ropes wound around the trees. Notwithstanding these serious drawbacks this pass will probably be used as long as the mines can be made attractive, as it is many miles more direct than any other route from Del Norte, the immediate point of supply.

The fifth division forms the southern wall of the Rio Grande Cañon, and in all respects resembles the last. It is exceedingly abrupt on the face toward the river, but has more gradual slopes southward. The only trails across it are a continuation of the one already mentioned as leading from the Indian agency to the Rio los Pinos and the Pagosa Springs, which being over a comparatively low pass, has been found available for pack-animals, and has been employed by trains going to Animas Park on the river of the same name, and another almost in disuse, leading from the Upper San Juan to the South Fork of the Rio Grande.

The fifth division merges into the sixth, which, beginning near the head of the so-called South Fork of the Rio Grande, follows an irregular south or west of south course to the line of New Mexico, where it turns to south of southwest. For a considerable distance, indeed to near the New Mexico line, it coincides with the mountains called the San Juan, and separates the waters of the San Juan River from those of the Rio Grande. Beyond that line it is lower, and separates the Rio Chama, a tributary of the Rio Grande, flowing on the west side of the San Juan Mountains, from the Rito Navajo, an important tributary of the Rio San Juan. At the north, it reaches to a great altitude, and is very rugged in its western slopes, but followed southward it diminishes in importance, breaking down into table-land as it crosses the line into New Mexico

Within the limits of Colorado there are no true passes over this portion of the divide. The mountains have been crossed from San Luis Valley to the headwaters of the Rio San Juan, but only once, the difficulty being so great as to prevent repetition of the attempt. In New Mexico, not far beyond the line, an excellent pass leads from the Rio Chama to the Laguna de los Caballos, and is known as Horse Lake Pass. It is very low, and the grade is almost imperceptible. It is crossed by the old wagon-road leading from Animas Park to Abiquiu, N. Mex., which coincides mainly with the homeward trail of Capt. J. N. Macomb, Corps of Topographical Engineers, in his expedition of 1859.

Divide between the Arkansas and the South Platte.—This divide is very narrow and in many portions quite intricate. Beginning near Mount Lincoln it follows a southerly course to the summit of Trout Creek Pass, a distance of twenty-eight miles, beyond which it is deflected eastward, and has a south of east, then east, trend until it passes beyond our eastern limit upon the plains.

The first division forms the western boundary of South Park. The general slope toward the park is quite regular, but the numerous streams flowing into the South Platte have their sources in huge cul-de-sacs near the central line of the divide. On the Arkansas side the slope is abrupt. At the north, the crest is quite irregular, with several sharp peaks rising far above timber-line. Mounts Mary and Sheridan are rude cones, with an altitude of 13,900 and 13,850 feet, respectively, while in the immediate vicinity are Goat Peak, 14,100 feet, and Fourth-of-July Mountain, 13,600 feet. Southward from these the crest is quite even until it reaches Buffalo Peak, its altitude being about 13,000 feet. Buffalo Peak consists of two great humps, 13,329 feet high, dome-shaped as seen from South Park, but having on the northern side an enormous gash, with walls almost vertical and rising 2,500 feet from the bottom. Though quite regular in outline, its ascent is much more difficult than that of many of the more rugged peaks on the other side of the Arkansas.

The passes over this division are quite numerous. Mosquito Pass ascends the ridge from a deserted village of that name and reaches the Arkansas water, near Oro City, at the head of California Gulch. It is of little value, and is seldom used, as its grades are difficult even for pack-animals lightly loaded. Its altitude at the summit is 13,308 feet. The ordinary route of communication between South Park and the Upper Arkansas is *via* the Stony Point or South Fork Pass, over which a good wagon-road has been constructed. From the east, it is reached by a comparatively easy grade along the South Fork of the Platte, through a romantic cañon, but the descent on the Arkansas side is very rapid. The summit, with an altitude of 12,108 feet, is closed ordinarily for several months, but that it can be kept open throughout the year was proved in the early days, when ten thousand men were engaged in gold-washing at California and Colorado gulches, on the Arkansas. The best pass is the Trout Creek Pass, which leads from the Arkansas up Trout Creek to its head, and descends thence into South Park, entering it not far from the Salt Works. The grade throughout is very easy, and the altitude at the summit is only 9,612 feet. It is an excellent wagon-road pass, and may yet be utilized for railroad purposes.

The second division begins a few miles south from Trout Creek Pass and extends to the main easterly range of the Rocky Mountains. It is the southern boundary of South Park, and so irregular in direction as to be defined only with much difficulty. It consists of low, rounded or rudely conical hills, seldom reaching to timber-line, yet ordinarily bare of trees, with numerous little areas of undulating surface called parks. Through these, the tributaries of the Platte and Arkansas wind about in the most perplexing manner. No peak in this portion of the divide attains considerable height, though two of them are very conspicuous, owing to the low altitude of their surroundings. Basalt Peak, between Thirty-one-Mile Creek, Buffalo Slough, and Badger Creek, is a curiously eroded hill, a fragment of the great sheet of eruptive rock formerly covering the entire region. In shape, it is an inclined plane, sloping westward, but with precipitous sides toward other points. It is over 11,000 feet high, and is a topographical station of much value. Thirty-nine-Mile Mountain, at the head of Currant Creek, a tributary of the Arkansas, is a cumbrous mass of trachytes and volcanic breccias, whose altitude was not determined.

Across this divide is a wagon-road leading from the South Platte by way of Buffalo Slough to the head of Currant Creek and thence to the Arkansas River. The pass is very low and is open during the greater portion of the year. It is, however, by no means a satisfactory one, as the structure of the country renders swamps a common feature, while the absolute sameness of the scenery for miles would make it difficult to follow the road, were there merely a few inches of snow.

From Thirty-nine-Mile Mountain eastward the divide is exceedingly complicated, taking in the line across the front range of the Rocky Mountains, and reaching as a high ridge covered with timber far out into the plains. In this portion of the divide there are no high peaks, though both north and south of it there are several of great altitude. The passes are the Ute, Hayden's, and Cherry Creek. The crossing at the head of Cherry Creek is quite easy, being approached by very moderate grades. The summit is broad and exposed, so that it readily catches the snow, and is said to be one of the coldest localities east of the mountains.

Divide between the Arkansas and Rio Grande.—This divide, the Sangre de Cristo Mountains and Spanish range, extends southeast from Poncho Pass beyond the southern boundary of Colorado. In its northern portion, from Poncho to Sangre de Cristo Pass, seventy-five miles, this range, in average altitude, sharpness of outline, and general impressiveness, is scarcely inferior to that on the west side of the Arkansas above. In some respects it is better defined, rising abruptly from the Wet Mountain Valley on one side, and from San Luis Valley on the other. The crest is irregular, deeply serrate or cleft into many fine peaks, which retain their individuality to below timber-line. Coalescing, they thrust into the plain long, narrow, bench-like tongues, separated by trough-like ravines, heading far up in the mountains, and usually closed in front by heaps of talus. Through these heaps narrow cañons have been torn by streams flowing in the ravines. The range is narrow, not more than twelve miles wide, but some of its peaks are of magnificent proportions. On the Rio Grande side, and overlooking Sangre de Cristo Pass, is the group called Sierra Blanca, of which the most conspicuous is Old Baldy Mountain. This is a naked mass of eruptive rock, reaching beyond 14,000 feet, a grand landmark, visible for many miles north and south. Beyond Sangre de Cristo Pass the range is much lower, though some of its peaks, as the Trinchara and Culebra Peaks, attain to nearly 14,000 feet altitude.

The passes across this divide are quite numerous, but with two exceptions they are seldom employed. Poncho Pass, leading from the Arkansas to the head of the Rio San Luis, is a broad low pass, and is one of the best in this whole country. It has an elevation of only 8,900 feet at the summit, and is crossed by an excellent wagon-road. The Sangre de Cristo Pass leads from a branch of the Huerfano River, a tributary of the Arkansas, to a branch of the Trinchara, a tributary of the Rio Grande. Its altitude at the summit is 9,600 feet, and it is said to remain open during the winter, there being seldom more than two feet of snow. It is crossed by a wagon-road which follows the natural grade. At some points this is difficult for a short distance, but could be improved easily and at slight expense. The Mosca and Sand Hill Passes are lower than either of these, but are impracticable on account of the heavy sand-hills which obstruct them on the western slope.

Subordinate divides.—As several of these will be referred to frequently in the following pages, it is best to give some details respecting them here, in order to avoid repetition.

The *Kenosha range*, forming the eastern boundary of South Park, divides the North Fork of the Platte from the river. It is a bold, rugged range, and joins the main divide a few miles east from the Jefferson Pass. Near its northern extremity it is cut by Tarryall Creek, a tributary of the North Fork, and at the southeastern corner of South Park it is broken by the South Platte, which there has worn a magnificent cañon. For the greater portion of its length the range is badly broken into ridges, and is impassable for even unloaded animals; but near its northern extremity it is crossed by the Kenosha Pass, leading from South Park to the village of Grant. This, though attaining an elevation of 10,200 feet, has comparatively easy approaches on each side, and is on the direct road from Denver to South Park. Four or five miles north from the Platte Cañon the range is crossed by the road to Colorado Springs, which has easy grades throughout. The altitude of this range is not great, and few of the peaks rise beyond 12,000 feet. Followed southward, this range becomes the Hardscrabble or Greenhorn Mountains, and terminates almost northeast from the Sangre del Cristo Pass. This portion separates Wet Mountain and Huerfano Parks from the plains, and is cut by the Arkansas River and Grape Creek, these streams uniting at the mouth of the cañon above Cañon City.

The *Blue River range*, as it is locally termed, is merely the extension northward of the western boundary of South Park, and derives its local name from the fact that the Blue River flows along its eastern base. It begins at the head of Blue River in the Quandary Mountain, which is but 150 feet lower than its neighbor, Mount Lincoln, with which it was formerly one. The general trend of the range is nearly north 12° west. In its southern portion, where it forms the divide between Blue River and Ten-Mile Creek, it is a rugged, unbroken mass, showing a comparatively easy slope on the east, but jagged and abrupt on the west. Beyond the junction of Ten-Mile Creek and Blue River it gradually breaks into individual peaks of great height and abruptness, the whole apparently increasing in these characteristics northward within our limits. The most prominent peak of this range is a massive, dome-shaped mountain, not far below the junction of Ten-Mile Creek and the Blue, which has been called Colorado's Skull in honor of a Ute chief, who, with a small band of followers, infests North and Middle Parks. Unfortunately, the only available path to its summit was choked with snow at the time of our visit, and any attempt to climb it would have been not only hazardous but fool-hardy. Its height, therefore, is still undetermined. Over this range no satisfactory pass has been found within our area. A trail leads from Breckenridge on the Blue to McNulty's Gulch on Ten-Mile Creek. It is very difficult even for lightly-laden pack-animals, and is now little used.

THE STREAMS.—*The South Platte River.*—This stream has its source in two small lakes in a magnificent glacial amphitheater directly under Mount Lincoln. It follows a southerly course for eight or ten miles through a broad, deep gorge, between Mounts Lincoln and Bross on the west and Mount Morton on the east, and enters South Park near the village of Fairplay. From that village the course is southeasterly until the river reaches the Kenosha range, where it enters a close cañon. There it turns toward the northeast and holds that direction somewhat rudely to the plains, after which its course is more toward the north until it passes beyond our northern line. Above Fairplay it receives several strong tributaries, and at or near that village it is joined by a number of small streams, so that it is at once a river of much importance. Twelve miles below Fairplay it is still further increased by the addition of the South Fork, which has its origin in several small streams far up in the divide at the west. Below this, within the park, a few other tributaries are seen, but they are very insignificant.

The North Fork of the South Platte lies wholly without the park, separated from it by the Kenosha range. Rising under Evans and McClellan peaks, this stream follows an east of south course for several miles, when, turning more sharply to the east, it enters a cañon and soon after empties into the main stream. Its principal tributary is Tarryall Creek, which rises in the Hamilton Pass and breaks through the Kenosha range. The North Fork carries little less water than the main stream itself. East from the foot-hills, along the east face of the range, the tributaries of the South Platte are numerous, but for the most part comparatively insignificant, until we reach Clear Creek, which enters the river near Denver. Of this the South Fork has its source in several large streams, rising under Gray's Peak and McClellan Mountain, and uniting near Georgetown. Thence the stream flows through a most magnificent cañon to the plains. The North Fork lies without our area.

The Arkansas River rises in an enormous gorge, directly adjoining that of the South Platte, to which it bears great resemblance. The river flows southwestwardly for about ten miles to its junction with Tennessee Creek, after which the course is about south of southeast through a succession of broad, alluvial plains, separated by cañons, until it reaches the mouth of the South Arkansas. Then it turns to south of east, and retains this general direction until it passes beyond our line on the plains. This portion of its course is simply a succession of cañons, first through the range forming the western boundary of South Park, and afterward through the Greenhorn Mountains and their spurs.

In its upper portion the Arkansas receives many tributaries. Those from the east are for the most part insignificant, as the divide is narrow, but from the west flow down Tennessee, Willow, Half-Moon, Lake, Cottonwood, and Chalk Creeks, and the South Arkansas River, all of them large streams, and carrying much water throughout the year. In the second portion of its course it receives few accessions until it reaches the great cañon extending to somewhat more than twenty miles above Cañon City. Near the western extremity of this cañon it is joined by Badger and Currant Creeks from the north, and by Texas and other smaller creeks from the south, while at the mouth of the cañon, Grape Creek enters it, having come from Wet Mountain Park at the south, and broken through the Greenhorn Mountains. A number of petty tributaries, of which Oak and Hardscrabble Creeks are least insignificant, are added to it below Cañon City, while at a considerable distance beyond our eastern limit it is joined by the Huerfano River, which rises in the Sangre de Cristo Mountains, and flows out to the plains at the southern extremity of the Greenhorn Mountains, and by other tributaries, such as the Apishpa, Purgatoire, and Fontaine qui Bouille, heading in our area.

The Rio Grande del Norte rises about eighty-five miles west from the town of Del Norte in the San Luis Valley. In relation to this matter the knowledge of settlers seems to be somewhat indefinite. In 1849, Captain Frémont ascended the river to Antelope Park, about fifty-six miles from Del Norte, and there met with the disaster which put an end to his explorations in that direction. Up to that park the river is generally known as the Rio Grande. Above it, about twenty-two miles, the stream is seen to be formed by the union of three forks. The Middle Fork is known as Deep Creek, and, being regarded as the main fork, this name has been retained for the river to its entrance into Antelope Park. The Rio Grande, however, really begins at the junction of the forks about sixty-eight miles above Del Norte. The Middle Fork is not the main fork, for the greater body of water evidently comes down by the North Fork, or Pole Creek, which rises near the Uncompahgre Mountains, and not far from the head of the Rio de las Animas. Deep Creek rises near the wagon-road pass, already described as leading to the San Juan mining district. The South or Hines Fork carries much water, but is not very long, as the divide on that side is quite narrow. These streams all flow in deep, dismal cañons, cut out of eruptive rock, which unite to form a stupendous cañon, extending quite to Antelope Park. Below the park the river flows through an excavation, bounded on both sides by high mountains, and varying in width from three hundred yards to almost a mile, until a few miles above Del Norte, where the valley widens out as it enters the Great San Luis Valley. In this portion its tributaries, with the exception of the South Fork, which drains a considerable area, are unimportant.

After reaching San Luis Valley the river turns sharply toward the south, and retains that course until it passes beyond our southern limit. Here its branches are very numerous, coming from the Sangre del Cristo and Spanish ranges on the east, and from the Sierra San Juan on the west. From the former the Rio Trenchara flows out near Fort Garland, being formed by a number of small streams rising in or near Sangre del Cristo Pass. A few miles farther south the Rio Culebra, formed by the union of many insignificant rivulets, breaks through a mesa-like wall, separating its park from the valley, and enters the Rio Grande not far from the mouth of the Rio Trinchara; while on the boundary of New Mexico the Rio Costilla, a petty stream, is the last tributary from the east. From the west we have the Rio Alamosa and the Rio Conejos, both large streams, rising far up in the high and rugged Sierra San Juan, and following exceedingly tortuous courses from their headwaters to the Rio Grande. On the west side of the Sierra San Juan, at a short distance south from the Colorado line, the Rio Chama drains the whole country east from the Horse Lake, and follows a rudely southeast course until it enters the Rio Grande in New Mexico.

In the northern portion of San Luis Valley there is a small area containing numerous streams which have no true outlet. The main streams are the Rio San Luis and Saguache Creek, both large and carrying much water, which empty into the swamp or "sink" termed San Luis Lake. Numerous petty creeks issue from the mountains on each side, but of these, few reach the streams mentioned, as, at a short distance from the mountains, they sink in the sand. This interesting district, formerly joined to the Rio Grande, will be fully discussed in another connection.

Leaving now the streams which flow on the Atlantic slope, we come to those on the opposite side, and first review the complicated net-work in the great area of the *Grand* and *Gunnison*. The Grand River lies wholly without our boundaries, and of the Gunnison we have not more than fifteen, or, at most, twenty miles. We have to deal, therefore, with their tributaries.

The streams emptying into the Grand have a northward course, while those tributary to the Gunnison flow in a southerly or westerly direction.

The *Blue* River rises under Quandary Mountain, almost within stone's throw of the headwaters of the Arkansas and Platte, and flows in a north of northwest direction, at the base of the Blue River range, until passing beyond our northern line it enters the Grand River near Gore's Pass. It is a rapid stream, and receiving many accessions, is barely fordable at Breckenridge, eleven miles from its source. Below that village it is further increased by Swan River, rising in Georgia Pass, and by Snake River coming from Peru, under Gray's Peak, and from Saint John's, under Glacier Mountain. On the west side it has many larger tributaries, of which Ten-Mile Creek is, perhaps, the most important.

The East Fork of Ten-Mile Creek begins in a small crateriform cavity overlooking the Arkansas at the Arkansas Pass. It flows in a northerly direction, and breaks through the Blue River range, cutting a magnificent cañon from which it issues to join Blue River. The West Fork comes in about ten miles from the Arkansas Pass. It is a stream of small importance, flowing almost east. It heads near the *North Fork* of *Eagle River* in a morass, which crosses the almost imperceptible divide between the two streams. Though this morass crosses the divide there can be no doubt that the junction is merely superficial, and that the water of the summit does not pass indifferently into either stream, except, perhaps, by capillary attraction through the matted layers of vegetable matter forming the crest.

The fall of the North Fork of the Eagle for the first six miles is nearly 250 feet per mile, and for the next sixteen miles about 70 feet per mile. This rapid descent has induced the formation of a very close cañon, which, with occasional openings, continues to the junction with the *South Fork*, a distance of about twenty-three miles. The latter stream rises in a group of glacial excavations nearly west from Tennessee Pass, and flows north and northwest to the junction with the North Fork, after which the stream flows west of north. Like the North Fork, this is a large stream, with rapid descent, and its course is marked by several cañons of great depth.

The *Roaring Fork* of the Grand River heads against the main divide near Red Mountain, and in the Elk Mountain group near Mount Whitfield, in a number of magnificent gorges, or rather *culs-de-sacs*, from each of which flows a little stream, cutting for itself a deep cañon. These unite to form one broad, deep cañon, through which the main stream flows in a north, and afterward in a northwestward, direction.

Almost due west from the head of Roaring Fork, at a distance of not more than ten miles, we find the headwaters of *Rock Creek*, another tributary of the Grand River. This stream for the first eight miles has a fall of 300 feet per mile, and at one mile from its source enters one of the most remarkable cañons in this area, which continues for six miles, and afterward opens into a narrow plain beyond the extreme western limit of our district.

The remaining streams in our portion of this area are tributary to the Gunnison River, which is formed by the union of Taylor and East Rivers about fifteen miles above the Indian stock ranch.

Taylor River is formed by several small streams, each about five miles long, which unite directly under the main divide about south of west from Twin Lakes. It flows through an open park for about nine miles, and there enters a narrow and with difficulty passable cañon, which continues for nearly sixteen miles to the junction with East River. The tributaries of Taylor River are very numerous, and before reaching its cañon it is a stream of much importance.

East River, the other fork of the Gunnison, rises near Rock Creek, and has an east of south course to its junction with Taylor. For the most part it flows through a broad, open plain, has a fall of about 25 feet per mile below the union of its forks, and carries a by no means inconsiderable body of water. West from East River, and entering the Gunnison about eleven miles below the junction, is *Ohio Creek*, an important stream, flowing through a very broad and rich plain. It comes from the northwest, and has its source beyond our western limit.

The principal tributary of the Gunnison from the east is *Tumichi Creek*, which enters the river about one mile below the stock ranch. It is an important stream and drains a large section of country. Its northerly fork is almost parallel with Taylor River, and flows through a similar cañon for twelve miles. The southern fork rises not far from the headwaters of the South Arkansas and joins the other near Tumichi Dome, a round mountain about thirteen miles from the Gunnison. Nearly three miles below the junction, *Cochetopa Creek* comes in from the south, draining an immense extent of country, almost the whole of Division No. 3 of the main divide. It is, however, a stream of small importance, owing to the absorbent nature of the soil through which it flows. It is formed by the confluence of a vast number of petty streams near the Indian agency, and is little more than twelve miles long.

The *San Juan River* rises in Division No. 5 of the main divide, and flows in a southerly direction until it crosses the New Mexico boundary, beyond which it soon turns to the southwest and then to the west. In Colorado the San Juan is a stream of rapid flow and carrying a by no means inconsiderable quantity of water. It receives no noteworthy accession from the east until near the line of New Mexico, where it is joined by the Rio del Navajo, a stream of moderate size, rising in the Sierra San Juan, and flowing in a south of west direction. Westward, however, we find several streams of importance, all flowing from the north and rudely parallel to that portion of the Rio San Juan which is in Colorado. The first of these is the *Rio Piedra*, a large, rapid stream, and scarcely inferior to the San Juan. Besides its two main forks, its only tributary is the *Rio Nutria*, which comes in from the east, the course of which is very irregular, but for the most part southwest to its junction with the Piedra near the territorial line. The width of its bed and the numerous ravines seen along its course are evidence that at some seasons of the year it is a comparatively rapid stream, but in autumn and most probably during the latter part of summer it is quite dry. This is due to the rapidity of its fall, as well as to the fact that its drainage area is small.

The *Rio de los Piños*, about fifteen miles west from the Rio Piedra, is somewhat larger than the latter, and flows through a broad, rich valley. The next stream is the *Rio Florida*, a branch of the Rio de las Animas, and of not great importance.

The *Rio de las Animas* is much larger than any of those yet mentioned. It is a bold, rapid stream, rising near or in the Uncompahgre Mountains, not far from the North Fork of the Rio Grande. It follows an almost due south course through a succession of wonderful but small parks and impassable cañons to the Rio San Juan, which it enters in New Mexico. The scenery along this river is unequaled by any observed elsewhere within our district, and will be discussed in another connection.

SECTION II.

CLIMATE AND AGRICULTURAL RESOURCES.

The mountain region of the Arkansas and South Platte areas affords little opportunity for agricultural operations, and the same is equally true of so much of the Grand and Gunnison area as is embraced within the limits of our survey. The land is sufficiently fertile and the supply of water for irrigation is ample, but the climate is so harsh that the cultivation of even the hardiest garden vegetables is exceedingly uncertain everywhere.

In South Park the air is pure, but during the agricultural season the climate is by no means mild or dry. During the day the thermometer frequently shows a range of 40°, diminishing rapidly after sunset, rendering heavy clothes and a good fire essential to comfort at all seasons of the year. Observations made in the southern and lower portion of the park on the last three days of July, 1873, showed a temperature of 26°, 28°, 28°, respectively, at sunrise, while at 2 o'clock on the same days, the mercury varied little from 70° in the shade. Heavy rain fell on six of the twelve days during which we were engaged in the park or its outlying valleys, while on two days large hail accompanied the rain, and on two other days snow fell to the depth of one inch. Notwithstanding the great fall of rain, the air is by no means saturated with moisture, there being sometimes a difference of 20° between the readings of the dry and wet bulb thermometers. Heavy dew was deposited during eight of the twelve nights, but disappeared quickly after sunrise. The winters are long, but not continuously severe; the thermometer seldom falls below zero, and over the greater portion of the park snow rarely falls to a depth of more than two feet. The change from summer to winter and from winter to summer is very abrupt. The average altitude of the park is between 8,500 and 9,000 feet.

Owing to the great and sudden variations in temperature, due, doubtless, in part to the comparative dryness of the atmosphere, South Park is much disturbed by high winds, which descend from the cold mountains to the heated plain. The sky is usually more or less cloudy during July and August, and the mountains are rarely altogether free from clouds. As might be expected, this park, having an area of not far from nine hundred square miles, and hemmed in by high mountains, afforded excellent opportunities for determining the effect of mountains upon the course of storms. These usually began at the southwest corner and followed the rim entirely around, the sky over the park being only partially overcast. With but one exception no rain fell within the park until the storm had passed around the border, following the mountains, and had reached the low divide at the south.

The northeastern portion of the park is well watered by Tarryall Creek and its tributaries, but is so poorly drained that much of it is a treacherous marsh covered by a dense growth of coarse grasses. South from Tarryall Creek to the southern border, the eastern portion is almost without water, and consequently destitute of vegetation. Some white sage is seen, but so dwarfed as to resemble a moss; a small flowering plant occasionally occurs, but the only plant which seems to flourish is the melon cactus, which, however, does not attain large size. On the western side of the park, where streams are very numerous, native grasses grow abundantly upon the "bottoms," and in moderate quantity upon the higher ground. In the southern portion, and on the divide, the grass is most luxuriant, growing in bunches 18 to 20 inches in diameter, and occasionally matting over the surface so as to render traveling difficult. The many ravines in the mountains show little parks or meadows, covered with grass, which prove very valuable for winter pasture.

The only trees in South Park are cottonwoods, pines, and spruces, which cover the little hills, and stretch far up the mountain sides. The timber line varies only from 11,200 to 11,500 feet, being higher on the northern side of the mountains. Above that line, no trees exist, but a scraggy pine, usually prostrate, reaches in small clusters sometimes to 200 feet beyond. The cottonwoods are almost as hardy as the spruces, and thrive well up to within 1,000 feet of the timber line. Wherever the pines and spruces have been burned off, the cottonwoods have replaced them, having overcome the slowly-developing conifers by their rapid and vigorous growth. It is by no means probable, as some have supposed, that the cottonwoods were the original possessors of the soil. Their seeds being provided with a pappus, are carried by the wind and deposited in the open space, where they rapidly develop. Along the streams of South Park there are willows, birches, and alders, small swamp species.

For the most part the soil is very porous. In the southern portion of the park it is undoubtedly alkaline, for there are frequent white patches, containing much saline matter, which bear no vegetation, and when well wet are, to all intents and purposes, bottomless. In most portions it is very good, though light and absorbent. This property, combined with the rapid evaporation which goes on in the sunlight, renders necessary a very abundant supply of water to render it productive. An interesting illustration of this is found on the low divide at the south, The low, broad, rounded hills of the divide in no case reach to timber line, yet in nearly every case they are entirely bare of timber. The exceptions are those hills whose slopes are steep so that the northern side is protected from the sun's rays. On that side small trees are found reaching quite to the summit, the porous soil, unaffected by the intense heat of the day, retaining the moisture, and yielding it to the trees. For purposes of irrigation the supply of water in South Park is practically unlimited everywhere, except along the eastern border, where the streams are few and very small.

Still the advantage of irrigation is questionable. For ordinary farming purposes South Park is worthless. Not even the hardy garden vegetables can be raised, potatoes being cut down by the July frost. Along the North Fork of South Platte, and on Tarryall Creek in the Kenosha range, potatoes have been cultivated successfully at several localities, and oats have been known to ripen. These crops, however, were obtained, not in the park, but beyond its eastern limit, and at an altitude of 1,200 to 1,500 feet below the lowest point in the park. The only use to which South Park can be put is the pasturage of stock. During the summer, cattle feed on the grasses which grow on the bottoms, in the autumn on the bunch grass of the bluffs, while in winter they disappear in the mountains, where they find abundance of food in the little meadows or parks already referred to. The area of summer pasture can be greatly increased by irrigating the bluffs, but if the number of cattle were larger than now, winter feeding would be necessary, as the winter range in the mountains is limited. At present stock raising is very profitable. Whether or not it would bear the additional expense involved by irrigation and winter feeding is questionable. In this connection it is well to note that the native grasses found throughout this Rocky Mountain region are by no means as valuable as the domestic grasses of the East. They are not less nutritious, but do not bear continued cropping. Growing, too, in bunches, and ordinarily forming no mat upon the loose soil, they are easily tramped out. The result is that great "ranges," formerly supposed to be capable of supporting an indefinite number of cattle, have become exhausted. This, I understand, is now the condition of one of the finest portions of South Park. Under such circumstances the cattle are removed to some distant locality, and in about five years the grass is in a measure restored.

Along the line of South Clear Creek and its branches, agriculture may be regarded as impossible. The cañons of these streams are too narrow to afford room for farming, while, aside from these, the whole country is irregularly mountainous, with an average elevation of little less than 11,000 feet. At Idaho Springs potatoes have been raised successfully, but every other article of consumption, even hay, must be brought in from the plains east of the mountains.

In the *Arkansas area*, within the mountain region, there is much variation in climatic conditions, owing to the extent of the area, and the difference of altitude. Even in the upper portion, extending from the junction of the river and Tennessee Creek to the mouth of the South Arkansas, the rapid fall of the river induces well-marked differences in agricultural conditions. This portion consists of two subbasins, the upper reaching from the mouth of Tennessee Creek to the Granite Cañon, a distance of about seventeen miles, and the other extending from the mouth of that cañon to the cañon below the South Arkansas River. In the larger part of the upper basin, which is broad, and covered with a fairly-rich soil, agricultural pursuits are impracticable, as the surface is usually deeply buried under snow for about six months each year, and occasionally for a longer time. The snow ordinarily disappears about the beginning of June, and keen frosts occur early in September, giving a brief season of less than three months, during which frosts are almost unknown. The change from winter to summer is very abrupt, so that the more rapidly-growing vegetables can be raised with good success. Mr. Dumary, living at the mouth of Colorado gulch, near the upper end of the basin, states that for a number of years he has succeeded in raising turnips, lettuce, radishes, and onions in considerable quantity. He has several times endeavored to raise oats, but has found the season about two weeks too short. The grass in this region is good, though not abundant, and little has been done in stock raising. Mr. Dumary, however, had, at the time of our visit, one hundred head of cattle, which were evidently thriving. He thinks that this would be a good summer range for ten times that number. During the winter, cattle must be sent to the lower basin, or driven out upon the plains.

Toward the lower portion of this basin the climate is milder, there is less snow, and the season is somewhat longer. The difference in elevation is not sufficient to account for the diminished rigor, and evidently is not the only cause, for at Twin Lakes, on Lake Creek, emptying into Granite Cañon near its head, we find at an altitude of 9,300 feet a much milder climate than at Colorado gulch. The difference in altitude is very little, while the difference in latitude is barely one-fourth of a degree. Yet at Twin Lakes it is possible to cultivate the more tender garden vegetables, and the fall of snow is not sufficient to incommode seriously the family living on the lake shore.

In the lower basin, the country is open throughout the year. Some snow falls, and the thermometer occasionally indicates a very low temperature, but upon the whole the winter is mild, and cattle run during the season without shelter. The rain-fall in the basin is small, the clouds discharging chiefly upon the mountains on each side. The atmosphere is quite dry, but the daily variations are not so great or so abrupt as those in South Park.

The high and numerous terraces on the west side of this basin interfere much with its agricultural value. Fortunately, however, erosion has greatly removed these in several portions, so as to leave a broad, level plain as the main terrace, varying in width from two to four miles. The river flows near the eastern side and considerably below the plain, while the creeks from the mountains on the west, Chalk, Brown, Squaw, and Gas, have excavated deep, broad troughs in the basin on their way to the river. These troughs are several hundred feet wide, with a deep, rich soil, which yields excellent crops of wheat, and of nearly all the common garden vegetables. They are already cut up into small farms, which belong chiefly to persons engaged in stock raising. The plain itself presents a most forbidding aspect. For miles one sees not a single blade of grass, and the soil, is apparently too poor to sustain even cactus. But all it needs for reclamation is a plentiful supply of water. Some adventurous ranchmen have tried the experiment and have been rewarded by crops of the most satisfactory character.

The irrigation of the greater portion of this plain on the west side is a problem of no slight difficulty, owing to the fact that it is so much broken by deep troughs as to render transfer of water from the Arkansas by canal exceedingly expensive. The mountain streams themselves issue from their cañons usually at a level below that of the plain, so that they are not immediately available. The southern portion can be irrigated without much difficulty from the South Arkansas, and two or three small creeks above can easily be utilized for the same purpose. The trouble is to water that portion between Cottonwood and Gas Creeks, and the only way to effect this seems to be by building flumes in the cañons of Cottonwood, Chalk, and Brown Creeks, by which a sufficient supply could be brought into ditches on the plain. The cost of this work, however, will prevent any from attempting it until our population becomes very much denser than at present. On the east side the difficulty is not great; few streams come in from that side, and the plain can be irrigated readily with water drawn from the river itself.

Through the cañon beginning below the mouth of the South Arkansas, and continuing for nearly twenty miles, the river falls with great rapidity, so that at Pleasant Valley, between this and the great cañon, the altitude is greatly diminished. In this little basin there are several good farms on the lower terrace, which are irrigated by water obtained from the river or from Little Cottonwood Creek. Passing southward into the basin of Texas Creek, the character of the country is much changed. Hitherto we have had a dreary plain, destitute of vegetation and relieved only by the occasional troughs of mountain streams. Here, however, we have a broad basin, seven to nine miles wide, well watered by numerous streams flowing from the Sangre de Cristo Mountains, and supporting a good growth of grass. Texas Creek flows in a cañon along its eastern side to the Arkansas, entering the great cañon a few miles below its head. Few ranches are found in the basin itself, though there are several in the broader portions of the cañon, the selections having been made doubtless because of the greater ease of irrigation, as the fall of the stream is very rapid. Good farms, however, can be obtained in many places in the basin itself.

The divide between this basin and that of Grape Creek, or Wet Mountain Valley, is very slight, and so badly drained as to be a marsh of the most treacherous character. It is covered by rich grasses and can be used as pasture for cattle, but is dangerous ground for horses or mules. Wet Mountain Valley has many features in common with the basin of Texas Creek. The name was given because, during June, July, and August, each day a severe storm of rain, frequently accompanied by hail, breaks over the valley and extends into Huerfano Park at the south, as well as into the basin of Texas Creek at the north. These rains begin at about three in the afternoon and continue well on into the night. The lowest point in the valley has an altitude of 7,200 feet. The agricultural season is long, beginning early in May and ending in the latter portion of September. In summer, the heat is intense during the day, but at night the temperature is moderate. The winter is mild, there being but little snow and seldom any extremely cold weather. Notwithstanding the great rain-fall, the atmosphere is not heavily saturated with moisture, and traces of the storms disappear rapidly in the sunshine.

The principal stream in this basin is Grape Creek, which receives a number of small tributaries from the Sangre de Cristo Mountains on the west, but no permanent ones from the Greenhorn Mountains on the east. From the south its only branch is Antelope Creek, a small stream carrying no large amount of water, but having a somewhat rapid fall. The surface of this valley descends from all sides to the center, there being a succession of broken terraces, distinct on the southern and eastern sides, less so at the north and almost obliterated at the west. At the bottom there is a considerable area of land, probably sixty square miles, requiring no irrigation, having in some parts a surplus of water. The whole is a natural meadow of the finest character. Barley, wheat, and potatoes grow well and mature when not injured by storms or insects. No difficulty is caused by the frequent rains of summer, as the surplus moisture in most places is quickly removed by evaporation, but the hail is often fatal to the crops. From all accounts this valley is a favorite resort of grasshoppers, which do a vast amount of injury. At the same time, farming on the bottom has proved reasonably successful.

On the bluffs or terraces, and on the gently-sloping land surrounding the bottom, irrigation is essential, as the soil is so porous that the frequent rain-falls are of little positive advantage. These bluffs are far more extensive than the bottom; but, though covered by good soil, are so dry that they are almost destitute of grass, and support only the common species of cactus. This is especially true of the western and southern portions, where the soil is sandy with but little clay. On the eastern and northern sides the soil is richer and more retentive of moisture, being made up chiefly of detritus from the eruptive rocks of the Greenhorn Mountains.

Unfortunately, the amount of water available for irrigation of these higher portions is very small. The streams from the Sangre de Cristo Mountains are of insignificant size and barely sufficient for the small farms adjoining them. Many of them are simply wretched sloughs 6 or 8 feet wide. South from Grape Creek the supply is derived from Antelope Creek, which, though not large, has sufficient fall and water to render it of much service in irrigation. On the east side there are no streams, which is the more to be regretted since there the soil is exceedingly rich and so retentive that only a small amount of water would be needed.

Stock raising is an important occupation in Wet Mountain Valley, and one which has proved eminently successful. The rich grass of the bottom is supplemented later in the year by the bunch grass, which grows in remarkable luxuriance in all the ravines of the Greenhorn Mountains opening toward the valley. In 1873, the number of cattle was estimated at twenty thousand, and many more were in the basin of Texas Creek. The opinion prevails that sheep driving is permanently injurious to any cattle range, and heavy penalties are imposed upon any who bring sheep into the valley. It is certain that sheep nibble the grass even with the ground, so that it revives with difficulty, and that where they do not crop it so closely they impregnate it with an odor which seems to be especially offensive to horses and cattle. This was our own experience, for our mules frequently refused to feed on excellent pasture, over which sheep had passed. Whether or not the injury to the range is permanent, is difficult to ascertain from the conflicting accounts of those interested.

Crossing the divide at the south we descend rapidly into the basin of the Huerfano River, or Huerfano Park. Unlike Wet Mountain Valley, this is not a broad, open park. It undoubtedly was such at one time, as is amply evident from the almost uniform height and level surface of the bluffs. This old basin has been cut and eroded into broad, deep swales by the numerous streams, so that the area of arable land is considerable. The climatic conditions are similar to those of Wet Mountain Valley, except in this, that owing to the lower altitude and the sheltering influence of the bluffs, the seasons are more regular and the mean temperature somewhat higher. The soil is exceedingly rich, the supply of water for irrigation ample, and wheat and Indian corn mature well, yielding good crops. The inhabitants are mostly Mexicans, and are exceedingly negligent in their method of farming. They raise much wool, but the quality is inferior, as the sheep are mostly Mexican, unmixed with any other breed.

In the *Rio Grande* area, the arable land is found principally in the San Luis Valley. The numerous parks in the Rio Grande cañon are at too great an altitude for farming, and are useful only for grazing purposes. In San Luis Valley rain is almost unknown, and in winter only a thin coating of snow is ever seen. The houses are built of adobe, plastered outside with clay, and have no projecting eaves upon the roofs. During the long spring and summer the temperature is high. Winter sets in about the end of October and practically closes in February. During this season the thermometer occasionally marks excessively low temperature, but this condition seldom continues for more than two or three days. For the most part the weather is very mild, resembling the close of September or the beginning of October on the Middle Atlantic coast.

The soil is rich throughout the valley, being simply volcanic sand and dust. Near the mountains it is somewhat too coarse for farming, but where it has been subjected to the sorting action of streams, it forms a soil which cannot be excelled. In the northern portion, in and around Saguache, is an old Mexican settlement, long celebrated for the fertility of its soil, which has recently attracted the attention of Americans, many of whom have entered it. This region is low, and, to the eye, a perfect plain, almost level with the surface of Saguache Creek. Nothing can be simpler than irrigation here, for one need only plow a furrow from the stream through his land. This creek rarely overflows, and maintains a steady supply throughout the year. The excellence of the soil is shown by the fact that the Mexicans have frequently obtained thirty bushels of wheat per acre with their rude and careless modes of cultivation. Vegetables of all kinds thrive well, and Indian corn matures notwithstanding that the altitude is somewhat more than 7,500 feet. Hay ranches are numerous along the little streams issuing from the mountains, and occasionally a grain field is seen. The grain crops are not very satisfactory in most cases, as the Mexican proprietors are usually too lazy to do the preparatory work properly.

In the southern portion of the valley there are numerous Mexican villages situated along the tributaries of the Rio Grande, around each of which is a greater or less area of cultivated land. The soil yields readily, and the principal crops are corn, potatoes, and red pepper, these, with a little wheat, seeming to supply all the necessities of the inhabitants. Away from the streams the whole valley presents a very dreary aspect. There is no grass, and the vegetation consists only of the various plants grouped under the vulgar name of "greasewood," with here and there a little sage brush.

The many ravines along the water courses, especially those on the west side of the valley, are exceedingly important as cattle ranges. In some of these the grass is remarkably fine. The little parks on the Upper Rio Grande, as already mentioned, support many cattle. Statistics can be procured only with great difficulty, but the best information leads me to believe that more than twenty thousand head were in the valley during the autumn of 1873. The Mexican residents in the southern portion pay attention especially to sheep and goats. The result is that there the grass has been so closely clipped that the country resembles a desert. The sheep are still poor, but the rancheros are endeavoring to improve the stock by crossing with merinos. Labor being exceedingly cheap, wool raising proves quite as profitable and quite as easy as stock raising. On the west side of the Sierra San Juan, along the Rio Chama, it is the chief dependence of the population, there being, according to the statement of the assistant agent at Tierra Amarilla, not less than two hundred thousand sheep within a radius of twelve miles from the agency. The wool is inferior, but the proprietors are making vigorous efforts to improve their stock.

In the *San Juan* area no agricultural operations have been carried on for many years. Until recently the greater portion of this area, as embraced in our district, was within the reservation of the Ute Indians and inaccessible to the whites. That which lay outside of the reservation has always been regarded by the Jicarilla Apaches as their hunting-ground, and consequently was not a desirable locality for settlers. It is impossible, therefore, to give any satisfactory statement respecting its meteorology, the more so as we were prevented by snow from spending much time in this area. This region is well watered by large streams, flowing through broad, level valleys, covered with rich soil bearing a magnificent crop of native grasses. Where the influence of the streams is not felt, there is evidence that the country is agriculturally dry. On the elevated plain between the Rio Piedra and the Rito Nutria, there is little grass, but the excellence of the soil is amply attested by a wonderful forest of sage brush, averaging more than five feet in height. This growth is unequaled in our whole district, and is approached only by that on the terrace of the Rio Chama, near Tierra Amarilla, where the soil is so fertile that it has in one instance yielded eighty bushels of wheat per acre under Mexican cultivation. The climate in these broad valleys cannot be severe, for at Animas City, on the Rio de las Animas, no frost occurred until October 15. In Animas Park, a few miles below the "city," the newly arrived settlers were making extensive preparations for farming, and it was expected that in 1874 nearly the whole park would be put under cultivation.

Throughout this region the timber is magnificent. Along all the streams there were seen groves of white pine, in which the trees were one and one-half to two feet in diameter, and in similar groves were yellow pines, two to four feet thick. No such timber was seen elsewhere. Fine grass, with wild rye and oats, is plentiful in nearly all portions of the area, so that the region will probably prove, as a stock country, worth fully all that the Government has agreed to pay the Indians for it. The sheep drivers, however, are already invading the eastern portion, and are likely to injure it as a range for larger stock. They claim, it is true, that sheep driving does not destroy the grass, which is said to come up as strongly as ever in the following spring. This seems hardly possible, for along the Rio Navajo the sheep have eaten the grass down to the very roots, and in addition have torn out the roots with their hoofs. If this be the ordinary result of sheep pasturing, one can hardly conceive the possibility of recovery.

Of the *Grand* and *Gunnison* area little of interest from an agricultural point of view is embraced by our district. We have, for the most part, only high, rugged mountains, broken by deep, narrow cañons, which here and there widen into little parks. In the northern portion the altitude is so great as to cause long, dreary winters, followed by brief summers, whose nights nearly always bring frost. Southward, beyond the junction of East and Taylor Rivers, the conditions are somewhat changed, as the country is more open. Yet here, owing to the altitude, the winters are harsh and frosts are not unknown during summer. Respecting the meteorological conditions little is known. Until very recently, the whole area west of the main divide was supposed to be within the Ute reservation, and was shunned by all the whites, except a few adventurous prospectors. The mean annual temperature varies greatly in different portions, for at the north, on Rock Creek, the timber line is barely 10,000 feet, while on the Rio Grande divide, at the south, it reaches to nearly 12,000. To explain this great difference is not easy, for the distance between the two localities is hardly one degree of latitude.

No attempt has been made to test the availability of the country for farming purposes. At the Indian agency, on Los Piños Creek, a tributary of Cochetopa Creek, very near the southern limit, and almost directly under the Rio Grande divide, a small garden is cultivated, in which the ordinary vegetables are raised so successfully as to give reason for supposing that in this little basin some of the grains might mature. The soil is rich enough throughout the whole area, and along the river bottoms is usually covered with bunch grass and wild oats. This mixture of grasses is remarkably abundant in the valleys of East River and Ohio Creek. The many ravines in the Rio Grande divide will eventually prove very serviceable to stock raisers. Like the *San Juan* area, this whole region is almost untouched, nothing having been done beyond the herding of a few cattle at the Indian stock ranch, on the Gunnison. The supply of water is ample everywhere, and the streams maintain a steady flow throughout the year, being sustained by the heavy snows of winter and the equally heavy rains of July and August.

Of the *Great Plains*, lying east from the great mountain region, only a narrow strip, from five to fifteen miles wide, reaching from Denver to the New Mexico line, and embracing portions of the Platte and Arkansas areas, falls within the limits of our survey. Though this strip is so small, it includes no inconsiderable part of the land already under cultivation in this region, and is of much interest, as in or near it there have been performed successfully some gigantic experiments in artificial irrigation. Rain or light snow is of frequent occurrence during the winter and early spring, while later, until about the beginning of June, heavy rains are common. From June until well on in the autumn the climate is agriculturally rainless, and artificial irrigation is necessary to successful farming.

As a whole the climate has some interesting features. By those interested it is said to be mild and uniform; but such a statement needs to be much restricted before final acceptance. The long summer and autumn are pleasant, the days being warm and cheery, while the nights are invariably cool. Toward the close of November the weather changes somewhat abruptly, and the thermometer is apt to fall to zero, or to several degrees below it. From this time until the middle of March the variations in temperature are very great and equally abrupt. Ordinarily, January is quite mild, but during February the thermometer may vary in twenty-four hours from 20° to 70°. These abrupt changes cannot fail to prove injurious to invalids, notwithstanding the many violent assertions to the contrary. At the same time, owing to the dryness of the atmosphere, the evil influence is very much less than it would be on the Atlantic coast, where the air is so frequently saturated with moisture. The climate of the year, as a whole, however, is exceedingly favorable for those afflicted with diseases of the digestive and respiratory organs. There can be no doubt that many lives have been prolonged here by the climate alone. The advantages of this portion of Colorado in this respect are so evident that the very exaggerated statements made by many are inexcusable, not only because they are false, but because they are unnecessary, the simple truth being sufficient for all purposes.

As the dry season begins in June, and continues until autumn, all farming operations are entirely dependent upon artificial irrigation. The supply for this purpose is drawn from the Platte and Arkansas, with their numerous tributaries. These streams derive their water, in the early part of the season, from the melting snows of the mountains, and later on from the heavy rains falling on the interior ranges, so that they always carry abundance to meet all necessities. The soil along the rivers, both on the bottoms and the higher terraces, is very good, though somewhat coarse on the latter. It is from 18 inches to 4, or even 6 feet deep, resting in many localities on a white tufaceous limestone, or fresh-water marl, which decomposing readily may eventually come into use as an amendment. This soil is easily prepared, and yields very good crops. The average number of bushels of wheat per acre has been put at twenty-eight, but this is too high, and the best information within our reach leads us to place it at not more than twenty, nor less than eighteen. Exceptional cases near Denver show in one instance thirty-seven, and in another sixty-five bushels per acre. These, however, are useful only to prove what can be done by skillful farmers, of whom there are too few in the Territory. The wheat, like that of California, is of very superior quality, and seems to contain much more gluten than wheat raised east of the Mississippi. The dry atmosphere renders the crop more certain, as many of the diseases so injurious at the East cannot exist here. Oats do fairly, averaging thirty to thirty-five bushels, while barley yields thirty-five bushels per acre. Vegetables of all kinds do well, and in the southern portion Indian corn gives a fair crop.

Along this strip there is little timber, except upon the mountains facing it, but on the higher portions piñon and red cedar grow in large quantity. Along the streams cottonwoods grow to large size, but the wood is worthless as timber. On the upper terraces southeast from Cañon City cacti grow to a great size.

Stock raising has proved more profitable than farming. Bunch grass is found everywhere, in greater or less abundance, and in quantity sufficient to support a vast number of cattle, owing to the great extent of range. The climate is such that ordinarily no winter shelter is required, and the snow fall is so slight as hardly to interfere with pasturage. The only expense is the outlay for herders. Sheep do well, being free thus far from diseases common east of the Mississippi, and the wool is clean as there are no plants to injure it.

The extent to which irrigation of the plains can be carried is now a question of much importance, and, having been formally presented in a message by the President, deserves at least passing reference here. These plains are not, as is commonly supposed by those who have not seen them, a vast level, broken only by occasional waves. On the contrary, the surface is exceedingly irregular, and, though in the distance resembling a plain, it is in fact anything else, being much torn by erosive agencies. Only a small portion of this great area can ever be cultivated by irrigation. That which is available lies along the larger streams and their tributaries, some of which are now permanently dry, and consists of the flood-plains, and the older terraces rising above them. These present the level surface which is essential to successful irrigation. Of such land, immediately available, it is estimated that Colorado, east of the mountains, has in all barely four millions of acres, or about six thousand two hundred square miles, an area scarcely larger than a strip extending from Denver to the New Mexico line, with a width of thirty miles. It might be possible, by means of extensive and very costly works, to double this area, but not more. Under such conditions, one can hardly fail to doubt the feasibility of an enterprise to recover any considerable portion of Colorado by irrigation.

Even were Colorado, east of the mountains, one unbroken plain, the difficulties would be quite as serious. To irrigate, one must have an abundant supply of water. As the rain falling upon the plains is uncertain in amount, it can afford no assistance, and the whole supply must be drawn from the mountain region. The problem, then, would be to irrigate, in Colorado alone, nearly sixty thousand square miles, with the water which falls on less than eleven thousand. Could this water be husbanded in such a manner as to lose none, this would not be impracticable, for irrigation is needed only from the beginning of June until at farthest the early part of August. But such a husbanding is impossible. A large part of the water precipitated upon the mountains never reaches the plains by the streams, and were irrigation fully carried on along the Upper Arkansas and the Upper South Platte, only a small portion would pass east of the mountains. As it is, the Arkansas, where it issues from the mountains at Cañon City, is very much smaller than at Pleasant Valley, only thirty miles above. More than this: The atmosphere on the plains is so dry, that the temperature frequently falls 40° without inducing deposition of dew. It is clear that the loss by evaporation would be enormous. The porous soil would absorb an equal amount, and from these two causes not less than half the water entering the canals would be lost within sixty miles. The amount of water issuing from the mountains is not sufficient to bear this loss and still supply what is needed for irrigation. Careful calculation has shown that the water of all the streams would hardly suffice to irrigate the whole country to a distance of thirty-five miles from the base of the mountains. The Platte itself, though constantly receiving tributaries, diminishes in importance as it descends, until at Julesburg, during the agricultural season, it is comparatively insignificant.

CHAPTER XI.

METAMORPHIC ROCKS.

The metamorphic rocks are well exposed in the complex east range, fronting upon the plains, as well as in the range west of South Park. On the former range they prevail, none of the unaltered rocks occurring, except at the foot on the east, in the narrow series of hog-back ridges. In the second range they are seen only on the west side, facing the Arkansas River, being concealed on the east by rocks of Carboniferous and Silurian Age, except near the heads of the numerous streams, which run through deep gorges cut out of the eastern slope. In the Sangre de Cristo Mountains they are seen only on the western slope, where the exposed mass is quite extensive. The numerous spurs, passing from the eastern range, are usually made up of metamorphic schists. In the range west from the Arkansas, rocks of undoubted metamorphic character are not seen until we approach the head of Tennessee Creek, from which point northward they prevail near the center of the axis. West from this range, in the area of the Grand and Gunnison, they are exposed in only a few localities, and in those principally because of the extensive series of faults. This area is covered, for the most part, either by rocks of volcanic or eruptive origin, or by unaltered sedimentary rocks. Along the various axes seen in the San Juan area, the metamorphic schists were observed.

The prevailing rock is a micaceous schist passing into gneiss, and containing much granite, which in some localities entirely replaces the others. Not unfrequently the mica-schist is displaced gradually by hornblende-schist, which becomes a hornblende-gneiss, containing masses or strings of syenite, as the other form contains ordinary granite. Slates are almost wanting, and thick strata of quartzite belonging to this series were observed at only two or three localities. Serpentine and limestone seem to be absent altogether. It is impossible in the present state of our knowledge to come to any definite conclusion respecting the relations of these rocks. Dr. Hayden, in one of his reports, has referred them, with doubt, to the Laurentian. To determine this matter, careful investigation at the north is still needed.

At several localities in the Grand and Gunnison area there is found underlying the lowest stratified rock a peculiar gneiss. This is regularly laminated, and from dark-brown to almost black in color. In structure and appearance it frequently resembles a micaceous sandstone, and, hastily examined, might be mistaken for a rock of that kind. At most exposures it is little distorted by pressure, the laminæ being straight for many feet, and preserving distinctly the original planes of bedding. Struck by the hammer, it breaks along well-defined lines of cleavage into fragments 6 inches or more in length, but along the plane of deposition it splits like straight-grained wood. Indeed, so regular is this splitting, that large fragments are not unlike silicified wood. Occasionally it shows small flexures, as if from lateral compression, and at some exposures it contains thin seams of quartz, or of quartz and feldspar, occupying the cleavage planes. At the junction of Taylor and East Rivers, this rock is seen in the cañon almost black and somewhat contorted. Followed up East River, it becomes lighter in color, more micaceous, and the wrinkling of the laminæ disappears. About a mile above the junction it contains a good deal of segregated granite, by which, apparently, it is eventually displaced. In the cañon of Taylor River it continues for two or three miles above the junction and then disappears, the walls of the gorge thenceforward consisting of coarse granite. At the head of this cañon the stratified rocks are again seen, and under them appears this gneiss, showing the same characters as before. In Beattie Park, about a mile south from the cañon, it is somewhat talcose, and portions of it bear much resemblance to serpentine. In the long cañon of the Arkansas, just below the junction with the South Arkansas, it is quite variable in its character, sometimes resembling a red micaceous sandstone, and at others so much like a diorite in physical character as to be somewhat perplexing. This rock is of extensive distribution west of the Arkansas, but was not seen in or east from South Park. It always occurs directly under the sedimentary rocks, and no similar formation occurs lower down. It is clearly unconformable to the great mass of the schist and gneiss, though precisely like them in its changes. In consideration of all the circumstances, one cannot resist the temptation to regard it as belonging to a later period.

On the North Fork of the South Platte the schists are exceedingly contorted. Thin layers of quartz or feldspar are separated by laminæ of mica, which readily give way, so that one not unfrequently sees a very pretty little arch lined with mica, the lower layers of the rock having been removed. Near Bailey's ranch, on this stream, mica occurs in very large sheets. A very interesting feature was here observed for the first time. The schist contains nodules of quartz or feldspathic granite, with but little mica, which are usually quite small when abundant, and vary from one-fourth to one-half inch in length. Their longer axis bears no necessary parallelism to the lines of bedding in the rock. In some of the especially-micaceous layers these nodules are very numerous, and are regularly arranged, as if in accordance with some law. At several localities they were observed in layers. Though ordinarily small and rudely oval wherever they are numerous, they occasionally attain a length of 3 or 4 inches as independent nodules. The especial interest attaching to them lies in the fact that they are often combined, giving a mass 2 or 3 feet long, true granite imbedded in the gneiss. In many instances the large masses of gneissoid granite string out like veins on all sides from the center, and these vein-like projections break up into these nodules, and thus finally disappear. It is sufficiently evident, then, that these are not metamorphosed pebbles, but concretions, the result of segregation, which mark the formation of the separate layers of quartz, feldspar, and mica in gneiss, and of the great masses of coarse granite which occur so frequently in the gneiss and schists.

Gneissoid granite is exceedingly common. It often occurs in the gneiss as great included masses, of irregular shape or in elongate-vein form, spreading from a center, and throwing out seams which become exceedingly thin before they disappear. In each instance the deposit seems to bear no relation to the bedding of the including rock. For the most part, however, it is found entirely displacing the gneiss, and forming the prevailing rock for miles. In every such instance, however, it occasionally changes into gneiss for short distances. Not unfrequently seams of granite are found along the planes of cleavage. This granite, which may be termed segregated granite, to distinguish it from the granite which many regard as eruptive, is coarsely crystalline, with the feldspar in great quantity, while the proportion of mica is very small. The feldspar varies in color from white to red, and the rock as a whole yields readily under the influence of the weather.

A syenite of similar character is occasionally seen. It occurs in masses in hornblendic gneiss, and often as veins along the cleavage planes. It bears a very close relation to the other rocks, for in several cañons it is easy to follow mica-schist into gneiss, and this into either hornblende-schist or hornblende-gneiss, and the latter into syenite, which may pass into schist within a few feet, and this again into the ordinary granite. So indiscriminately are these several rocks, the micaceous and hornblendic, thrown together, that there is no room to doubt their common origin.

In the cañon of Taylor River the prevailing rock is this gneissoid granite, soft and coarse, here and there changing somewhat abruptly into gneiss. The granite frequently contains only rare scales of mica, which preserve a rude parallelism to each other. Toward the middle of the cañon this rock passes into a very fine, compact, feldspathic granite, showing many crystals of feldspar 2 inches long. This bears close resemblance to the granite ordinarily regarded as eruptive; but since cliffs along this cañon, 1,000 feet high, exhibit both varieties distinctly, passing the one into the other, with no line of separation, there is no room to doubt that they are of common origin, and that the whole is a metamorphic rock.

At the junction of the two forks of Ten-Mile Creek the gneiss is exceedingly compact, and upon hasty examination some portions might be mistaken for quartzite. Some of the layers are made up of geodes lined with drusy quartz, but they are not extensive. Half a mile below the junction, and where the stream enters a very fine cañon, the wall of gneiss on the east side rises almost vertically for nearly 2,000 feet, and, being entirely naked of vegetation, offers a good exhibition of the rock. Here we see an immense segregation of granite, thoroughly vein-like, interlacing in every conceivable way, running in all directions, with and across the bedding, but not persistent, as each of the veins, if we may so term them, tapers off until it disappears. Above the forks a porphyritic gneiss was seen in fragments, but not in place.

At the head of Tennessee Creek the gneiss is somewhat variable in character; sometimes so compact and free from mica as to resemble quartzite; at others it is schistose, with the layers thin and straight for many feet, causing it to cleave like dry wood. The quartzose layers are sometimes granitic, and in such cases originate as laminæ, one-eighth of an inch to one inch thick, but in all cases these unite to form a thick layer. Their thickness varies from one-eighth of an inch to 20 feet. In every instance they resemble in structure the little nodules of granite already referred to, which are very numerous here, and can be traced in connection with the larger masses. Similar segregations form along the planes of cleavage, and are often seen intersecting each other along the main planes. Upon the east face of this range the gneiss and schists are well exposed northward, but very sparingly southward from the head of Tennessee Creek.

In the cañon of the Arkansas, above the junction of the river with Tennessee Creek, there is a gneiss which bears close affinity to the granites usually called eruptive. It contains very beautiful crystals of translucent feldspar, one inch long and one-third of an inch wide, closely packed together. This gneiss gradually passes into a micaceous schist, in which the crystals are seen, but they are neither so numerous nor so exact in form as in the gneiss. In the vicinity we find immense fragments of a granite, reddish, and coarsely crystalline, very compact, and containing similar crystals of feldspar in vast numbers; indeed, some fragments seem to consist almost wholly of these crystals. The granite could not be traced into the gneiss, as the rocks were not seen in contact; but so marked is the similarity in constitution, that we must regard them both as metamorphic, unless, indeed, we are willing to concede that gneiss is eruptive. On the east side of the Arkansas River the metamorphic rocks can be traced all the way to the great cañon below the South Arkansas. On Trout Creek syenite occurs in small quantity, but is displaced by a soft, coarse granite, which gradually assumes a gneissoid structure. It contains fragments of gneiss from 6 to 20 inches in diameter, which are fragmental in shape. Their presence is difficult to account for. If the granite be eruptive, these might be included fragments, but there is no reason to assign any such origin to it, for its gradual passage into the gneiss is easily traced. This rock exhibits thick seams of grayish-red quartzite, which invariably occur along the cleavage planes. In the lower cañon of the Arkansas, above the bridge, the gneiss is dark and very micaceous, and contains much coarse granite. The latter rock weathers here as well as on Trout Creek most readily along the cleavage planes, and at length separates into rounded blocks, which resemble enormous bowlders. Near the mouth of Texas Creek a high knob is covered by such fragments, and looks as though it were part of a great mass of drift.

On Currant Creek, a tributary of the Arkansas, the changes are very prettily shown. There the mica-schist becomes a schistose gneiss, containing numerous segregations of the granite of large size, together with immense numbers of the little nodules already mentioned. The gneiss gradually becomes more compact, and at last is lost in the granite. In the long Dry Cañon, leading from the Arkansas River to Wet Mountain Valley, the exhibition is equally satisfactory. The transition from mica schist to granite, and from hornblende schist to syenite, is shown quite frequently, and the rocks of one series readily give place to those of the other.

On the west side of South Park the exposures of the metamorphic rocks are not extensive, as they occur only in the gorges of the streams, but in the vicinity of Mount Lincoln the cliffs are from 2,000 to 3,000 feet high, and show most satisfactorily that the coarsely-crystalline feldspathic granite is not of eruptive origin. The prevailing rock of the mountain is gneiss, but near Montgomery a magnificent bluff, overlooking a glacial amphitheater, exposes immense masses of granite having a vein-like form. These are very irregular in shape, and vary in dip from 25° to 90°, while the including gneiss varies only from 15° to 26°. These masses can be traced many hundreds of feet on the mountain-side, and are seen to cross each other at varying angles without any faulting. Viewed from a distance the granite and gneiss are distinctly separate, but when one examines closely he finds that for many feet on each side of the granitic mass the gneiss shows an approximate structure, with more and more of the granitic concretions as it approaches the mass, so that at last the change is absolutely imperceptible. A similar condition exists in the cañon of Fairchild's Creek under Mount Bross.

Entering the eastern range at Mount Vernon Gulch, a few miles south from Golden, we find the sedimentary rocks resting on a schistose gneiss containing many thin layers of pegmatite. From this locality to Clear Creek the character is the same, but beyond the crossing of the creek the gneiss is more compact with here and there narrow dikes of eruptive rocks. There is not much of the coarse granite until we have passed Idaho, but from that village to Georgetown this increases in quantity. At Idaho there is much syenite which changes, often abruptly, into hornblende schist. Along the road from Idaho to Chicago Lake the coarse granite is in large quantity, and shows more of the dike-like form than at any other locality examined. About one mile above the saw-mill, on Chicago Creek, a great mass of coarsely crystalline granite feldspathic and yellowish-white stands boldly out from the wall. It contains very little mica, and occasionally a little hornblende. It is about 70 feet wide and dips 8° more than the surrounding gneiss. The most interesting feature here is the abruptness of the transition from the gneiss to the granite and the absence of strings from the latter. The line of separation between the two is almost as distinct as that between a trap-dike and the adjoining gneiss. No similar instance was observed elsewhere. At Georgetown, Leavenworth Mountain consists principally of gneissoid granite and gneiss cut by several dikes of trachyte, which is quite porphyritic. In the Marshall tunnel, at 980 feet from the mouth, there is a seam of metamorphic slate, 30 feet thick, gray, finely laminated, and disintegrating readily upon exposure to the atmosphere. This was not seen on the surface. No similar slates were observed elsewhere within our area, except in the vicinity of Mount Lincoln. On Brown and Republican Mountains, near Georgetown, the rock is chiefly the coarse gneissoid granite, with but little gneiss. This rock seems to pass into syenite. In all these mountains, as well as along the upper portion of Clear Creek Cañon, there is much porphyritic granite which will be referred to in another connection. A similar rock is found in very considerable quantity from Georgetown to Gray's Peak.

On the Peru Fork of Snake River, heading directly under Gray's Peak, the soft coarse granite is predominant, there being little gneiss. On the other, or Montezuma Fork, we find at Montezuma some gneiss with much gneissoid granite. In the tunnel of the Saint Lawrence Mining Company a wide layer of quartzite occurs, which is traceable a long distance upon the surface. On the opposite side of the mountain the rocks are chiefly syenite and hornblende schist, with occasional exposures of gneissoid granite. At Breckenridge, on the east slope of the Blue River range, the granite is in thick layers in the gneiss, and is very coarse. The mica, instead of being distributed regularly through the mass, is scattered in blotches which are cruciform concretions made up of minute scales of mica. These give the rock a peculiar and somewhat ornamental aspect.

In the eastern range, between South Park and the plains, the prevailing rock is gneiss, with much schist. Near Bailey's ranch, on the North Fork of the South Platte, a syenite granite occurs in small quantity. The gneiss in the vicinity is very beautifully waved and cleaves readily along the curves, causing here and there overhanging arched cliffs, whose under surface is a thin layer of mica. These curves do not seem to be parallel to the bedding, and so are merely the result of foliation. On the first ridge west from the river, the gneiss becomes a mottled schist, with little feldspar and many pebbles of quartz, while farther on the whole becomes a feldspathic granite almost without mica. In the schist some layers contain small concretions of silvery-white mica, with minute proportion of quartz. On top of the ridge these are no longer mica, but composed of feldspar alone or of feldspathic granite. In the same ridge some syenite occurs, in which are large lumps of milky quartz inclosing fine crystals of hornblende.

On the east side of South Park, in the low hills cut by Tarryall and Michigan Creeks, we find north from the cañon of Tarryall Creek a coarsely crystalline granite, very feldspathic. The feldspar is red, the quartz milky, and the mica silvery-white in crystals an inch in diameter. Little or no gneiss occurs with it. Southward from the cañon the rock gradually changes until within a distance of five miles the granite has almost entirely disappeared, having passed into gneiss. This red granite therefore bears the same relation to the gneiss that the light-colored rock does elsewhere. It is usually classed among the eruptive rocks, but this condition shows that sometimes, at least, it is the result of metamorphism.

Economic geology of the metamorphic rocks.—The chief economic interest of the metamorphic rocks lies in the veins of silver and gold bearing ores.

By far the most important of these are north of area, but the mining operations within our district have been carried on extensively and with more or less activity since 1860. It will readily be understood that during a rapid reconnaissance there is no opportunity for close investigation, such as will determine the extent of mineral deposits, especially of those that occur in the vein form, so that reference can be made only to localities where veins have been worked somewhat largely. The region thus carefully prospected is quite limited, and lies principally along South Clear Creek and its tributaries, and upon Snake River, or rather upon the tributaries of the Blue River. There is much reason to suppose that, when the eastern range has been systematically prospected southward, it will prove to be quite as important, economically considered, as that portion lying northward from South Clear Creek.

On the road from Denver to Georgetown quartz veins were first observed at about five miles from Mount Vernon Gulch, which lies at the eastern base of the mountains. These veins all strike about north 30° west. Some have been opened, but none of them has proved other than barren. Similar veins, carrying little or no ore, are of frequent occurrence up the creek to Idaho, where the condition changes and we find a number of lodes which carry a large quantity of rich ore. The important vein is the Seaton lode, which has been worked almost continuously since 1860. It is a fairly defined vein 4 to 9 feet wide, and carries a "pay-streak" varying in width from 2 to 30 inches. Originally it yielded from $18 to $40 of gold per ton, and was worked exclusively for that metal, the existence of the silver in the other being unknown. As the workings descended, the gold became less in amount and finally disappeared. The lode is now worked only for the silver. Closely selected ore yields three hundred ounces per ton, while the other grades run down to fifty-six ounces. The ore is somewhat refractory and consists of galena, zincblende, iron pyrites, and brittle silver, the latter increasing in quantity below. It is reduced by smelting, the ordinary mill process having failed to extract the silver.

Of the other lodes in this vicinity only the Schaffter has yielded any gold. The others are argentiferous only, and carry the same refractory ore as that seen in the Seaton. The Victor is a cross-lode, intersecting the

Seaton at an angle of 70°, is 4 feet wide, and has well-defined walls. In cutting through the Seaton it preserves its identity, showing slicken-sided walls in that vein, but has produced no throw in it. At the intersection there is no increase of size, or material increase of ore in either lode. The Victor has yielded quite largely. The veins in this vicinity strike north 55° east magnetic, and dip northwestwardly at an angle of 45°. They bear no relation to the stratification of the gneiss or schists.

Between Idaho and Georgetown very many veins have been opened to a greater or less extent, but at the time of our examination most of the workings were either temporarily abandoned, or had been newly resumed after long inactivity. Little information could be obtained respecting them.

On Leavenworth Mountain, near Georgetown, many openings were seen, but the labor has been expended chiefly upon the Colorado Central lode, which is worked by three strong companies, one of which has already 2,000 feet of shaft and tunnel work, including one tunnel 1,150 feet long. The ores from this are very complex, consisting chiefly of galena and zinc-blende, with ruby, brittle and native silver. Associated with these, in small quantities, are azurite, gray copper, wulfenite, anglesite, smithsonite, and more or less iron and copper pyrites. The zinc blende is not in sufficient quantity to be a very serious drawback. The ore is exceedingly rich, the first class yielding nearly one thousand ounces per ton, while the other grades vary from sixty to three hundred ounces. The veins on this hill are somewhat eccentric in character, though apparently well defined, and giving no ground for the assertion they are not true veins. In the Marshall tunnel, which cuts twelve lodes, the characteristics are well exhibited. The "crevices" are very wide, and limited distinctly by a clay casing, rarely more than one inch thick, and usually less than half that. In the Colorado Central, which is a type of those seen in the tunnel, the width from casing to casing is 22 feet. The "vein-stuff" is gneiss, and gneissoid granite, and the ore-bearing streak is very irregular, varying from 4 to 20 inches in width, with strings scattered through 7 or 8 feet. Two of the veins are evidently contact deposits, between the gneiss and trachyte. A somewhat remarkable feature in this tunnel is that of the twelve lodes cut by it, not one is of any value at that level, though several of them, notably the Colorado Central and the Equator, are exceedingly rich at higher levels. Were this degradation found in only one or two, it would be unworthy of note; but the utter barrenness of all the lodes is far from encouraging to those who look forward to indefinitely-increasing richness in the mines of this mountain as they descend. At the same time the lodes retain their form and general characters, there being no pinching out of the veins; they have only ceased to carry the ore. These lodes strike nearly northeast, and dip northwest.

On Brown Mountain, in the same vicinity, the principal mine is on the Terrible lode. The others are idle. The Terrible has not well-defined walls, and the vein-stuff is the same as the country rock, characteristics common to all the veins on this mountain. The ore is scattered in strings through a mass of rock varying from 3 to 8 feet in width, as that much of low grade is brought out, which must be closely selected. This ore, consisting of galena, with some ruby, native and brittle silver, with much zinc-blende, is exceedingly refractory. It is unfortunate that no economical method of reducing the argentiferous blende has been devised, for that is a rich ore. At present it is almost essential to have the zinc separated before the ore is sent to the smelting-works. The first-class ore from this mine yields six hundred ounces of silver, and one and two-thirds ounces of gold per ton. The lower grades are carefully concentrated at moderate cost by "jigging," whereby not only the rock, but also the blende is separated. On the same mountain the Burleigh tunnel has been driven 1,475 feet, without cutting any productive vein. Some have supposed that this is evidence of "pinching out" of the veins at a considerable depth. It is not so. By an error the tunnel runs north 25° west, while it should have been in the direction north 45° west, in order to reach the sought-for vein within the shortest distance; the veins on this mountain striking almost northeast. The tunnel therefore, as yet, proves nothing respecting the richness or poverty of the Brown Mountain lodes at its level.

On Republican Mountain, which adjoins the last, mining operations are extensively and energetically prosecuted. Most of the lodes are ill defined. The most important are the Coldstream and the Pelican. The former shows no walls, but is one of the richest in the whole region. The ore averages 1 foot in width, and in some extensive pockets is 3½ feet. From the main body, strings 1 to 4 inches wide pass out for several feet into the surrounding rock. The ore is somewhat more refractory than any yet noticed, owing to the great quantity of zinc-blende, which frequently occurs in crystals of remarkable size. The galena is in beautiful crystals, some of which are an inch in diameter. The proportion of metallic zinc in the ore varies from 3 to 25 per cent, and that of lead from 12 to 72 per cent. The yield of silver varies from one hundred and sixty to five hundred and forty ounces per ton. Some gold is found, but the quantity is very small. Associated with the galena and blende there is much iron pyrites, as well as ruby silver. This vein throws off many spurs. Its direction is north 66° west magnetic. The Pelican lode varies from 5 to 8 feet in width, and has a well-defined hanging-wall. The foot-wall is not so well marked. The vein-stuff is quartz, very compact. The ore occurs in strings, which are 1 to 6 inches wide, and form a rather pretty net-work in the upper levels. Farther down they show a tendency to unite. The yield is from sixty-five to five hundred ounces of silver per ton. The ore consists of galena, zinc-blende, gray copper, ruby and native silver, with some silver glance. The strike is north 75° west magnetic, and the dip northeast, at an angle of 65°. As this and the Coldstream are the only lodes on this mountain having a northwest strike, it has been supposed by some that they are really one lode. The other veins on Republican Mountain have a course varying from north 23° east magnetic to north 38° east magnetic. The Pay Rock dips southerly at 40°. At the end of the main tunnel it is shifted 12 feet to the east. The Silver Plume dips westerly at 80°, and in the upper level shows a side throw of 60 feet toward the west.

Not far from Gray's Peak is the International mine, so high that even in June the main tunnel was choked with ice. The vein is inclosed in granite, and strikes north 25° east, dipping westwardly at 65°. The ore is galena, and contains beautiful crystals of anglesite. It yields from forty to two hundred ounces of silver per ton.

At the head of the Montezuma Fork of Snake River the argentiferous veins are large and rich. The Silver-Wing lode strikes north 34° east true, and dips westward at 33°. The hanging-wall is well defined, and near it is a strong body of ore 18 to 20 inches wide. This ore consists of galena and blende, with much ruby and native silver. In small pockets the ruby silver is beautifully crystalline. The only working at the mill gave a yield of four hundred and fifteen ounces of silver per ton. This is a fine vein, and is well opened. The Comstock lode, on the opposite side of the mountain, strikes almost northeast, and dips northwest at 70°. Both walls are said to be well defined. The ore unselected averages sixty ounces of silver per ton, and consists of galena, gray copper, and blende, with some ruby and brittle silver. In this, as in the Silver Wing, much carbonate of barium occurs with the ore.

CHAPTER XII.

PALAEOZOIC ROCKS.

SECTION I.—SILURIAN AGE.
SECTION II.—CARBONIFEROUS ROCKS.

SECTION I.

SILURIAN AGE.

The thickness of the Silurian rocks within the district visited is not great, and it is difficult, or almost impossible, to determine with certainty the boundary between them and the Carboniferous, which everywhere rest conformably upon them.

Rocks of the Silurian age were identified in the mountains forming the western boundary of South Park, not only in ravines opening into the park, but also in the Arkansas Cañon through that range and at various localities in the same range, along the Upper Arkansas. Thence they were traced across the divide by Tennessee Pass to Eagle River, South Fork, in whose great cañon they are finely exposed. No rocks of this age were satisfactorily recognized on the east side of South Park, or along the Greenhorn Mountains, though above Cañon City rolled fragments of a very siliceous limestone were seen containing well-marked examples of *Orthis lynx*, *Rhynchonella capax*, and *Leptaena sericea*, thus proving beyond doubt the existence of Lower Silurian rocks in the vicinity. The Silurian was not recognized along the east face of Pike's Peak range from Cañon City to Golden. It is possible, however, that some portion of the enormous deposit of red and gray sandstone, extending along the face of the mountains and around their extremity, may belong to this age, but as the deposit is unbroken throughout, and is entirely devoid of fossils, I am inclined to regard the whole as belonging to a later age, and to believe, that if the Silurian be indeed present, it was not exposed by the upheaval, and that, along the east face of the Pike's Peak range at least, its western limit is some distance east from the range, having been overlapped during a time of subsidence by the succeeding deposit, which is now exposed.

In South Park the Silurian rocks are exposed more or less satisfactorily in every large cañon from Mount Lincoln southward. Here, as at other localities, I have regarded as Silurian all strata underlying the Carboniferous limestone. The following section was obtained on Bald Peak, in the cañon of Four-Mile Creek, descending:

	Feet.
1. *Limestone*, red, argillaceous, fissile, much affected by metamorphic agents; non-fossiliferous, but containing curious concretionary markings, whose section resembles a weathered *Discina*. Some portions banded white and blue	20
2. *Sandstone*, more or less conglomerate throughout, especially so near the top, where the fragments are of large size and cemented by carbonate of lime, which often exhibits fine geodes of dog-tooth and pearl spar. Below, it is finer in grain, showing rounded pebbles. Some thin and fine-grained layers are entirely metamorphosed, being a structureless quartzite	25
3. *Sandstone*, fine-grained, mostly converted into quartzite	75
4. *Sandstone*, thoroughly metamorphosed into a brittle quartzite. Indistinct fucoidal markings are not rare. Some layers are micaceous; others, ferruginous. It contains a thin layer of siliceous limestone	70
5. *Limestone*. Between this and the sandstone above is a stratum of red shale 3 feet thick. The rock is coarsely crystalline in many portions, but for the most part is very siliceous. The surface on top, immediately underlying the red shale, is covered with indistinct markings, whose relations cannot be determined. Some of the layers contain molluscan fossils, usually too imperfect for even generic identification. Near the base, a siliceous layer about 3 feet thick is made up entirely of individuals belonging to *Orthis?* They weather out badly, and two imperfect specimens only were obtained. Farther up the cañon, at another exposure, where the rock is less affected by metamorphosis, an *Orthoceras* and a nautiloid shell were observed, but the rock was so fissile that both specimens were hopelessly shattered in the effort to work them out	40
6. *Sandstone*, calcareous, thin bedded, in some portions shaly, with dendritic markings, fine-grained, light-gray, with faint traces of fossils	23
7. *Sandstone*, unaltered, coarse-grained, dark-gray, some shaly partings, with carbonaceous matter and fucoidal markings	17
8. *Sandstone*, almost unaltered, reddish, irregular in structure, much cross-bedding, many thin, shaly layers with carbonaceous matter	35
9. *Sandstone*, somewhat altered, bluish-black to reddish-gray. Layers of the former color contain much mica and bear some resemblance to mica schist	12

Feet.

10. *Sandstone*, for the most part entirely metamorphosed; color, white to light-gray. The lines of cleavage are very distinct, and are at right angles to each other, one set striking north 40° east, and the others north 40° west, magnetic. In these lines of cleavage are thin deposits of quartz one-eighth to one-fourth of an inch thick, which show slickensided surfaces.......... 35

The last stratum rests on the metamorphic rocks, which here are ordinary mica schist with more or less segregated granite. The last four strata are undoubtedly one, but the division was made to show the gradual disappearance of the metamorphism in the stratum, that it may be contrasted with the conditions above, where metamorphic action has been quite as effective as in Nos. 9 and 10.

On Fairchild's Creek, near the village of Buckskin, these rocks are again exposed. The thickness of the sandstones, which there have been wholly converted into light-colored quartzites, is 175 feet, as repeatedly measured by Mr. Alfred Dubois, of Buckskin. Upon the quartzites rests a siliceous limestone of light color, somewhat metamorphosed by the intrusion of eruptive rocks, which, in one locality, have separated the layers and forced themselves between them. Though siliceous, some portions of this limestone have been burned, and the lime was of fair quality. On Mount Lincoln the series is well exposed, and there the quartzite at the base is dark-colored, and might readily be mistaken for limestone if hurriedly examined. Northward along this range, in the valley of Blue River, the same rocks are seen, and the quartzite below is light-colored as at Bald Peak.

Following the eastern slope of the range southward from Bald Peak, we find at Stony Point Pass the same white quartzite on the summit, while above it is the limestone with *Discina*-like markings, blue and unaltered. At Trout Creek Pass the white quartzite is replaced by a massive, dark-blue quartzite nearly 200 feet thick, which weathers much like limestone. The weathered surface is often curiously pitted, as though it were regularly honey combed by thin, hard seams, and the interstices filled by a softer material. Here the stratum rests on a coarse, feldspathic granite.

Still farther south in the cañon of the Arkansas, and about four miles below the mouth of the South Arkansas, the series is well displayed, giving the following section, descending:

	Feet.
1. *Sandstone*, partially altered, with layers of quartzite; somewhat argillaceous; weathers to ochery color; contains many large fragments of jasper.	75
2. *Clay*, calcareous, indurated, reddish, weathers into mud	20
3. *Limestone*, siliceous above, more argillaceous below, with thin layers of comparatively pure bluish limestone..	27
4. *Limestone*, varying from dove-color to black; several argillaceous layers; near the top vast numbers of crinoidal stems, with many sections of cyathophylloid corals and *Brachiopoda*. As these are not silicified, they cannot be separated. Near the base is a thin, argillaceous layer, which contains many compressed individuals of *Rhynchospira* sp., and occasionally a bryozoan. From this layer was obtained also a fragment of a large trilobite	35
5. *Limestone*, mostly quite siliceous and compact; varies from dove-color to black; layers of the latter color are very fetid when struck; weathers in lines and disintegrates readily; almost entirely non-fossiliferous, but near the top saw a few crinoidal plates, and some very indistinct bryozoans....	50
6. *Sandstone*, grayish-blue in color, fine-grained, and entirely converted into quartzite. Below this we find an exceedingly dark, hornblendic gneiss.	

This section differs very materially from that obtained at Bald Peak. There we have but 60 feet of limestone, and that in two strata, separated by 170 feet of sandstone, whereas here we find 112 feet of limestone in one mass. The conglomerate is absent, unless it be represented by No. 1, while the quartzite at the base is bluish and not white. The limestones, Nos. 3, 4, and 5 of this section, are certainly equivalent to No. 5 of the Bald Peak section, and it is more than probable that the Arkansas exposure does not exhibit the complete section, being defective on top.

Ascending the Arkansas, these rocks are seen at several localities near the crest of the range on the east. The dark quartzite at the base disappears between Trout Creek and Stony Point Passes, and the white quartzite prevails to the headwaters of the stream. At the head of Iowa and California gulches it is beautifully dendritic. Following it to Tennessee Pass, we find fragments of it scattered in great numbers over the surface of the enormous moraine through which that stream flows. These can be traced along the stream to within three miles of its head in the main divide. There can be no doubt, therefore, that, although now unknown on this range west from the Arkansas, at one time the Silurian rocks stretched across the space where now we find the broad valley of the river, and covered the crest of the range at the west. The white quartzite is traceable across the divide at Tennessee Pass, in small isolated patches, which have escaped removal by erosion; but when we descend to the South Fork of the Eagle River, it has disappeared, or has changed its lithological character, for there a massive, dark quartzite rests upon the gneiss. No detailed section was obtained in this region, owing to the extreme haste in which we passed through it; but the exposures are exceedingly fine, and the section appears to differ little from that of Bald Peak.

On Taylor River, at its head and along the west side of Taylor Park, as well as at its southeast corner, the Silurian rocks are well exposed, underlying the Carboniferous. So, also, at the head of Tumichi Creek. Throughout this region it seems to be almost entirely free from limestones, and the sandstones give no evidence of calcareous matter. At the head of Taylor River the following section, descending, was obtained:

	Feet.
1. *Sandstone*, very dark, somewhat vesicular in portions; contains much calc-spar and some iron-ore. It is not at all certain that this is Silurian. In many respects it is more nearly allied to the Carboniferous above	20
2. *Sandstone*, completely converted into quartzite; fine-grained, light-gray	20
3. *Shale*, arenaceous above, white on fresh fracture, bright buff on weathered surface. Below quite argillaceous, with layers of cone-in-cone and in parts quite micaceous	18
4. *Sandstone*, quartzite, coarse above, fine below; contains much chert, usually in lenticular nodules, but sometimes united so as to form continuous layers; this chert is mostly bluish-black, but occasionally light-colored and dendritic; geodes of quartz are numerous, 1 to 3 inches in diameter. The stratum is very thick-bedded	75
5. *Sandstone*, slightly altered, grayish-yellow, fine-grained, micaceous, shaly, with thin films of quartz along cleavage-planes	45
6. *Sandstone*, on top completely altered, and for 20 feet has fracture like flint, is perfectly smooth, without grain, but shows clearly the lines of deposition; color, bluish-white. Lower down, is less altered, and the rock is a coarse-grained, compact sandstone. At the base is a conglomerate quartzite, the pebbles being usually as large as a pea. This stratum rests upon coarse granite	70

At the head of Taylor Cañon, No. 4 is quite light in color, and the chert is almost white, while at the head of Tumichi Creek it is as described in the section above. At the head of the cañon, No. 5 is greatly increased in thickness, and is of Venetian-red or burnt-umber color, and has the same character where exposed along the headwaters of Tumichi Creek. Along the old miners' trail from Taylor to East River, this section is occasionally seen, and differs from that given above only in that No. 3 becomes quite calcareous, being at one locality an argillaceous limestone. Nos. 3 and 5 are very characteristic and persistent throughout this region. In the southern portion of this area, the Silurian has always been thin. On the lower portion of Tumichi Creek, and at two localities west from the Indian agency, isolated exposures are seen where erosion has removed the overlying eruptive rocks. The rocks here belong wholly to No. 6 of the section above, and have a total thickness of not more than 70 or 80 feet.

Minerals.—The mineral-deposits in the Silurian are of little interest. At Buckskin, in Park County, some irregular and ill-defined deposits of iron pyrites occur, which carry a large percentage of gold and silver. These have not proved of permanent value, though most of them have at times yielded a considerable quantity of very rich ore. Mr. Alfred Dubois, of Buckskin, has made frequent analyses of the quartzite in that vicinity, and in every instance has found an appreciable amount of gold. Near Oro City, at the head of California gulch, some irregular seams of gold-bearing ferruginous quartz occur in the quartzite, but are not worth working. It is quite probable that these quartzites contributed not a little to the enormous deposit of placer-gold which rendered that gulch so famous fourteen years ago. In like manner it is likely that the same rocks are the source of some of the gold in the Blue River placers below Breckenridge, though most of it was derived from the eruptive rocks.

SECTION II.

CARBONIFEROUS ROCKS.

The Carboniferous formation is very widely distributed, having been identified in the range forming the western boundary of South Park, and in its southern extension, the Sangre de Cristo Mountains, as well as west from the main divide, where its rocks are the prevalent ones north from the union of Tumichi Creek and the Gunnison River. South from the Rio Grande, in the San Juan area, they were identified over a large extent of country, where they rest upon the flanks of the mountain-axes.

But though thus widely distributed, satisfactory or connected sections are rare, even west from the divide, and a complete section of the whole series can be obtained only by following down the South Fork of Eagle River to its junction with the North Fork, and following the latter to its head. As exhibited there and elsewhere, the succession seems to consist of, first, a group of sandstones, resting on a thick limestone, and holding beds of gypsum, interstratified with thin limestones; second, resting on No. 1, a group of limestones and coarse sandstones; third, above all, a great mass of coarse sandstone, in which no beds of limestone were seen. This series is seen in full, without a single break, on the forks of Eagle River.

Near the head of Rock Creek, the following section, descending, was obtained, which is very incomplete, but possesses much interest, as it gives a good idea of the character of the rocks belonging to this age:

	Feet.
1. *Limestone*, black, very compact, with but little siliceous matter; is very rich in fossils, which readily separate from the rock in weathering. The most abundant species are *Spirifer cameratus*, *S. lineatus*, *S. rockymontani*, *Spiriferina kentuckensis*, *Retzia mormonii*, *Athyris* sp., *Rhynchonella uta*, *Productus muricatus*, *Chonetes*, n. sp., *Astartella vera*, *Bellerophon carbonarius*, *Pleurotomaria*, near *P. grayvilliensis*, *Euomphalus sub-rugosus*, *Lophophyllum proliferum*, and spines of a *Zeacrinus*, nearly allied to *Z. mucrospinus*.	10
2. *Conglomerate;* the fragments are principally a bluish limestone	25
3. *Sandstone*, red, shaly, micaceous, with rude fucoidal impressions	15
4. *Shale*, arenaceous, drab; some mica	15
5. *Limestone*, black, compact, with seams of calc-spar; some fossils	8
6. *Sandstone*, gray, shaly, micaceous	12
7. *Limestone*, black, siliceous, non-fossiliferous	2
8. *Limestone*, very light blue, weathering yellow, somewhat micaceous, non-fossiliferous	15
9. *Sandstone*, light-gray, micaceous, fine-grained and thin-bedded; shows numerous vertical seams of calc-spar, and includes a layer of limestone, 1 foot.	100
10. *Limestone*, blue, non-fossiliferous, above compact, below argillaceous and shaly	10
11. *Sandstone*, red, shaly, comparatively fine-grained	50
12. *Conglomerate* and *sandstone*, at the base of this mass there are 35 feet of very coarse conglomerate, made up of gneiss, quartzite, chert, and limestone, the latter predominating. Above this, for 30 feet, the rock is a coarse sandstone. From the sixty-fifth to the one hundred and eightieth foot the conglomerate gradually displaces the sandstone, and at last becomes exceedingly coarse, containing fragments of gneiss and limestone 6 inches in diameter, as well as much larger fragments of a coarsely conglomerate sandstone. Above 180 feet, the conglomerate alternates with a blood-red	

	Feet.
micaceous sandstone, very fine-grained, thin-bedded, and showing casts of flowing mud. In the lower conglomerate there are many cross-seams of calc-spar, which cut the limestone fragments, but in no wise affect those of gneiss or quartzite	225
13. *Sandstone*, fine-grained, shows cross-bedding everywhere, below white, but gradually changes into blood-red above; more or less micaceous throughout	60
14. *Limestone*, siliceous, dark-blue, very compact, non-fossiliferous; contains numerous seams of arragonite and some of chert	15
15. *Shale*, gray, arenaceous, not well exposed	60
16. *Sandstone*, slightly altered, with thin, calcareous layers, red, quite ferruginous, shaly, and brittle	20
17. *Sandstone*, white to light-blue, for the most part fine-grained, but containing occasional layers of coarse conglomerate, made up of chert, quartzite, and limestone, the fragments varying from 1 to 3 inches in diameter. Toward the top it contains many thin layers of quartzite, alternating with bluish shale, and on top it is a coarse, red, feldspathic sandstone	60
18. *Sandstone*, shaly reddish-brown; contains much iron, disseminated and in nodules; slightly altered near the top, where it is less shaly and of light green color	125
19. *Limestone*, dark reddish-blue, weathering light-blue, non-fossiliferous, very compact, and breaking with conchoidal fracture	25
20. *Shale*, unaltered, fissile, upper portion bluish-black, middle drab, and lower portion dark-gray; below, contains a few fossils, which seem to be all arranged across the bedding, and so are invariably broken up in getting them out; above, it contains many thin seams of arragonite, and occasionally films of calc-spar crossing the bedding. Near the top it is somewhat arenaceous	300
21. *Conglomerate*	20
22. *Concealed*	30
23. *Shale*, on top unaltered, ash-colored, argillaceous; in middle, bluish-gray, with some compact layers, containing indistinct fossils; at the base, bluish-black and arenaceous, with occasional thin layers of quartzite. Some galena near the base. The lower portion is not well exposed. Except in the thickness this stratum is almost an exact duplicate of No. 20	225
24. *Sandstone*, quartzite, very fine-grained, light-blue to dark-brown, slightly calcareous; contains much galena	45
25. *Sandstone* and *conglomerate*, completely altered throughout. Upper portion is light-colored, fine-grained quartzite, in layers, 2 to 6 inches thick. The main mass is conglomerate, gray to white, weathering reddish-brown, and made up of grains varying from fine sand to one-half inch in diameter. It contains rounded fragments of gypsum, oval in outline, and 1 to 3 inches long. Toward the top, these are replaced by quartz-pebbles and geodes. Toward the base, they are less numerous, and the rock shows cross-bedding	200

		Feet.
26.	*Limestone*, siliceous, dark-blue, but weathering to dove-color; contains some exceedingly minute and imperfect fossils	30
27.	*Sandstone*, completely altered into quartzite. Portions of this stratum are exceedingly rich in galena, which is disseminated, in greater or less quantity, throughout the entire mass. At two small openings, made by prospecters, galena, with iron and copper pyrites, is seen irregularly distributed in strings. The galena is often aggregated against thin films of quartz occupying the cleavage-planes, and occasionally surrounds geodes of quartz. Blue and gray copper occur sparingly, and hematite, in stellate crystals, is present in considerable quantity. The thickness was not satisfactorily determined	150
28.	*Concealed;* in this space there is some dark-blue limestone	100
29.	*Sandstone*, quartzite, contains much galena, associated with zinc-blende, gray copper, and hematite	20
30.	*Shale*, calcareous, with thin layer of gypsum on top	15
31.	*Gypsum*, anhydrite, rudely concentric in structure, and on weathered surface looks as though composed of nodules cemented by finer gypsum	30
32.	*Limestone*, blue, shaly, siliceous. Fossils, unsilicified and obscure; some sections of *Spirifer*, *Productus*, and *Lophophyllum*	25
33.	*Sandstone*, quartzite, dark-colored, thin layers; contains much galena, aggregated in layers or in nodules, the former one-half inch to three inches thick. The metalliferous portion is about 30 feet thick	60
34.	*Gypsum*	25
35.	*Sandstone*, quartzite, calcareous on top; contains an irregular layer of gypsum	45
36.	*Sandstone*, quartzite, thin-bedded, alternately dark-brown and light-blue, the former containing some galena	40
37.	*Gypsum*, separated near the middle by a thin, dark-brown quartzite containing much galena	65
38.	*Sandstone*, quartzite, dull dark-brown, with much galena and gray copper disseminated throughout the mass	30
39.	*Sandstone*, quartzite, snow-white and friable below, bluish, calcareous above	25
40.	*Sandstone*, quartzite, variable in color; contains a few very thin layers of limestone, and some galena	100
41.	*Limestone*, blue to bluish-gray, shaly, and somewhat siliceous above. Near the middle contains a thin layer of gypsum; shows many fossils on the weathered surface, among which are *Spirifer cameratus*, *Retzia mormonii*, and fragments of *Chonetes* and *Productus*	20
42.	*Sandstone*, quartzite; at base, reddish-brown, much drusy quartz, accompanied by azurite and galena; above, it is very dark, with much iron, and occasional geodes of galena; on top, coarse, light-gray, and not metalliferous; exposed	70

With this stratum the section stops in this vicinity, all exposures of lower rocks being inaccessible or concealed by heavy slides of *débris*. At the head of the West Fork of Taylor River the base of the series is well exposed, but there is a gap of unknown thickness between No. 42 of the Rock Creek section and the highest stratum accessible on Taylor River. This interval is occupied principally by coarse sandstones, which were observed with the glass, and seen to underlie the gypsum. The section continued, then, would be as follows:

	Feet.
43. *Sandstones*, coarse, red to gray.	
44. *Conglomerate*, a coarse sandstone with many large fragments of limestone..	100
45. *Shale* and *sandstone*. The shale is dark-brown to black, and contains much carbonate of iron, which is sometimes a black-band of very low grade, alternating with more or less plate-ore. The plates vary in thickness from 2 to 3 inches, and often give place to nodular calcareous ore. The shaly ore is very sulphurous, and probably of no value. It is persistent for only a short distance, changing abruptly into one or other of the more compact varieties	100
46. *Limestone*, dark-blue to almost black, but weathering to light bluish-gray; is fissile, and contains much calc-spar in seams, masses, and geodes. The stratum is massive, some layers being 20 feet thick. The sparry character is more pronounced near the base. Fossils are numerous, but not being silicified cannot be separated from the rock. For the most part they are corals, *Syringopora* and cyathophylloid forms. Sections of *Productus* and *Spirifer* are not infrequent	75
47. *Limestone*, varies from dark-blue to red, yellow, and white; contains much iron, with some carbonate of copper and galena; is very sparry, the spar being in thick strings, so interwoven as to give the surface a honey-combed appearance	25
48. *Limestone*, on top grayish-blue, hard, and showing a few very minute fossils. Spar occurs in thin lines, and sometimes in nodules, five or six inches in diameter. Contains occasional nodules of chert, and is somewhat altered. Farther down it becomes siliceous, and runs into a coarse sandstone about 1 foot thick. Under this is a yellowish layer, with wavy lines upon the surface, which changes gradually into a black limestone below, containing much iron on calc and dog-tooth spar. At the base is a dull-yellow limestone, somewhat argillaceous, and thinly banded with white and blue....	40

In the curious divide between Rock Creek and Roaring Fork, of which we shall speak at length in Chapter V, these rocks apparently occur in full, the limestone being seen at the base of the ridge looking toward Roaring Fork, while above it rises an unbroken cliff of nearly 2,000 feet. On the west side of the ridge the whole face is precipitous, and is made up of red and gray sandstones, with shales, an alternation of colors which aids much in producing the peculiar effect which the ridge has upon the eye.

As we were at no time nearer to this divide than six miles, it is not possible to state anything respecting the occurrence of limestones there.

In Taylor Park the Carboniferous are seen occasionally in fragmentary exposures on the crest of the ridge forming the western boundary of the park, but none are satisfactory until we pass the head of the cañon and enter Beattie Park, the southern prolongation of Taylor. Here, along the western side, the limestone at the base is well exposed for miles and dips sharply eastward. It can be traced almost uninterruptedly across the divide to the headwaters of the Tumichi Creek, showing the characters given under Nos. 46 and 47. It differs, however, in that it contains a good deal of nodular chert, which seems to have concreted about fossils, for in many of the nodules specimens of *Productus semi-reticulatus* were observed. On the east side of the park the limestone was not seen, but there are some sandstones, whose exact position was not determined, although they undoubtedly belong to this age. Between Taylor and East Rivers, along the old miners' trail, this limestone is frequently seen, owing to the numerous faults in this ridge. At three localities, within six miles, it is seen upturned almost on edge. It is dull bluish-gray on the weathered surface, with but little cherty matter, and contains the usual radiate fossils in abundance. Twelve miles from Taylor River we find the lower portion of the series well developed, but differing somewhat from the section as observed at the head of that river. The shales, No. 45, are here nearly 200 feet thick, dark-colored, and containing several thin bands of limestone. They contain many ferruginous nodules, but not in connected layers. As a whole the mass may be regarded as non-fossiliferous, though in two thin arenaceous layers bits of carbonaceous matter, the remains of plant-stems, are abundant, and, in a black limestone, minute *Lamellibranchi* resembling *Cardiomorpha* are quite numerous. From the limestone underneath I obtained an imperfect specimen of *Productus nebrascensis*. Above the shales is a coarse sandstone, which is the base of the conglomerate, No. 44, fragments of which are thickly strewn over the whole surface in the vicinity. Thence to East River, along the trail, Carboniferous rocks are seldom seen, and the exposures belong chiefly to the Silurian.

The strata, from 16 to 25, inclusive, are undoubtedly *Cretaceous*, notwithstanding their anomalous position. The shales form a striking feature in the scenery on both the East and West Forks of East River above the junction and near the heads of these streams cover the hills, giving a very somber appearance to the whole region. At first sight, along the line of section, the series appears to be continuous, the shales being evidently conformable, the whole having an eastward dip, increasing in sharpness from the base to the top of the section. But similar shales holding this relative position are unknown elsewhere in the Carboniferous of this region, and the lithological character is precisely that of the Middle Cretaceous, as seen in the San Juan area. The section gives some evidence of terrible disturbance, for Nos. 20 and 23 are exact duplicates only in reverse order, such as would occur were a compound stratum folded closely upon itself. No satisfactory fossils were obtained in place here, though numerous *Gryphæa*-like impressions were obtained. One fragment of a Cretaceous *Ostrea* was found in *débris*, but unfortunately has been mislaid. The impressions occur in the drab, slightly Calcareous portions of both 20 and 23. These shales are traceable to the junction of the forks of East River, where they are overlaid by volcanic rocks and contain *Inoceramus*. At the junction of East and Taylor Rivers the sandstones of the Lower Cretaceous occur.

In crossing from the West Fork of East River to Ohio Creek the dark shales are seen at one locality covered by trachyte which has issued from a fissure involving the shales. The lines of superior and lateral contact are distinctly visible, but the shales are unaltered except for a few inches from the contact.

Exposures of sedimentary rocks are rare along Ohio Creek, as the whole country is covered by eruptive rocks, and where these have been removed a deep mass of *débris* conceals everything. No Carboniferous rocks were seen before reaching Tumichi Creek, where, at a few miles above its mouth, some quartzites occur which very probably belong to the lower portion of the section. Southward from Tumichi Creek everything is deeply buried under the eruptive rocks. From the headwaters of the North Fork of that stream to near Hunt's Peak the Carboniferous rocks, as exhibited in the Taylor River portion of the section, extend as a series of strips resulting from the numerous faults.

On the forks of the Eagle River, beginning on the South Fork about four miles above the junction, and following round to the head-waters of the North Fork, there is an unbroken section of the whole series of Carboniferous rocks. If we cross the divide and follow them down the West Fork of Ten-Mile Creek, we find the highest rocks of the series abutting against the granite wall forming the west side of the Blue River range. This they seem to do as far as our survey extended. The dip is somewhat flexuous, but the prevalent direction is sharply toward north of northeast. The section there obtained, beginning at the head of the North Fork, is as follows, descending:

	Feet.
1. *Sandstones.* These are coarse throughout, and, for the most part, of a reddish-gray color. About 400 feet from the base is a thick stratum of light-gray, very coarse rock, which is persistent. There are other similar layers. Limestones and shales seem to be entirely wanting. These rocks form the walls of the cañon of the North Fork, and at its mouth, six miles from the head, the lower portion forms a bluff 1,200 feet high; estimated thickness	2,500
2. *Limestone,* dark-blue, weathering dove-color; slaty, argillaceous, non-fossiliferous	3
3. *Sandstone,* gray, ripple-marked, thinly laminated, laminæ separated by films of mica	4
4. *Limestone,* very dark-blue, shaly, micaceous, non-fossiliferous	2
5. *Sandstone,* compact, fine-grained, very light-gray	4
6. *Limestone,* very dark-blue, somewhat siliceous, compact, slightly conglomerate, some sulphuret of iron distributed, fossils rare and indistinct	1
7. *Sandstone,* light-gray, very friable, fine-grained, and micaceous above. In middle, reddish, with cross-bedding; at base, very fine-grained, hard, and slightly calcareous	12
	Inches.
8. *Limestone,* dark-blue, siliceous, contains a few minute crinoidal stems	10
	Feet.
9. *Sandstone,* color varies from dark-brown to nearly white; at top is conglomerate for several feet; below, consists of alternate layers of conglomerate and fine-grained sandstone. Fragments in conglomerate seldom larger than a pea, and are chiefly quartz, with some feldspar, limestone, and mica schist. All parts of this stratum are not satisfactorily exposed. About midway, there seems to be a thin layer of blue, siliceous limestone, containing many minute fossils	45
10. *Concealed.* Probably coarse, reddish sandstone throughout, there being several exposures of that rock in this interval	70
11. *Conglomerate,* quite coarse	10

	Feet.
12. *Sandstone*, reddish-gray, micaceous, fine-grained, except at base, where it is conglomerate with fragments 1 inch in diameter....	40
13. *Limestone*, on top, gray, shaly, micaceous; lower, blue, siliceous, and very hard; then, blue, shaly, ferruginous, and weathering yellow; at base, bluish-gray, shaly, micaceous, and passes imperceptibly into No. 14....	12
14. *Sandstone*, light reddish-gray, laminated, micaceous, calcareous	10
15. *Imperfectly exposed.* At Red Mountain, four miles above the junction of the forks, where this section was obtained, this interval is mostly concealed; but in a bluff three miles farther up the stream, it is occupied by limestones and sandstones. The former predominate and are bluish-gray and fossiliferous. The latter are fine-grained and reddish-gray. From the limestones I obtained *Athyris subtilita*, a *Bellerophon*, near *B. montfortianus* and *Lophophyllum proliferum*	100
16. *Sandstone*, red to gray, laminated, soft, micaceous.......	25
17. *Limestone*, blue to nearly black, somewhat siliceous and very brittle; compact above, shaly below; shaly portions almost black, with thin films of quartz and cherty nodules; fossils numerous and minute, chiefly crinoidal stems, with occasional mollusks, but all so badly weathered as to be indeterminate under a strong glass.........................	20
18. *Sandstone*, above, gray to white, and coarse; below, red and very coarse....	75
19. *Sandstone* and *Limestone.* Not well exposed; some shale; sandstone fine-grained and gray. Near the middle of this interval is a limestone, 7 feet, bluish-gray, brittle, and with much calcspar. It is rich in individuals of a few species of fossils, among which are *Productus prattenianus*, *Productus muricatus*, *Spirifer Rocky-Montani*, *Retzia Mormonii*, and *Athyris* sp. These all occur in good condition.....................................	50
20. *Sandstone*, light-gray, friable, shows much cross-bedding..................	20
21. *Sandstones* and *Shales*, including the *Gypsum* beds. This enormous mass is first seen on the North Fork, about three miles above the junction of the two forks, and continues in view along the South Fork to above the cañon. The gypsum-beds are best seen below the junction, where they are visible for seven or eight miles, the stream running in the direction of the strike. In the upper portion, for 700 or 800 feet, there is nothing but very coarse sandstones, some of which are very coarsely conglomerate, containing fragments of gneiss, in many, 10 inches long and 4 to 8 inches wide and thick. These fragments are but little water-worn. In this portion the color is reddish-gray. As we ascend the South Fork, we find the character changing. The sandstones become finer in grain and less massive, many of them being laminated. The color becomes lighter, and light-yellow is the prevailing tint. Interstratified with the sandstones are reddish arenaceous shales, which, as we descend in the series, increase in importance, until at length they equal in amount the sandstones with which they are interstratified. The yellow sandstones are more or less ripple-marked, and one enormous stratum of conglomerate, nearly 150 feet thick, shows as handsome ripple-marking on its finer layers as I have ever seen. This group is fully exposed	

	Feet.
along the South Fork. It was examined as closely as was possible under the circumstances, but no limestones were seen; estimated thickness.....	2,000
22. *Conglomerate.* This is somewhat altered, but in all other respects resembles the conglomerate seen at the head of Taylor River; exposed............	40

With this stratum, which is not more than 200 feet above the bottom limestone, the measured section closes. The river here issues from a deep, narrow cañon, in which the lower rocks of the Carboniferous can be seen, which is utterly impassable, and the trail mounts rapidly up the cliff, and continues along the edge of the cañon for several miles. Here the whole country is covered with *débris*, and no exposures were seen. Along the trail, however, fragments of the Carboniferous limestone were seen mingled with others of Silurian Age.

It is somewhat difficult to connect this section with that obtained on Rock Creek. The portion from No. 2 to No. 19, inclusive, bears some resemblance to the group overlying No. 20 of the Rock Creek section, in case we regard the latter as inverted. Still, this comparison would require a very considerable thickening of the sandstones westward, the number and general character of the limestones being much the same in each case. I am free to confess that the material at my command does not justify me in any attempt to connect these sections to any degree of detail. Our line of survey did not extend far enough northwestward to enable me to pass round the short mountain spur on the west side of the Eagle, so as to make direct junction with the rocks of Roaring Fork, and thence with those of Rock Creek. The exact relations can be determined in no way other than by making detailed sections along this somewhat crooked line. In addition to this, the country between Roaring Fork and Rock Creek is faulted in so eccentric a manner, that to make any conjecture whatever respecting its geology would be hazardous in the extreme.

Crossing Tennessee Pass, we reach the Arkansas region. On the west side of this river no rocks belonging to the Carboniferous are seen until we reach the vicinity of Hunt's Peak. Specimens brought to me by members of our party show that there these rocks occur. To what extent I am unable to say, as I was unable to visit the locality. That the Silurian rocks at one time reached to the west side of the river has already been asserted, and I feel no doubt that the Carboniferous rocks, before the great upheaval causing the mountains, formed an unbroken sheet, stretching from South Park westward to beyond our western line.

On the east side of the river, upon the ridge separating it from South Park, the exposures are by no means infrequent, but they show only the base of the series. At Iowa Gulch, immediately south from Oro City, there is a very satisfactory exhibition. The crest of the ridge is covered by trachyte, below which is a mass of sandstones resting on the dark limestone, which here does not weather to a light color. Immediately underlying this limestone is a thin stratum, much resembling one in similar position at the head of Taylor River. A section of this gives, descending—

1. *Limestone*, with much azurite, some malachite, and gray copper....	3 feet.
2. *Hematite*..	1 foot 6 inches.
3. *Limestone*, with azurite, hematite, heavy spar, and some galena....	1 foot 6 inches.

Nos. 2 and 3 are quite rich in silver. The stratum rests upon a light-colored siliceous limestone. Following down the river to its cañon, through this ridge, we find, about two miles below the head of the cañon, the limestone well exposed, while not far above, and separated by shales and sandstone, the gypsum beds are seen on both sides of the river. The ready decomposition of these beds has covered the walls with variegated *débris*, a feature by no means uncommon. Upon the gypsum rests an enormous mass of reddish and gray sandstones and shales, not less than 2,500 feet thick, which form the cañon's walls to its mouth at Pleasant Valley. Here, as on Eagle River, no limestones were observed. The sandstones are coarse, and, where massive, show cross-bedding. The shales are all arenaceous, and in greater quantity toward the base. The whole mass is micaceous. Following this range southward, we find these sandstones in the Sangre de Cristo Mountains, until we pass the divide between Wet Mountain Valley and Huerfano Park. Beyond this to Sangre de Cristo Pass they have been cut off by dikes and removed by erosion. The lower portion of the group is very coarsely conglomerate, with rolled fragments of granite and gneiss, varying in size from 2 to 8 inches in diameter. In Sangre de Cristo Pass the sandstones are finely exposed, and at one locality the limestone is seen, with many imperfect fossils, of which *Productus semi-reticulatus* is most abundant.

Going northward and following the eastern slope of this range, we trace the Carboniferous rocks into South Park. At Trout Creek Pass the limestone is seen, with the overlying sandstones and shales. A curious condition exists in the pass, for the sandstones are seen abutting against the Silurian rocks, while the Carboniferous limestone is far above them on the cliffs. It would seem as though there had been a double fault here crossing the line of strike.

In the cañon of the South Fork of the Platte the limestone is occasionally seen. Where the cañon opens out there are numerous exposures of the gypsum beds, resting on a reddish-gray sandstone. The gypsum is of a dull gray color, and is by no means so pure as that seen on Rock Creek. Though containing much foreign matter, it is burned and employed in finishing the interior of houses. It is known as "mountain gypsum." The demand must be somewhat extensive, for along the road numerous heaps were seen, and at one spot rude machinery had been erected for grinding it on a large scale. At no place in this vicinity is the rock exposed for a thickness of more than 40 feet. Followed southward, we find the same gypsum beds between the forks of Salt Creek, underlying the overflow of eruptive rock. Here the surface is broken down to a fine powder, and in wet weather the whole vicinity is covered with a gypsum mud. On the North Fork of Salt Creek there is a mass of fine-grained, rather shaly sandstones, red and gray, and more thickly bedded on top, having a total thickness at the exposure of about 150 feet. The precise relation of this to the gypsum was not accurately determined, but the latter seems to underlie it. The underlying sandstone is well exposed on Buffalo Peak, where it is capped by the eruptive rocks.

Following down Salt Creek, we find the surface deeply covered by gypsum, which has been mistaken by some for an alkaline efflorescence. At the Colorado Salt-Works is a butte capped by trachyte, but composed mainly of gypsiferous shales, overlaid by gray, thin bedded sandstone, more or less micaceous. The salt-works are quite extensive, but at the time of our visit were not in operation, owing to litigation among the owners. The brine is obtained from two springs, which must yield very abundantly, if the statements of those in charge can be relied upon. There is sufficient to produce from one hundred and fifty to two hundred barrels of salt daily, and the strength of the brine is 5.75° Beaumé, or about one-half pound of salt to the gallon. Two wells were drilled to reach the reservoir of brine, but were unsuccessful. No record of the borings was preserved, but in the first well the succession descending was shaly sandstone, conglomerate sandstone, and imperfect quartzite, the last at a depth of 150 feet. In the second, the tools were caught in gypsum at the depth of 225 feet, and the work was stopped. The salt is said to be of good quality.

From the cañon of South Fork of Platte, the Carboniferous rocks are more or less fully exposed in most of the deep ravines running far back into the mountains. On Four-Mile Creek, the limestone at the base is seen near the top of Bald Peak, very dark, almost black, and showing only rare fossils. Here, too, we find the curiously-banded limestone observed on Taylor River. In the cañon of Fairchild's Creek, the same rock is well seen, while above it the sandstone is exposed to a thickness of 270 feet. This contains many layers of lead-colored, somewhat argillaceous shale, with much iron-ore, and is clearly equivalent to the sandstone and shale directly overlying the limestone at the head of Taylor River. On Mount Lincoln the limestone is well exposed, and, like the same rock on Taylor River, is very sparry, especially in its lower portion. It is of much interest, as containing the singular deposit of silver-ore, which is now assuming some economical importance. On the crest of the mountain we find a thinly-bedded micaceous sandstone, of which but little is exposed. The metamorphic influence of a dike is well seen on this mountain, where for 3,000 feet no trees or vegetation of any sort conceal the rocks. A dike of moderate dimensions and almost vertical passes from the summit downward along the face. The sandstones in contact with it have been converted into a structureless quartzite for nearly 20 feet on each side, while the limestone was affected to a much less distance and to only a slight extent. Its color was changed from black to brownish-yellow and the rock was rendered fissile.

Along the eastern border of the park no Carboniferous rocks were seen, and, to my mind, it is doubtful whether they ever existed there. But at various localities, for eight miles east from the base of the mountains at the west, occasional exposures occur of coarse sandstones, with a few thin siliceous limestones of dark-blue color, and containing many small univalve mollusks. Following these exposures northward, we see on enormous mass of red and gray sandstones, more or less finely conglomerate, capping the mountains on the main divide, and including several of these thin limestones, two of which are seen in Hamilton Pass. This sandstone forms the crest of Mount Morton, and is the rock which prevails on the northwest side of Georgia Pass. On the Quandary Mountain, at the head of Blue River, the dark limestone was observed, and it was traced some distance northward. On Snake River the gypsum shales occur, and the rocks in the vicinity are evidently saliferous, as the springs have a distinctly brackish taste.

In the *San Juan* area* the Silurian rocks are nowhere exposed, or, if they are, it was impossible to identify them, and the Carboniferous series rests directly upon the metamorphic rocks. Along the upper portion of Rio de las Animas, the disturbance produced by dikes is so extensive, that the relations of the quartzites in the San Juan mining district could not be determined accurately during a preliminary reconnaissance. They belong to the Carboniferous series, but beyond this nothing was ascertained. The metamorphosis is complete, every trace of lamination having disappeared. These quartzites contain much iron pyrites, and numerous veins of argentiferous galena, more or less well defined, and for the most part quite narrow. Aside from these are some enormous deposits of galena, whose true character cannot be determined without extensive development. The quantity of argentiferous galena here is very great.

In crossing the first summit from the San Juan mines to Las Animas Park we find a mass of sandstone, more or less conglomerate, with some shale, and near the top a thin siliceous limestone, the whole having a thickness of about 500 feet. Leaving the summit the trail falls rapidly into a deep cañon between the first and second summits. In the sides of this cañon exposures are unsatisfactory at the best, and when we passed through the whole was covered with snow. Occasionally one sees a conglomerate sandstone of gray color, and here and there he catches a glimpse of a thin siliceous limestone containing few but characteristic fossils of Carboniferous

*The examination of this area was almost wholly for topographical purposes, and the geological notes are simply those of a hasty reconnaissance, with a view to more systematic work during the coming season of 1874.

Age. Near where the trail strikes the bottom of the cañon the limestone at the base is seen, at a depth of nearly 2,500 feet below the conglomerate on the summit, which I regard as belonging to the upper sandstone group of the Eagle River section.

On approaching the second summit we cross an axis on which are exposed some bluish quartzites, whose age is uncertain. At the summit the dark shales of the Taylor River section are well exposed. From this down the river to Animas Park the Carboniferous rocks continue in view on each side of the valley forming great bluffs. On Cascade Creek there is a dark-blue limestone, which contains in large masses a *Chaetetes*, which is hardly distinguishable from *C. milleporaceus* of the Coal-Measures in the Mississippi Valley. Together with this are numerous sections of crinoidal stems and of characteristic brachiopoda. About seven miles below Animas City another limestone was seen in the bluffs, which contains *Productus semi-reticulatus*, *Productus Prattenianus*, *Productus Nebrascensis*, and *Athyris subtilita*. The Carboniferous rocks are exposed no farther south than half way down Animas Park, where they underrun rocks, identified as Triassic, by Dr. Newberry, which rest unconformably against the older series. The Carboniferous rocks exposed along the Animas River from the second summit, referred to above, to the disappearance under the Trias, evidently belong altogether to the lower series of sandstones in the Eagle River section, and have a total thickness of little more than 1,200 feet. South from Lieutenant Macomb's trail from the Rio San Juan to the Rio de las Animas, no Carboniferous rocks are exposed in Colorado. Between those rivers, and north from the trail, they form the numerous hog-back ridges of the several anticlinal axes, but they disappear at some distance west from the San Juan, where the axes are so gentle that they involve also the overlying rocks. They are not seen again until we reach the Sierra San Juan, where they are entirely metamorphosed, and in an almost vertical position. On the trail from Tierra Amarilla, New Mexico, across this range to Conejos, Colorado, these rocks occasionally contain small amounts of galena and iron pyrites. On the east side of the San Juan axis the Carboniferous series is entirely concealed by the overflow of eruptive rocks.

Along the east face of the Rocky Mountains, the Pike's Peak, and Greenhorn ranges no Carboniferous rocks were seen. It is highly probable that, like the Silurian, the Carboniferous has its western outcrop far to the east of the base of the mountains, and that it is deeply buried under the more recent formations. This appears the more probable since we find the Triassic rocks tilted at an angle varying from twenty to eighty degrees, and in some cases even pushed over five or eight degrees, yet not exposing the underlying Carboniferous.

Careful investigations by Mr. Gilbert have proved the existence of a great limestone group at the base of the Carboniferous in Arizona, and full of remains, which show it to be of Lower Carboniferous age. A similar limestone, less thick, is at the base of our series, but the fossils obtained are insufficient to decide the question of age, as they are species of the widest range, reaching from near the bottom of the Lower Carboniferous to the Upper Coal-Measures. Enough has been found, however, to determine that the section at Rock Creek, as well as the limestones on North Fork of Eagle River, belong to the Coal-Measure epoch, the species of mollusks being those which are familiar to every one who has worked in either the Illinois or Appalachian coal-fields.

Economical geology of the Carboniferous.—As already intimated, the stratigraphical relations of the quartzites along the Upper Animas have not been accurately determined, though they, beyond doubt, belong to the Carboniferous. They hold mineral deposits which have attracted much attention in Colorado, and for several reasons deserve especial notice here. As one descends Cunningham's Gulch toward the Animas River he sees on the opposite side of the river an abrupt wall rising nearly 3,000 feet from the plain. On the face of this, quartz veins stand out in relief and interlace so as to form a rude net-work. The first impression is that a great number of logs have fallen down the cliff and been caught on projecting points of rock. From the head of the Animas to Baker's Park the veins are as distinct as these and show the same mode of interlacing. I know of no other district in our whole western region where the veins are so numerous, so distinct, or so easily followed as in this one.

Up to the time of our visit to this, the San Juan mining district, only one lode had been developed to any extent. This, the Little Giant, is evidently a true vein varying from 2 to 20 inches in width, but probably averaging about 4. In the quartz some zinc-blende, iron pyrites, and galena occur. With these is a dark chloritic rock, which not infrequently shows specks of native gold. The ore is *said* to be remarkably rich, and there seemed to be a very positive notion that a little pocket had yielded about $100,000.

In this district there are many very extensive deposits of low-grade galena and numberless thin veins carrying quite rich ore. But up to the time of our visit nothing had been done, and indeed nothing was known respecting the value of the lodes in the district. The many wild statements made, which produced so great excitement throughout the Territory, were based upon surmise, or very possibly were worse. That good mines may yet be found within the limits of the San Juan district is very probable, but none had been certainly proved to be such up to the middle of October, 1873, all claims being undeveloped.

The mines on Rock Creek are still undeveloped. In that vicinity there are no veins but mere aggregations of mineral matter in the Carboniferous rocks. They are not even gash-veins, and are of very uncertain extent and value. The ore is present at some localities in large quantity, and consists of galena, zinc-blende, iron and copper pyrites, with some gray copper.

On Mount Lincoln mining operations are carried on very extensively, but the manner in which the ore is distributed is still somewhat uncertain. As the manager of one company put it, "We all go for the ore as we do for potatoes." When a string of ore is seen it is followed up until it disappears. The deposit is in the limestone at the base of our Carboniferous series. Though so irregular in its distribution that discoveries have been taken up in every conceivable form, from lodes to ten-acre lots, it is nevertheless extensive, and many of the companies at work have been remarkably successful. Most of the mines yield only silver, but gold occurs in some of them in considerable proportion. The ore is principally galena and sulphuret of silver. In the mines producing gold, iron pyrites is found in addition. Along the range on the west side of South Park this limestone is argentiferous at nearly every exposure.

The gypsum and salt of the Carboniferous series have already been referred to in another connection.

CHAPTER XIII.

MESOZOIC ROCKS.

SECTION I.—TRIASSIC AND JURASSIC.
SECTION II.—CRETACEOUS.
SECTION III.—AGE OF THE COLORADO LIGNITES.

SECTION I.

TRIASSIC AND JURASSIC.

Triassic.—Rocks of *Triassic* age are exposed over only a small area in the district examined. Along the Rio Florida and the Rio de las Animas they are seen abutting against the lower sandstones of the Carboniferous, about ten miles below Animas City. From that line, according to Dr. Newberry, they are well exposed on the walls of Animas Park and the cañon of the river below, where they show a thickness of not less than 1,500 feet. From the Animas River to Tierra Amarilla, in New Mexico, no Triassic rocks were observed along our trail, but near Tierra Amarilla, on the trail leading from that place over the Sierra San Juan to Conejos, the mass of sandstones underlying the Cretaceous shales and abutting against the Carboniferous is so great that it cannot all be Lower Cretaceous and must be in part Triassic. The whole of it is so altered that nothing determinate can be ascertained respecting its relations.

Along the east face of the Rocky Mountains we find a coarse sandstone mostly conglomerate, extending from our northern line to Cañon City without interruption, and there curving round the extremity of the Pike's Peak range to the western base of that axis, along which it passes northward. In the vicinity of Cañon City this rock is not seen on the Greenhorn Mountains, nor was it positively identified on Hardscrabble Creek, but at the southern extremity of the Greenhorn range it is again seen curving round the point into Huerfano Park. South from this I have no personal knowledge, but the observations of Drs. Newberry, Hayden, and Professor Marcou show that it reaches far on into New Mexico. In Colorado the group shows no fossils, and no clue to its age can be obtained except from its stratigraphical relations to the Jurassic and Cretaceous. In New Mexico it is seen overlying the Carboniferous series, from the top of which Dr. Newberry obtained species of undoubted Permian age. In Eastern Colorado it underlies, unconformably, the Jurassic and Cretaceous. It is therefore Triassic to the base. It would, indeed, be impossible to separate the series as exhibited on the east base of the mountains, although some have referred a portion of the mass to the Carboniferous, and on a map recently published in the Report on the Census, vol. III, a line of Silurian is marked all along this face. The fact that this mass, as traced into New Mexico, overlies the Permian, leaves no room for any doubt respecting its relations.

On Beaver Creek, a few miles northeast from Cañon City, the following section was observed descending:

	Feet.
1. Sandstone, soft, blood-red, shaly above conglomerate below	100
2. Gypsum	100
3. Sandstone, soft, mostly deep-red, with layers of gray, somewhat micaceous, shows much cross-bedding and is entirely unaltered. It is conglomerate throughout, but especially so at the base, where for several hundred feet it contains pebbles as large as a hen's egg and completely agatized. The coarseness of the material diminishes regularly to the top, where it is comparatively fine in grain. Estimated thickness	2,500

Above No. 1 there is a gap of 200 feet unexposed, after which the sandstones of the Lower Cretaceous are seen. The rocks of the section are unconformable to those above. At the cañon of the Little Fountain Creek the upper portion of the section is exhibited as follows:

	Feet.
1. Sandstone, gray to red	160
2. Gypsum and shales	120
3. Sandstone, red.	

In the little park lying behind the hog-back ridge northeast from Cañon City and watered by Ute and Beaver Creeks, the red sandstone at the base rests against the mountain until we reach Beaver Creek, where it fills up the valley in a succession of low hog-back ridges, and at length closes up the whole with the exception of a very narrow gorge, which is occupied by a branch of Beaver Creek and by the road from Cañon City to Colorado Springs. From Ute Creek to Beaver Creek the gypsum bed is a well-marked feature of the outer wall of the park and seems to be in thin layers alternating with drab or lead-colored clays. At the crossing of Beaver Creek these shales are quite well marked, the road passing directly through the gypsum bed. The gypsum is light-gray in color and occurs in thin laminæ, which are very distinct on the weathered edge of a layer, but the whole has a concretionary structure, which gives a mammilated surface to the slabs. In this respect it resembles the Carboniferous gypsums, which are always concretionary.

On Oil Creek, which flows southward between the Pike's Peak spur and the Greenhorn Mountains to the Arkansas, the red sandstone yields petroleum and salt. These are obtained from springs. Deep borings were made at one time to reach a reservoir, but were unsuccessful, and the quantity obtained by "skimming" the salt water is comparatively small. The oil I was informed is of good quality, and in quantity nearly sufficient to supply the local demand.

Following down Beaver Creek to strike another road to Colorado Springs we find the Triassic rocks disappearing under the upper rocks, nor do they re-appear again along the road until near Turkey Creek, where, in a very extensive park, the sandstones have been entirely removed. But in the outer wall, protected by the Lower Cretaceous sandstones above, the gypsum is again seen. In the park near the wall there are several low hills covered by gypsum. The alternation as seen in this locality is—

	Feet.
1. Arenaceous shale, fine-grained, deep-red	40
2. Gypsum and blue clays	60
3. Shale, dark-red, with layers of gypsum	40

There is evidently much variation in the character and thickness of the stratum on top, but the gypsum beds are very persistent, varying little from 100 feet at the several exposures.

From the time we leave Dry Turkey Creek until we pass through the cañon of the Little Fountain Creek we ride almost uninterruptedly between hog-back ridges of the lower sandstone. Near the cañon this sandstone is quite fine-grained and soft in the upper 300 feet, while below that it is conglomerate, as on Beaver Creek, but contains more gray layers than at that locality.

At Colorado Springs, or rather three miles above the city of that name, on Fountain Creek, this group is well exposed in the "Garden of the Gods," and by its peculiar contrasts of color, as well as by the fantastic shapes produced by weathering, it contributes largely to produce the weird scenery which renders that locality so attractive to tourists. The red rocks here reach well up on the mountain. Above the springs, at Manitou, six miles from the city of Colorado Springs, beds of soft argillaceous shale were observed below them, and under these a non-fossiliferous limestone. It was impossible, under the circumstances, to delay long enough to determine the relations of these beds. No limestone was observed in the Trias at any locality along this line, nor were any clay beds similar to these seen elsewhere. They may be Carboniferous.

From Colorado Springs northward to Golden the Triassic rocks may be traced almost without interruption, though, owing to the increased dip in the northern portion of this line, erosion has acted so powerfully upon the unprotected gypsiferous shales that they are rarely exposed. The sandstones change materially in color, becoming gray to light-gray, but retaining the conglomerate character. Everywhere along the line from Cañon City northward the Triassic rocks are unconformable to those above.

Jurassic.—In the interior region no rocks were observed which could be referred to the Jurassic age, except, perhaps in the blue limestone under the Cretaceous in the Rock Creek section. At the same time no evidence has been obtained which tends to prove conclusively that they are absent, for at few localities was the junction of the Cretaceous and the directly subjacent rocks seen. Along our eastern border, however, from Cañon City northward, there was observed a bluish-gray limestone, containing some indistinct fossils, which lies almost immediately under the Lower Cretaceous sandstones, and rests unconformably on the Trias, being conformable to the rocks above. On Oil Creek, near Cañon City, we find above the oil-works an exposure of light-colored sandstones and shales, amounting in all to about 120 feet, which seem to be connected with this limestone. The same series overlies the limestone in the park between Ute and Beaver Creeks, behind the hog-back ridge, but is apparently wanting in Beaver Creek Cañon. At the latter locality the limestone is thin, very fine, compact, with flinty fracture, and almost salmon colored. The fossils are chiefly branching bryozoans, though there seem to be some of the higher molluscan forms present, for some sections of those were seen on the weathered surface. The shales seen in Oil Creek again appear in the park near Turkey Creek. Near the head of West Plum Creek the limestone seems to rest almost directly on the Triassic gypsum, the intervening red sandstone or shale being absent or feebly represented. Near Mount Vernon this stratum has been used extensively in the manufacture of lime.

Geologists, who have examined this region, seem to agree in placing this little group in the Jurassic. This has been done chiefly on stratigraphical evidence, no assistance having been derived from animal remains. Underlying the lowest sandstones of the Cretaceous it cannot belong to that period, and it rests unconformably upon the Triassic rocks No decision, however, can be regarded as absolutely conclusive, until it is supported by the evidence of fossils. It is more than probable that this can be obtained by patient search, for, as has been stated, the limestone is quite fossiliferous. At all localities examined by me the fossils were unsilicified, and therefore do not weather out, while the rock itself is so compact that a fresh surface shows no evidence of fossils whatever.

SECTION II.

CRETACEOUS.

The rocks of this period are exposed over an extensive area within our district. Their line of outcrop along our eastern border is practically unbroken from Golden to New Mexico, and, according to other observers, even to Mexico. On the west side of the Front or Eastern range there is a narrow area, of which only isolated portions remain in Huerfano, Wet Mountain, Currant Creek, and South Parks. In the area of the San Juan they are the only rocks exposed between Macomb's trail and the New Mexico line, excepting the small patch of Triassic on the Rio Florida and Rio de las Animas. The Cretaceous rocks differ somewhat in details in the various portions of our district, but as a whole the series is made up of three divisions. The Lower Cretaceous is a mass of sandstone, 200 to 500 feet thick; the Middle is composed of shales and limestones, with, in the eastern localities, marls and sandstones 1,000 to 1,500 feet; and the Upper, chiefly sandstones, with intercalated shales and lignites, 500 to 700 feet. No Cretaceous rocks were observed in the Grand and Gunnison area, west from the Blue River range, excepting at the localities along East River and Rock Creek, referred to in the last chapter.

San Juan area.—Soon after leaving the Rio Florida, on the way eastward, along Macomb's trail, which is about fifteen miles north from the New Mexico line, one sees the Cretaceous rocks, but the first satisfactory exposure is on the divide between the Rio de los Piños and the Rio Piedra. This divide is made up of the Lower Cretaceous sandstones, which there are coarse grained and in some parts conglomerate. Beyond the divide the trail leads through narrow ravines, eroded from the black shales of the Middle Cretaceous, which are well exposed in the southwestern walls. They contain more or less ferruginous limestone, with some lenticular nodules of iron-ore, and are quite plastic. At the crossing of the Rio Piedra these rocks form high bluffs, capped by the Upper Cretaceous, and are visible in the mesas for many miles southward. From the Rio Piedra to the Rio San Juan the only rocks seen are those of the Middle and Upper Cretaceous; the former, dark shales, sometimes thinly laminated and fissile; the latter, massive yellow sandstones, for the most part fine-grained. As we descend to the San Juan, near Pagosa Springs, the sandstones of the Lower Cretaceous are fairly exposed for the first time along this line.

At Pagosa Springs these sandstones are much altered, and in the cañon, two miles below the springs, are not less than 500 feet thick. The surface of the upper stratum is covered by a mat of imperfectly-preserved fucoidal stems, which in some places is so close as to conceal the structure of the rock. In this vicinity no dicotyledonous leaves were seen. Upon the sandstone rests a very dark-blue, almost black, shale, the same as that observed all the way from the Rio Piedra, and seen at several points west from that stream, almost to the Las Animas. Toward the base it contains many layers of very dark, fetid limestone. At the springs it is argillaceous, but higher up it is quite arenaceous, though retaining the dark color. Throughout, in this vicinity, it is more or less fossiliferous, containing scales and teeth of fish, *Ostrea* sp., and several species of *Inoceramus*, one of which is from 6 to 9 inches long, and covered with large concentric wrinkles. The cleavage planes are very distinct, and so close, that of the large *Inoceramus* no perfect specimen could be obtained, though the species is exceedingly abundant. The thickness of the shales, as exposed at this locality, is about 400 feet.

From the San Juan to its tributary, the Rio Blanco, the road follows the shales, gradually rising so that the upper portions are exposed. These contain numerous thin layers of argillaceous limestone, grayish-blue, weathering light yellow, and full of *Inocerami*. The shales themselves are light-gray, and wear down to a whitish mud, which discolors the waters of the little stream; whence the name, signifying "White River." Crossing the Rio Blanco, the road passes through a somewhat romantic ravine, and rises quite rapidly, so that it soon reaches the sandstones of the Upper Cretaceous. These are mostly fine-grained, gray to yellow, somewhat argillaceous, and crumble readily under the influence of the weather. At the head of the ravine we come out into a beautiful park eroded from these sandstones. On its east side is the Cerro del Navajo, a low, mesa-like ridge composed almost wholly of the upper sandstones, bright yellow, and occasionally conglomerate, while at the southwest in another mesa we see the same sandstones resting on the dull shales of the Middle Cretaceous. Where the Rito del Navajo breaks through its mesa the shales are again exposed. In the park itself, exposures are few, there being none of any extent except one on a small tributary of the Navajo. The thickness of the Upper Cretaceous, as seen in the various exposures, is not far from 400 feet, that of the Middle Cretaceous is not less than 1,200, while that of the Lower Cretaceous sandstone, as determined on the Rio San Juan, is not less than 500, making the total thickness of the Cretaceous in this region not far from

2,100 feet. It is highly probable that the whole thickness of the Upper Cretaceous is not exposed along the line of our reconnaissance. The rocks of this upper division are, at most, sparingly fossiliferous here, for at the few exposures examined there were no traces of either animal or vegetable life, other than a single, somewhat indistinct impression very closely resembling the nodose fucoid, so characteristic of the Upper Cretaceous farther east and named by Mr. Lesquereux, *Halymenites major*. Dr. Newberry, however, finds this species in great abundance at this horizon farther south in New Mexico. From the Rito del Navajo to the Laguna de los Caballos, an ancient fresh-water but now brackish lake, the Upper and Middle Cretaceous are conspicuous, there being many fine sections exposed in the mesas near the road. Crossing Horse Lake Pass, a narrow gap between two bluffs of the sandstone, we reach the *Rio Grande area*, and, at a few miles beyond the pass, come again upon the Lower Cretaceous sandstones. These are more or less altered and show no fossil remains, except on top, where several layers are covered with the ill-preserved fucoids already referred to, as occurring near Pagosa Springs. Upon these rest the shales of the Middle Cretaceous. These contain, near the base, the dark-colored fetid limestone in thin layers alternating with layers of dark shale, which prevail higher up, exhibiting only rare layers of blue limestone, weathering yellow and sparingly fossiliferous. Farther up the limestones disappear altogether and we find only dark shales, more or less arenaceous, the arenaceous portions locally compacted into thin sandstones, while on top of all are the Upper Cretaceous sandstones, fine-grained, reddish-yellow below, and light-gray, weathering bright yellow above.

The sandstones of the Lower Cretaceous closely resemble those of the Upper Cretaceous, both in structure and color, so that were it not for the metamorphism of the former, as well as for the frequent exposures of both in proximity along the route, one might readily mistake one for the other. Through this region the Upper Cretaceous is almost wholly non-fossiliferous, and the Lower Cretaceous is equally so, except in its upper layers. On the west slope of the Sierra San Juan the Lower Cretaceous rocks are traceable along the mountain-side to Tierra Amarilla, our most southern point, and are well exposed on the trail leading from that locality to San Luis Valley.

Along the line of this trail they are completely metamorphosed, many of the strata having been converted into a structureless quartzite, showing no lines of bedding whatever. Toward its base, if we take its thickness to be about 500 feet, is a conglomerate, and somewhat higher up we find a stratum containing numerous very thin seams of quartz, occupying all the planes of cleavage and giving the weathered surface a reticulate structure. Below the conglomerate there is a mass of altered rock, which, as already stated, may be of Triassic Age. The whole series rests unconformably against the Carboniferous rocks, which are seen near the summit of the pass.

In the whole of San Luis Valley there are no exposures of Cretaceous rocks, everything, even on the eastern slope of the Sierra San Juan, being deeply buried under the eruptive rocks.

Crossing the Sangre de Cristo Mountains by the Sangre de Cristo Pass, we reach the region lying between this range and the Greenhorn Mountains. For convenience sake, I include under the former name, also the western boundary of South Park and the Blue River range, and under the latter, the Kenosha range, extending up to Gray's Peak. In this region there are isolated patches of Cretaceous in Huerfano Park, near the Arkansas Bridge, on Currant and Cottonwood Creeks, in South Park and on Blue River. In all these localities the character of the rocks is the same, but shows some interesting variations from that of the same series as observed in the San Juan country. The lower sandstones are variable in structure and thickness, and the Middle Cretaceous is a compound mass of clays, limestones, sandstones, and variegated shales. Exposures of the Upper Cretaceous are not frequent, but show the rock to be somewhat coarser than where previously examined.

At the lower end of Huerfano Park, where the road leading to Colfax, in Wet Mountain Valley, leaves Sangre de Cristo Pass, the Lower Cretaceous is represented by quartzites poorly exposed and abutting against the mountains. For the most part, these quartzites are very fine-grained, almost white on freshly fractured surface, and weathering to a brilliant yellow; but some of the layers are coarser, and weather to a dull, reddish-yellow. Near the Rio Puercos, a branch of Huerfano River, we find the sandstones of the Upper Cretaceous, which are unaltered. These rocks are moderately fine-grained, of irregular structure, and enclosing numerous patches of not very coarse conglomerate. They vary in color from gray to yellow, and are quite friable, weathering into fantastic forms. Some of the layers are quite compact and contain some calcareous matter, but no fossils were observed at any of these exposures, which are quite fragmentary. The total thickness is not less than 600 feet, but cannot be accurately determined.

Of the shales below these sandstones the exposures are unsatisfactory, except of those near the base, which are well seen on the south side of the North Fork of Puercos River. There we find a series of dove-colored limestones, some of them dark on fresh fracture, and including a reddish arenaceous limestone, which contains much calc-spar in very thin films. The limestones are in layers from 1 to 3 feet thick, and are separated by shales, some argillaceous, others arenaceous. The limestones are all more or less fossiliferous, especially near the reddish stratum, which contains great numbers of *Ammonites*, *Inoceramus*, *Gryphæa*, *Ostrea*, and occasional fish-teeth. The thickness of this stratum is about 6 feet. Below the limestones there is a dark-colored shale or clay, in which the river has excavated its ravine. The whole thickness at this exposure is not far from 250 feet. On the north side of the river the sandstones of the Lower Cretaceous are seen underlying the clay shale. They are imperfectly exposed, but are unaltered, and somewhat shaly in structure.

No rocks other than those of the Cretaceous were seen in Huerfano Park. On the east, at the base of the Greenhorn Mountains, the brilliant sandstones of the Upper Cretaceous are a striking feature, extending well up to the divide from Wet Mountain Valley, while west from the road they are seen capping the numerous mesas, and resting on the shales. They continue southeastward round the southern extremity of the Greenhorn Mountains to the plains. It is more than probable that the Cretaceous rocks once occupied Wet Mountain Valley, but the agent which scooped out that basin tore them away, and what remains of them is buried under the mass of *débris* forming the surface.

A small area of Cretaceous rocks occurs on the road leading from Currant Creek to Wet Mountain Valley, and extends from the head of Cottonwood Valley to the Dry Cañon about four miles beyond the Arkansas Bridge. Where the road first strikes Cottonwood Creek we find the Lower Cretaceous sandstones, white to grayish-yellow, and very friable, breaking down into loose sand under the influence of the weather. A little farther on the light-colored limestones of the Middle Cretaceous occur, but the intermediate clay has been entirely removed from the surface by erosion. Along this valley, or rather park, the Lower Cretaceous rocks form hog-back ridges on each side, and toward the center are low ridges of the limestones, which here hold midway a reddish limestone like that already seen in Huerfano Park. These limestones are rich in *Inoceramus,* and occasionally contain *Ammonites.* Near the bridge the lower sandstones are well exposed, and differ somewhat in character from those seen at the head of Cottonwood Park. A bluff afforded the following section, descending:

	Feet.
1. Sandstone, in thick layers, gray	20
2. Sandstone, red	15
3. Sandstone, dark-lead color, shaly	8
4. Sandstone, red, soft, ripple-marked	18
5. Sandstone, lead-color, shaly	13
6. Sandstone, white to grayish-yellow, soft	45
7. Sandstone, red, gray, and lead color, principally in thin layers, but contains a layer of coarse conglomerate, made of pebbles of quartz, granite, gneiss, and some *trachyte*	60
	179

No. 6 not unfrequently includes about midway a shaly layer, 6 to 8 feet thick. It, as well as the one below, is exceedingly friable. About a mile southward from the bridge No. 1 is seen to be light-gray on fresh fracture, but red on the weathered surface. It shows some cross-bedding, and contains numerous thin streaks of quartz closely crowded together, so as to give the weathered surface a reticulate appearance. A stratum of this character has been seen at nearly every exposure of the Lower Cretaceous sandstones.

At no locality in this little area were the clay-shales, overlying the sandstones, observed. Where they should be, we see only grassy swales. About two miles from the river we again come upon the limestones, amid which the red stratum is conspicuous. This bed is about 4 feet thick, and contains many species, of which those of *Ammonites*, *Gryphaea*, *Inoceramus*, and *Avicula* are most abundant. Five large impressions of *Ammonites* were seen on the surface of a slab barely 3 feet square. Unfortunately the specimens are all in bad condition, and the *Ammonites* are seen only as impressions. This rock does not yield distinct specimens, except on the weathered surface. The total thickness of the limestones, as here exposed, is about 70 feet. They become more and more argillaceous above, and are succeeded by a gray shale somewhat arenaceous, upon which rests a bright-yellow arenaceous and thinly-laminated shale, which is the principal rock in sight as we approach Dry Cañon. The Upper Cretaceous rocks do not occur anywhere in this area. Toward the cañon these rocks abut against a quartzite, reposing upon the metamorphic schists. The age of this quartzite is somewhat obscure, but owing to its position and its thickness, barely 200 feet, I am inclined to place it in the Silurian.

In South Park the Cretaceous rocks occupy a synclinal trough, lying east from Fairplay, and extending from the mountains at the north to very near the southern boundary of the park. The sandstones of the lower division are traceable along the western border in a series of broken hills. The first ridge, east from Fairplay, shows them to be mostly white or light-gray, of varying degrees of coarseness, very friable, and about 300 feet thick. Farther south the South Fork of Platte has cut a cañon through these strata in which they are seen resting directly on the metamorphic rocks, but are themselves entirely unaltered. The lowest stratum is fine-grained, white, quite soft, and shows thin streaks of quartz. Upon this rests a conglomerate made up of quartz pebbles, rarely more than one-third of an inch in diameter, and cemented by material evidently derived from disintegration of volcanic rocks. The highest stratum is a compact, gray sandstone, of which many layers are covered by remains of fucoids, similar to those occurring at the same horizon in the San Juan region.

On the eastern border the exposures are rare. A rock resembling the conglomerate was seen on Tarryall Creek, but the exposure is too fragmentary to admit of positive determination. At the Sulphur Springs the series is well exposed, but all parts are completely metamorphosed. A specimen of fossil wood was obtained from the top stratum. The conglomerate is converted into a quartzite of singular beauty. At this locality the group rests directly on the metamorphic schists. About four miles northwest from the Sulphur Springs there occurs a curious hill, tapering northward, and spreading out southward in three prongs. It is wholly covered by *débris*, except at the southern extremity, where a conglomerate is exposed, consisting of fragments of gneiss, granite, trachyte, quartzite, and limestone, all water-worn, and held together by sand resembling that of the surrounding plain. Pieces of silicified wood, also water-worn, are quite numerous. The fragments vary in size from small grains to 16 inches, and the mass is more or less ferruginous throughout. This conglomerate is occasionally seen farther southward, almost to the cañon of the Platte. Its age is very obscure. It certainly marks the ancient river-bed, and so is probably comparatively recent in its origin. At the same time it bears a remarkable resemblance in general structure to one stratum of the Lower Cretaceous seen near the Arkansas Bridge.

The Middle Cretaceous is imperfectly exposed in those portions of South Park visited by our party. The shales at the base, immediately underlying the limestone, are present in small quantity, or are entirely absent, in many localities. At the Sulphur Springs the limestones are imperfectly exposed. The rock is light-blue, somewhat fetid, variable in structure, from fine-grained to slightly crystalline. It has been affected to a considerable extent by metamorphosing influences, and breaks readily along well-defined planes of cleavage. An attempt was made to make lime from it, but the result was evidently unsatisfactory. Some of the half-burned fragments yielded specimens of *Inoceramus* and imperfect impressions of *Ammonites*. The rock freshly broken from the stratum showed no signs of fossils. Beyond the first ridge east from Fairplay is a broad swale, occupying the space in which the lower portion of the Middle Cretaceous should be exposed, so that neither the shales at the base nor the overlying limestones are seen. But the next ridge eastward is composed mainly of the dark shales belonging to the upper portion of the group, which contain nodules of limestone, more or less gypsum, and nodules of iron-ore, which frequently contain fossils. On Trout Creek (in South Park) there are several localities which yield characteristic Cretaceous fossils in great abundance.

The junction of the Upper and Middle Cretaceous was not seen. Indeed, at no place examined by our party are the Upper Cretaceous rocks satisfactorily exposed. Near the village of Hamilton two beds of lignite occur, in rocks belonging to the middle division of this group. The following seems to be the section at the locality, as determined by inspection of the several shafts sunk on and in search of the beds:

1. *Débris* and clay	10 feet.
2. *Lignite*	12 feet.
3. Fire-clay	2 feet.
4. Sandstone	2 feet.
5. Fire-clay	2 feet 6 inches.
6. Sandstone	12 feet.
7. Fire-clay	2 feet.
8. *Lignite*	6 feet.
9. Fire-clay, seen	2 feet.

It is by no means improbable that a third bed of lignite belongs to this group, for at the grave-yard, on a level with the outcrop of No. 2, and some distance east from it, the indications of coal are very distinct, but no examinations have been made to test the matter. Neither of these beds has been worked sufficiently to determine accurately the quality of the coal. No. 2 is opened by a shaft directly upon the seam, which, after passing through *débris* and fire-clay for 10 feet, reaches and cuts through the bed, exposing its thickness. The total length of the shaft and the incline at its foot is about 30 feet. The better coal is found at the bottom, and the proprietor mines only the lower half of the bed. The dip is very sharp, nearly 40°, so that mining operations will prove very expensive. This coal, when freshly mined, shows a clean fracture and a glossy look, not unlike that of cannel, but upon exposure it disintegrates rapidly. An analysis, by Prof. E. T. Cox, shows the following composition:

Specific gravity	1.254
Weight of one cubic foot, pounds	78.37
Fixed carbon	55.58
Water	4.50
Volatile combustible matter	37.92
Ashes	2.00
Coke	57.58
Color of ash	Fawn.

The coal is quite compact, and Professor Cox states that it yields a fair coke. The analysis takes no notice of the sulphur, which is present in very considerable proportion, in combination with iron. This is very unfortunate, as it prevents any utilization of the coking property for economic purposes. The sulphur acts very energetically on grate-bars, a single winter sufficing for the destruction of a set. The lower bed has been opened on the outcrop only, by an incline 14 feet long. It is more advantageously situated for working than the other, having a dip of only 28° where exposed. Though containing much sulphur, it is said to be purer and much better for domestic use than the seam above. Midway between the two openings a shaft has been sunk to strike the lower bed a few feet east from its outcrop. At the time of our visit this shaft was 18 feet deep, and stopped in sandstone, on which rests the fire-clay, No. 5 of our section. This clay is said to be of excellent quality, fifteen tons of it having been used at the smelting-works in Dudley, where it is said to have given complete satisfaction. The clay under the upper coal is much slicken-sided, and contains a large proportion of carbonaceous matter.

The last of the small Cretaceous patches within this division of our area is seen on Blue River below its junction with the Snake and Ten-Mile Creek. The Lower Cretaceous sandstones are exposed on Snake River, where they are about 300 feet thick. Upon them rest about 175 feet of dark shales, varying in structure from mere clays to thinly laminated fissile shales, the latter being on top. These form the bluffs of the river-valley for several miles and are well exposed, especially on the west side. About ten miles below the junction with the Snake, the limestone series is seen above the shales. For the greater part these limestones are light-colored and not rich in fossils. The reddish, arenaceous layer is here darker in color and more arenaceous than at any locality yet referred to. The fossils are numerous, chiefly *Ammonites*, *Gryphæa*, and *Inoceramus*, and all occur in a state of bad preservation. In the dark shales below, a few specimens of *Inoceramus* were obtained. With the exception of the yellow arenaceous shale, no rocks of the Middle Cretaceous above the limestones were seen, the whole being concealed by *débris*. The sandstones of the Upper Cretaceous were not observed, and it is quite probable that they do not come in until beyond our northern line.

The most satisfactory exposure of the whole Cretaceous series is found along our eastern border at the base of the mountains. There the line of outcrop can be followed almost uninterruptedly from our northern line all the way to Mexico, and there are several localities, at which complete sections of the series may be obtained. My own observations, however, reach only to Hardscrabble Creek, about twelve miles from Cañon City, the southern portion of the line having been visited by a small division of our party. In the vicinity of Cañon City there is a curving synclinal caused by the abrupt termination of the Pike's Peak axis, so that the rocks are very well exposed. The softness of the Middle Cretaceous shales renders them especially liable to erosion, and here they occur in a succession of mesas, which are in some cases quite widely separated, so that the true order and thickness of the strata are ascertained with some difficulty. The following section was obtained at this locality, and was verified in every possible way, cross and diagonal sections having been made after the main section had been secured. It may be regarded as typical of the formation along our whole eastern border, the information brought by the subordinate party working at the south showing no material difference there.

UPPER CRETACEOUS.

1. Sandstones .... 250 feet.

In the upper portion the rock is somewhat variable in composition; mostly fine-grained, but showing frequent layers which are more or less conglomerate. The thicker layers contain patches of coarse rock, which shows cross-bedding. Some contain a considerable proportion of iron, and are concentric in structure, the concentric layers being separated by films of limonite. The color is mostly light-gray on the fresh fracture, but the weathered surface is light-yellow. Toward the base are three thin seams of lignite with shales. Below these the rock is massive, slightly ferruginous, fine-grained and light-gray to light-yellow. It is marked by a poverty of cementing material and is exceedingly friable. In the layers of sandstone above the lignites there are many leaves of dicotyledonous plants.

2. *Shales*, *sandstones*, and *lignites* .... 175 feet.

In this series the shales predominate, and for the most part are dark-colored and argillaceous. The sandstones are thin, yellowish, fine-grained, and very friable. The lignite beds are numerous, but, with one exception, they are too thin to work with profit.

3. *Sandstone* and *shale* .... 350 feet.

The sandstone immediately underlies the lignite series. Above, it is reddish-yellow, more or less ferruginous, rather thick-bedded, and very soft. Near the base it includes some thin beds of lignite. It passes downward into shaly sandstone, which changes imperceptibly into dull lead-gray argillaceous shale, containing many layers of reddish sandstone. These clays give place to arenaceous shales below as gradually as they displaced them above. Near the top of the sandstone are layers which show numerous impressions of a curious fucoid, *Halymenites major*, Lesqx. Interstratified with these are other layers bearing many indistinct impressions, evidently of molluscs, but too indistinct for determination of any sort.

MIDDLE CRETACEOUS.

1. *Shale* .... 600 feet.

At the top these contain layers of calcareous fossiliferous sandstone. Below they are drab to dark-brown, and contain vast numbers of ferruginous nodules, of which fossils are the nuclei. The portion at the base is dark, almost black, very fissile, and showing selenite in streaks from one-eighth of an inch to one inch thick, and crossing the bedding. Gypsum occurs throughout this portion of the shales, in exceedingly thin laminæ of arrow-head crystals, between the laminæ of the shale. At irregular distances we find also layers of limestone nodules, which vary in diameter from 3 inches to 6 or 8 feet. The smaller nodules are encased in a shell of selenite and oxide of iron. The limestone is black, weathering light-blue, and is non-fossiliferous. No fossil remains other than carbonized stems of plants were seen in the shales themselves.

2. *Shales* .... 350 feet.

Blue, gray, and yellow. On top they are blue argillaceous and marly, but, descending, they become more and more arenaceous, until at the base they are entirely so. Toward the middle they are bright-yellow, and at the base light-gray. Usually the arenaceous portions are thinly laminated shales, but occasionally they are compacted into sandstones whose layers are 5 or 6 feet thick. This series appears to be wholly non-fossiliferous at all points examined.

3. *Limestones* and *shales* .... 130 feet.

This well-marked group is separated into two almost equal divisions by a reddish, somewhat arenaceous layer, 4 feet thick. The lower portion consists of dove-colored limestones, in thin layers, slightly argillaceous, and separated by thinner layers of argillaceous shale. The upper portion includes dark limestones, weathering light-blue, in layers 1 to 4 feet thick and separated by arenaceous. All the limestones are fossiliferous.

4. *Shale* .... 130 feet.

Argillaceous, red to blue and dark brown, shows much cone-in-cone structure, and is sparingly fossiliferous.

LOWER CRETACEOUS.

Sandstone .... 250 to 350 feet.

Light-gray to yellow, mostly fine-grained, but containing some conglomerate layers. Toward the base it includes shales, some of which are very bituminous. As a whole, this series bears a very striking resemblance to the Upper Cretaceous, and might easily be mistaken for it in the localities where it is entirely unaltered.

SUMMARY.

	Feet.
Upper Cretaceous	775
Middle Cretaceous	1,210
Lower Cretaceous	350
Total	2,335

Upper Cretaceous.—In the vicinity of Cañon City these rocks occupy a very small area. They begin about four miles southeast from that city, and continue for, say, six miles, reaching all the way to the base of the mountain and concealing the underlying rocks. From the mountain they extend northeastward to a distance of probably ten miles, barely crossing the river. The reddish-yellow sandstone of No. 3 forms bluffs along the road from Cañon City to the mouth of Oak Creek, near Labran, and at one locality two thin beds of lignite have been exposed by an excavation for a ditch, just above the road. These have been opened, but the result could not have been encouraging, as the opening was not pushed very far. About five miles below Cañon City some isolated hills on the north side of the river, dome-shaped, as seen from the west, show the passage from the sandstone to the argillaceous portion below. From these hills a line of broken mesas extends to the mouth of Oil Creek Cañon, in which the gradual change from argillaceous shales to arenaceous below, as well as the relation of this series to the Middle Cretaceous, is distinctly shown. The argillaceous portion is traceable to Oak Creek and along the road from Labran to the coal mines, where it is seen under the incoherent sandstone, whose harder layers contain *Halymenites major* and the indistinct molluscan impressions already referred to. This passes into the more compact sandstone, which continues up to the coal-mines. On Oak Creek the succession and the various changes are traceable directly.

The lignite series is found only on the southern side of the Arkansas, and covers an area of not more than thirty-five square miles. The following section was obtained at the base of the series at the coal-mines, and, though small, gives a good idea of the group:

	Feet.	Inches.
1. Sandstone	30	
2. Shale, brown	2	
3. *Lignite*	1	6
4. Black shale and clay	6	
5. Sandstone	7	
6. Shale	15	
7. *Lignite*	1	8
8. Shale and clay	9	
9. { *Lignite*.....13 inches. Clay...5 to 14 inches. Lignite....44 inches. }	5	7
10. Shales and clay	6	

The coal obtained from the large seam of the section is of excellent quality and is mined quite extensively. It finds ready sale at all points along the Denver and Rio Grande Railroad, and is reputed to be the finest coal in the Territory. It bears exposure well and contains comparatively little sulphur. The shales contain much iron-ore as carbonate, and no small amount of selenite distributed in films between the laminæ, as well as in thin cross-seams. In the sandstones of this series, according to Mr. Lesquereux, *Halymenites major* occurs throughout.

The sandstones of the upper division form a striking feature in the scenery on the south side of the Arkansas, capping the bluffs which begin three or four miles from the river and extend quite to the base of the mountains, over an area of about twenty-seven square miles. They do not occur on the northern side of the river.

From Cañon City to Colorado Springs, the Upper Cretaceous rocks do not appear within our area, but northeast from the latter city the upper division is seen forming a line of bluffs, through which the old stage-road passes. West from these bluffs to the mountains the exposures are very satisfactory, and show the succession to be similar to that at Cañon City; but the coal is in small quantity, so small that the whole vicinity is dependent on the Cañon City mines for its supply.* From this locality the Upper Cretaceous rocks are the only ones visible until we cross the Cherry Creek divide, which separates the waters of the Arkansas from those of the Platte. Above these, through this region, is a white conglomerate, with grains about as large as a pea, held together by an ash-like cement, which readily yields to the effects of the weather. Along our road this was frequently seen capping mesas, but no opportunity was afforded to determine its relations to the Cretaceous below, until we had passed Greenland Station, on the railroad. Between that station and the head of West Plum Creek, it was seen in several mesas, resting unconformably upon the Upper Cretaceous rocks below.

Northward from the Cherry Creek divide, no exposures of the Upper Cretaceous were seen along our road until we reached Green Mountain, near Golden, which is probably composed almost entirely of these rocks. At the western base of this mountain the lignites appear again. Two open-

*A newspaper item states that coal has recently been found, 5 feet thick, near Colorado Springs.

ings were seen, but they have been deserted, probably because the extreme dip rendered mining too expensive. The beds were 2 and 4 feet thick, respectively, and yielded coal of very fair quality.*

Middle Cretaceous.—The first exposure of the Middle Cretaceous, northwestward from Hardscrabble Creek and along the base of the mountains, is three miles from the creek. From that locality they are concealed under the Upper Cretaceous to Oak Creek, where the limestones form a bluff on the northwest side. An anticlinal is crossed beyond this creek, and on the next stream they are seen again with the under and over lying shales. Near Cañon City they are well exposed, resting on the Lower Cretaceous sandstones. Here the base of the group is a red-clay shale, somewhat laminated, and containing very few fossils. Toward the top it becomes calcareous and merges into the next portion, which shows the following section, descending:

	Feet.
1. Limestone, light-blue, very fossiliferous	65
2. Limestone, reddish, slightly arenaceous, many fossils	3
3. Limestone, light-blue, argillaceous, some fossils	60
4. Limestone, reddish, arenaceous, many fossils	6

No. 1 is much more frequently exposed than No. 3, as it is much harder. Both show some alteration, as they break readily, along well-defined lines of cleavage, into small fragments, rendering any attempt to secure fossils quite unsatisfactory. Above the limestones, gray and yellow to blue arenaceous shales are seen, having a thickness of about 350 feet. From Cañon City almost to Oil Creek, the lower or gray shales of No. 2 (principal section) are quite continuously exposed in a low, hog-back ridge in front of the main ridge, formed by the Lower Cretaceous sandstones.

On the northern side of the Arkansas, we find the rocks of the Middle Cretaceous well exposed in a series of mesas, relics of former terraces, extending along Oil Creek and reaching almost to Ute Creek, where, turning toward the river, they form a chain stretching to the dome-shaped hills, capped by the lower sandstones of the Upper Cretaceous. These afford a line along which, with a little difficulty, the succession of the Middle Cretaceous rocks can be determined.

*The examination in the vicinity of Golden was too brief to be satisfactory. A heavy snow-storm brought our explorations to a close quite suddenly on December 3, and prevented the performance of work in that district.

On Oil Creek the shales No. 4 are blue, very argillaceous, and poorly exposed. The lower red limestone of No. 3 is not seen, but the rest of the division forms a long ridge, extending east and west, upon which rests the lower portion of No. 2. The general succession in the latter is well shown, as well as the relation of those shales to No. 1, which is finely exposed in an irregular hill on the road from Cañon City to the oil-works. On the same road, these shales of No. 1 can be traced to where they underlie an irregularly stratified sandstone, very calcareous and very rich in fossils, containing *Baculites*, *Ammonites*, and many lamellibranchs in such vast numbers that they form the mass of the rock. The exposures of this rock are all fragmentary, but it shows so much intimacy with the lower portion of the Upper Cretaceous, that I have felt some doubt as to its true relations. On Dry Creek there is a fine exposure of the shales No. 1, and near Ute Creek the fossiliferous sandstone is seen.

At the mouth of Beaver Creek Cañon, we enter a narrow, irregular park, extending for several miles along the stream, almost to the McClure House. At its head the shales No. 4 are well exposed on the left side, red and black, while on the right side, No. 3, and the lower portion of No. 2, are nicely exhibited. The yellow, arenaceous shales of No. 2 are more or less compact, forming, in portions, a sandstone of fair quality, which has been quarried for building purposes. At McClure's, the upper layers of the limestone are very fossiliferous, being crowded with *Inoceramus* and containing numerous *Ammonites.* The shales separating the layers of limestone are sometimes calcareous, and in such cases contain teeth of fish. The reddish limestone contains *Gryphæa*, *Ostrea*, and *Inoceramus*. The fossiliferous layers of the other limestone are dull-brown on fresh fracture, but weather to a light-blue.

Along the road from the McClure House to Colorado Springs, the rocks of the Middle Cretaceous continue for several miles, after which they are left by the road and are not seen again until we reach Turkey Creek, at the east of which they occur in bluffs, the limestone series forming the groundwork of the vicinity. Shortly beyond that creek they are again left to the east, and so continue until we reach the Little Fontaine qui Bouille, where they are seen resting unconformably against the Triassic.

There is a difference here of nearly 60° between the dips. In the cañon below this point, the variegated shales and marls are beautifully exposed. On the Fontaine qui Bouille the whole series is exposed in the interval between the Garden of the Gods and the bridge. In this vicinity the shales are seen at various localities as far as the divide between the Arkansas and South Platte Rivers. North from that divide, near the head of West Plum Creek, the limestones occur, but erosive agents have been active and have removed the shales from the surface. Farther north, as we approach Thompson's Cañon, beyond Deer Creek, the exposures become more and more unsatisfactory, and so continue until we reach our northern line.

At the mouth of Thompson's Cañon the shales No. 4 are seen resting on the Lower Cretaceous sandstones. They are dark, almost black, and contain many streaks of bituminous matter. Between that cañon and Turkey Creek several openings have been made in these shales, probably with the hope that the streaks of Carbonaceous matter would unite, if well followed up, and eventually form a large seam. The efforts have met with no success. The limestone series was seen at these localities, everywhere light-blue and in thin layers, separated by calcareous shales. It has been used for making lime, but does not yield a good article. The variegated sandy shales are occasionally exposed, but those of No. 1 were not observed. From Thompson's Cañon northward the dip increases steadily in sharpness, until near our northern line the strata are vertical, and at one locality even pushed over to the extent of several degrees. The strata of the Middle Cretaceous, as well as those at the base of the Upper Cretaceous, are badly eroded, and the broad swales between the hog-back ridges are covered deeply with *débris*. For this reason no exposures of these softer rocks are seen, except in gullies eroded by small streams crossing the valley.

Lower Cretaceous.—In its passage down the easterly slope of the Greenhorn Mountains, Hardscrabble Creek has worn for itself a cañon, deep and narrow through the metamorphic rocks, but widening as it reaches the unaltered strata. The sandstones at the opening of the cañon rest directly on the gneiss and continue to the basin of the Arkansas below Cañon City. They are coarse-grained throughout and somewhat conglomerate at the base, where they are reddish-gray and contain some layers marked with seams of quartz, such as have been referred to in connection with the Lower Cretaceous at other localities. As seen along this cañon these sandstones appear to be about 200 feet thick and to belong altogether to the Cretaceous. Followed toward Cañon City they soon disappear under the Upper Cretaceous, which reaches quite to the mountains, but at and near that city they form a well-marked hog-back ridge extending from the southern side of the Arkansas northward to Oil Creek, and thence eastward to beyond Beaver Creek. The outcrop forms a curve around the southern extremity of the Pike's Peak axis.

Along the Greenhorn Mountains, in the vicinity of Cañon City, the sandstones are quite soft at the top, are comparatively fine-grained, and mostly yellow or gray. On Oil Creek they form a massive cliff on each side of the stream near the oil-works, showing a thickness of not less than 300 feet and resting on shales of Jurassic age. About midway they include a bed of bituminous shale, 3 to 5 feet thick, which contains many streaks of lignite. Lower down are other thin beds of dark-colored shale. The sandstones here are very soft, mostly fine-grained, yellowish, ferruginous, and near the top have numerous fucoidal casts, resembling those seen on the San Juan and at other localities.

In the little park behind the hog-back ridge, and extending from Ute to Beaver Creek, these rocks form the upper portion of the outer wall. They are more or less altered, and, as is so frequently the case with the altered sandstones of our district, weather to a brown or sepia tint, though on the surface of fresh fracture the color is usually light-gray. Toward the middle of the mass is a conglomerate with grains as large as a pea, but the rest of the series is very fine-grained, and where only slightly altered quite incoherent.

The upper layers show the films of quartz so often seen in these rocks. On the upper portion of Beaver Creek the sandstones are much altered, and several layers have been converted into a structureless quartzite. In some fragments of a less-altered quartzite perfect leaves of dicotyledonous plants were seen. Farther down Beaver Creek, near the mouth of its cañon, the upper layers are little altered, and are shaly. Along our road the sandstones continue in sight until we approach Little Fountain Creek, where they disappear under the Middle Cretaceous. They re-appear in the vicinity of Colorado Springs, near the Garden of the Gods, where the distortions of the strata expose everything from the metamorphic granites and schists up to the conglomerate overlying the Upper Cretaceous.

Crossing the divide between the Arkansas and South Platte we come again upon the Lower Cretaceous at the head of West Plum Creek. The rock there is a soft, grayish-yellow sandstone, which has been quarried somewhat for building purposes. Near the base the group contains a thin lignite seam, which has been extensively prospected. The bed must be too thin to be worked profitably, for the openings have long been abandoned. Below the bed is an arenaceous fire-clay, and almost directly above it is a seam of iron-ore 8 inches thick. At a short distance under the coal are the Jurassic limestone and shales, while not far above are the characteristic limestones of the Middle Cretaceous.

From Deer Creek northward almost to Golden, the Lower Cretaceous sandstones form a well-marked ridge which is sometimes double. At Thompson's Cañon the thickness is about 325 feet. The upper portion for 100 feet is light reddish-brown, somewhat ferruginous, and showing no fossils other than the characteristic fucoidal casts. For the most part this portion is fine-grained, but toward the base it is coarse. Below this, for nearly 100 feet, there are no full exposures anywhere from Thompson's Cañon northward, but from the numerous fragmentary outcroppings of shale and sandstone it is probable that the space is occupied by alternations of those rocks. Some of the shales are bituminous. The lowest portion, about 125 feet thick, is a light-gray, fine-grained massive sandstone with few fossils, all of them exceedingly indistinct.

Tertiary Rocks.—The only rocks within our area that can be definitely referred to Tertiary age are found along our eastern border on the Arkansas and Platte divide. They consist of a conglomerate already mentioned as occurring near Colorado Springs, and traceable thence to West Plum Creek. This conglomerate lies unconformably upon the Upper Cretaceous rocks, and undoubtedly marks the beginning of the Tertiary. Its particles are little larger than a pea and are cemented by a white ash. I am inclined to regard this as belonging to the Monument Creek group of Hayden, but my opportunities for determining its extent were limited, and I do not care to speak positively respecting its identity with that group.

On the Rio Grande, about thirty-five miles above the town of Del Norte, there occurs a fresh-water formation somewhat more than 250 feet thick, and dipping eastwardly about 3° or 5°. It consists of coarse-grained, thinly laminated shale, bright-yellow in mass, but usually bluish-gray on the surface of fresh fracture. It is composed of material derived by erosion from the eruptive rocks of the vicinity. Near the base it contains a few thin argillaceous or very finely arenaceous layers, which are rich in leaves of *Platanus* and some other dicotyledonous genera, as well as in leaves and cones of *Pinus* and *Abies*, all of which were floated or blown from the land into the lake on whose bottom this shaly rock was deposited. The flora found here has a very modern look, but the presence of *Platanus* shows certainly that the time of its deposit dates back into the Tertiary. Beyond all doubt it antedates the great change of climate ushering in the glacial epoch, since which time the temperature in this elevated region has never been such as to suffer any but conifers to sustain the extremes of heat and cold. The slight dip shows that its deposition is since the great upheaval of the mountain ranges, as it occurs at about 9,000 feet above the sea. The rate of dip is nearly the same as that of the Tertiary conglomerate observed at several localities on the eastern slope of the Rocky Mountains. I am inclined to regard the two as synchronous, or nearly so, and consequently of Eocene age, that being evidently the age of the conglomerate.

The terrace material along the Arkansas and in some portions of South Park is so far consolidated as to be a rock of some compactness. It, of course, belongs to the glacial epoch. In South Park there are some dull lead-gray to yellow shales of Tertiary age containing many leaves of plants as well as remains of insects. These I had no opportunity to examine, but I have been informed that their dip is slight. Upon the plains a marly or tufaceous limestone occurs, underlying the detrital material on the surface. It is evidently of fresh-water origin, and occupies the basins of ancient lakes.

SECTION III.

AGE OF THE COLORADO LIGNITES.

In the preceding description of the Cretaceous rocks, I have referred to that age the whole lignite-bearing series exposed at Cañon City and at other localities along the eastern base of the Rocky Mountains. As this reference differs from that made by Mr. Lesquereux and Dr. Hayden, it is well to give in detail the considerations which have led me to this determination.

This lignite series, the Upper Cretaceous of preceding pages, consists, according to the section already given, of, 1, sandstones, varying in color and structure, and including thin beds of lignite, 250 feet; 2, shales, sandstones, and lignites, 175 feet; 3, sandstone and shale, the former including thin beds of lignite, 350 feet; these measures being taken at Cañon City, where the only detailed section was made.

The stratigraphy shows that the rocks of this series form but a single group. The lignites begin near the base in the sandstone and continue at irregular intervals well up into No. 1 of the section. The strata are conformable throughout. In portions of the sandstone at the base a curious fucoid, *Halymenites major*, Lesqx., occurs in great profusion, and, in the thin sandstones of No. 2, it is found somewhat less commonly. Although experience has taught geologists to place little reliance upon evidence based on fucoids, yet the presence of this fossil confirms the conclusion derived from the stratigraphy that the whole series belong to one group, and represent a single epoch. Respecting this matter, there is no difference of opinion among geologists who have studied the rocks in place. The only dispute is in reference to the position which this group occupies in the geological column. Mr. Lesquereux and Dr. Hayden, depending entirely upon evidence obtained by study of the fossil flora, regard the whole as Eocene, while a careful study of the fauna and stratigraphical relations of the series has led Dr. J. L. LeConte and myself to refer the group to the Upper Cretaceous. Similar considerations have induced Professors Meek, Marsh, and Cope to refer to the Cretaceous several localities, in Utah and Wyoming, which have been regarded as Eocene by Dr. Hayden and Mr. Lesquereux.

Mr. Lesquereux, in Hayden, 1872, has given an extended discussion of the lignite group and its relations, the object being to show that the group is one from the New Mexico border, along the east face of the Rocky Mountains to Wyoming and westward into Utah, and at the same time to show that the whole belongs unquestionably to the Eocene. He has shown quite satisfactorily that the series can be traced northward into Wyoming, and in this has made a valuable contribution to the geology of the region. In the lower sandstone, No. 1, of our Upper Cretaceous section at Cañon City, he finds vast quantities of *Halymenites major*, Lesqx., which, from its close resemblance to a European species, he regards as Eocene. This he finds passing up into the sandstones interstratified with the lignites in No. 2 of our section. For this reason he regards the group as one and of Eocene age. In the shales and sandstones accompanying the lignites he finds great numbers of leaves, principally dicotyledonous, which, as a whole, have a very marked Tertiary facies. Of fifty-five species occurring in Colorado, east of the mountains, he positively identifies three with species of the European Tertiary, and finds eleven others so closely resembling European species that he hesitates to give them new names. There seems, then, no room for doubt that the flora is closely related to that of the European Tertiary, and, reasoning thus, Mr. Lesquereux unhesitatingly pronounces the whole group under consideration, Eocene. In addition, he presents a stratigraphical argument in this, that at Golden the lignite series rests unconformably upon the Cretaceous shales below.

Opposed to the conclusion arrived at by Mr. Lesquereux is the evidence obtained by a study of the fauna and general stratigraphical relations of the rocks. Few animal remains have been discovered above the sandstone, No. 3, of our section, but if we can determine the age of this portion, the question is determined for the whole, since there is no dispute respecting the unity of the group. For the most part the sandstone is a red to gray rock, with little calcareous matter and very friable. From the New Mexico border northward to Colorado Springs its structure is usually such as is not conducive to the preservation of organic remains; still, impressions of *Halymenites major*, Lesqx., are quite frequently seen in layers somewhat more compact than the mass, and in other similar layers there occur indistinct impressions of *Mollusca.* In the Raton Mountains, Dr. J. L. LeConte and Mr. R. E. Owen found *Inocerami* in this rock, and diligent search farther north would doubtless result in the discovery of identifiable specimens.

Following this rock down the South Platte River, we find the lower part of the section well exposed for many miles below the junction of Saint Vrain's Creek and the river. Here, at a horizon above that of the Platteville coals, the exposure is similar to that at Cañon City. At the river-level are shales, argillaceous and arenaceous, gradually passing upward into a bluish-gray, very friable sandstone, on which rests a red, friable sandstone, containing many thin layers which are slightly calcareous. Owing to the superior hardness of the calcareous layers this red sandstone, in weathering, assumes eccentric forms similar to those common on Monument Creek and illustrated in Dr. Hayden's reports. These harder layers are richly fossiliferous. Some of them are made up almost wholly of *Halymenites major*, Lesqx., others are literally crowded with remains of *Mollusca*, and one contains many leaves of dicotyledonous plants. The whole section overlies the important coal-beds at Platteville, and is traceable down the river for a long distance, the dip in that direction being very slight. Near Evans, and in the highest portion of the sandstone, the layers containing the fucoid alternate with those containing *Mollusca*, and the leaf-bed is underlaid and overlaid by both fucoidal and molluscan layers. Unfortunately the impressions of the leaves are not sharp, and but one specimen was preserved. The molluscan species obtained from a layer overlying the leaf-bed are as follows:

Nucula cancellata, M. & H.; *Cardium speciosum*, M. & H.; *Mactra warrenana*, M. & H.; *Mactra alta*, M. & H.; *Lucina*, sp. undt.; *Pholadomya*, sp. undt.; *Lunatia*, sp. casts; *Anchura*, sp. casts; *Ammonites lobatus*, Tuomey; *Ammonites pedernalis*, Roemer, and other species not determinable in any way owing to the imperfect condition With the coal there occurs in great numbers and in excellent preservation, an oyster not unlike *Ostrea patina*, M. & H.

The species named in this list at once fix the horizon of this group, showing it to be the same as the Cretaceous No. 5, of Meek and Hayden. The *Ammonites lobatus* is a species of wide distribution, having been found in New

Jersey, Alabama, and Dakota. *A. pedernalis* is a well-known species from Texas, and the fragments from Colorado cannot be distinguished from it, but as they are only fragments, the identification is not complete. The other species in the list, casts and all, are common in the Fox Hills group, (No. 5,) in the Upper Missouri region. The character of the sandstone as a whole is the same from the New Mexico border to this locality, and the underlying clays are so similar to those at Cañon City as to show that the general conditions differed in no wise along the line, so that this is not an "isolated patch of Cretaceous." In like manner, these fossils, occurring in such vast numbers, and at so great a distance above the clays, effectually dispose of the idea that the clays are merely "beds of transition."

The coals at Golden are regarded as belonging to that portion marked No. 2 in our section, and consequently above the sandstone of which we have been speaking. Fifteen miles above Denver, near the South Platte Cañon, there is a coal-bed formerly worked, which contains in all about 4½ feet of coal, divided into two parts by a clay parting. This bed closely resembles that at Golden, and by all observers is supposed to be the same. Dr. Hayden thinks it probably the Golden bed thinning out southward. Dr. J. L. LeConte states that the clays above and below this coal have furnished specimens of *Ammonites* and *Baculites*, which were collected by General John Pierce, ex-surveyor-general of Colorado.

Passing around the southern extremity of the eastern ranges, we enter the area of the Rio Grande, in New Mexico, and at a short distance beyond at the west, enter the San Juan area, a portion of the Great Colorado Plateau There is no break; we can trace our whole series, Lower, Middle, and Upper Cretaceous from the region east from the mountains to the Colorado Plateau. Throughout the western region all observers have regarded the Cretaceous as triple, composed of a heavy sandstone group at the base, a group of shales, marls, and limestones in the middle, and a mass of sandstone on the top. As already mentioned in another connection, the lithological character of the upper sandstone is very similar to that of the lower, and east of the mountains the same is true, so that in the two epochs the general conditions must have been much alike. There are, however, some interesting differences observed in the two regions. East from the mountains the Lower Cretaceous contains no workable beds of lignite, while at the west it has many. On the contrary, the Upper Cretaceous has no lignite at the west, while at the east the beds are quite numerous.

The lignites of the Lower Cretaceous in Colorado and New Mexico, observed by Drs. Newberry and LeConte, and in Utah by Messrs. Gilbert and Howell, are of enormous thickness, some of them reaching to 30 or 40 feet. No fossils, other than leaves and fucoids, have been obtained from these sandstones, but the stratigraphical relations determine beyond all doubt the position of the beds. They rest directly on the Triassic sandstones and underrun the shales of the Middle Cretaceous on which rest the Upper Cretaceous sandstones. The three divisions of the Cretaceous can frequently be seen at a single locality. Ordinarily, both east and west from the mountains, the Middle Cretaceous is barren of lignite, but during the season of 1873, Mr. Howell found a heavy bed almost directly under the limestones, or in the equivalent of the Fort Benton group of the Upper Missouri. In the Rio Grande region no lignites are reported from the Upper Cretaceous. The rock is very similar to that of the same series east of the mountains. It contains many *Ammonites*, *Baculites*, and *Inocerami*, with other genera characteristic of the Cretaceous. Associated with these, *Halymenites major*, Lesqx., occurs in prodigious quantities.

The Cretaceous series, then, may be regarded as lignite-bearing throughout. Each division is more or less so over a large extent of country. Excepting at Golden, Colo., where an eruption of trap has dislocated the rocks, the strata are conformable throughout, so that the stratigraphical evidence shows no break anywhere in the series. The palæontological evidence seems to be quite as satisfactory. Above the lignites of the Rio Grande and the Southern Colorado Plateau, we have the richly fossiliferous shales of the Middle Cretaceous. Everywhere the sandstones of the Upper Cretaceous present the same lithological character; and wherever they show remains of animal life, the species are those which have sufficed to prove the existence of Cretaceous in Dakota, Wyoming, New Mexico, and elsewhere, and in those localities the proof has been accepted as conclusive. It certainly seems proper that the same species should be relied on to prove the existence of the Upper Cretaceous in Colorado, the more so as these

Colorado rocks are merely a continuation of those already accepted as Cretaceous elsewhere.

Mr. Lesquereux's conclusion, then, that these rocks are Eocene, involves what seems to be a contradiction; for, assuming it to be true, we have here nearly 3,000 feet of Tertiary rocks containing a Cretaceous fauna and resting directly upon the Trias, while not a single Tertiary species occurs in the whole series. At the same time, this Cretaceous fauna is the same which has led geologists to call the very same rocks Cretaceous in Texas, Arkansas, and New Mexico, whence they may be traced through the Gulf and Atlantic States to New Jersey. This certainly follows, for Mr. Lesquereux throws our Upper Cretaceous of Colorado into the Tertiary, and without having seen the rocks he does the same for the Lower Cretaceous of New Mexico. If we have no Cretaceous in New Mexico and Colorado, we have none on the continent.

But at best, his arguments are of little value. The nodose fucoid, *Halymenites major*, Lesqx., cannot be Eocene, for it is never found associated with any but a Cretaceous fauna. It is as thoroughly characteristic as *Arthrophycus Harlani* is supposed to be of the Medina sandstone. In New Mexico the geologists regarded it as thoroughly diagnostic of the Upper Cretaceous; in Utah, Mr. Meek did the same; and in Colorado, I came to a similar conclusion. Wherever animal remains occur with this fucoid, they are invariably characteristic Cretaceous species; and in localities where no fauna occurs with it, the rocks have been pronounced Cretaceous by Messrs. King and Emmons, reasoning on stratigraphical grounds alone. We must regard it, then, as a Cretaceous species, just as in Ohio a *Spirophyton* which occurs in the Waverly group is called Lower Carboniferous because associated with a fauna belonging to that epoch; while in New York the same species is called Devonian because it occurs in rocks shown to be of that age by means of the fauna. If the *Halymenites* should be found at any locality associated with a Tertiary fauna, in that locality it would be Tertiary.

With regard to the land-plants, the case is hardly different. It is not well to forget that some time ago a dispute precisely similar to this occurred respecting the age of certain plants obtained on the Smoky Hill route. The species were identified and their relations were positively determined to be Tertiary. But the question of their age has now passed out of discussion, and all concede them to be Cretaceous. The specimens were imperfect then, and they are little better now. The leaves are mostly single, and the conditions of their preservation show them to have been blown from trees growing near streams or on the shore, whence they were washed into the sea. One of the species occurs associated with Cretaceous fossils at Nanaimo, and only a few have been regarded as identical with European species. Under the circumstances, the evidence in favor of Tertiary age being only fragmentary, while the evidence in favor of Cretaceous age is abundant, it does seem much more reasonable to suppose that in the later portion of the Cretaceous period the climate in our western region was like that of the European Eocene, than to imagine that our Cretaceous fauna is useless for determination of horizon in the narrow strip east of the mountains in Colorado, while the same fauna is decisive of Cretaceous age in New Mexico, the rocks being the same, but the leaves being absent.

CHAPTER XIV.

ERUPTIVE ROCKS.

In the heart of the eastern range, as well as in the magnificent divide between the Arkansas and Taylor Rivers, there is a porphyritic rock, sometimes granite, sometimes syenite, which I have placed among the eruptive rocks. This I have done in deference to the commonly-received opinion, and not because of any direct evidence obtained by myself. There is, it is true, less reason for referring this rock to the metamorphic series than in the case of the granite and syenite mentioned in Chapter XI, as it is rarely seen to pass into gneiss. In some cases its relation to gneiss is very intimate, as near Georgetown, where the line of separation between the syenite and the schists can be drawn only with difficulty. As exhibited in the eastern range this syenite is reddish, fine-grained, and very compact, containing small but beautiful crystals of feldspar. It forms the walls of the great amphitheater around Chicago Lake, under Mount Evans, where, in bluffs 2,000 feet high, not a single break occurs. It was not observed along Clear Creek below Idaho Springs, but becomes abundant above that village. It nowhere assumes the vein form, and ordinarily appears underlying the metamorphic rocks, with an irregular surface. A very similar rock has already been referred to as occurring near the head of the Arkansas under circumstances which seem to prove it a metamorphic rock.

In the range west from the Arkansas the rock presents a somewhat different appearance. From Lake Creek southward it is a very hard, compact syenite, except on Chalk Creek, where it is a granite. The feldspar is usually very light-colored, but in Lake Creek, and the adjoining cañons, the rock becomes very porphyritic, with embedded crystals of greenish feldspar 4 to 6 inches long, and 1 to 2 inches wide. Northward from Lake Creek it changes in structure, and the porphyritic character is lost by the time we reach the head of Roaring Fork. This rock is the lowest in the ridge, and clearly underlies the gneiss, the separation being distinctly marked at most exposures. At Colorado Gulch, however, it does seem to shade off into the schists in such a way as to render the doctrine of its purely igneous origin a somewhat doubtful proposition. A very similar rock forms the center of the Los Piños axis, and through it the Rio de las Animas has cut its great cañon. The cañon being inaccessible, information is to be obtained only from the bowlders in the bed of the river, and it is impossible to determine the relation the rock bears to those of the metamorphic series.

While this rock, especially that variety seen in the Arkansas range, has the aspect of having cooled from fusion, the evidence, upon the whole, seems to preponderate in favor of assigning all the granites and syenites of this region to the class of metamorphic rocks. There is no form or variety of either rock which is not found in some locality passing imperceptibly into gneiss. At the same time the peculiar position of the rock under consideration, it being everywhere the underlying rock, and in every instance forming the center of the axis, leads to the conclusion that it can hardly be associated with the great mass of other metamorphic rocks resting upon it.

The volcanic or eruptive rocks proper extend over a very large portion of the district examined. Beginning at South Park we find the southern divide between the park and the Arkansas simply an outlying portion of the great overflow stretching thence southwest and west, crossing the Arkansas, covering the whole region of the Rio Grande in Colorado, and concealing all other rocks over a large portion of the Grand and Gunnison area. In the great ranges on both sides of the Arkansas, as well as in the eastern range from our northern line to New Mexico, numberless dikes testify to the tremendous activity of the volcanic forces at different periods in ancient times. The rock for the most part is trachyte, which occurs in almost infinite variety of color and texture. It has been deemed unadvisable to enter into any detailed discussion of these rocks, many of which are entirely new, partly because the material on hand is meager, but especially because the collections made by Mr. Clarence King and his assistants are very rich in volcanic rocks, which are now being worked up with great care. The general term "trachyte" will be used, therefore, and I shall confine myself to the tracing of their distribution.

Near the Platte River, and five miles west from the Sulphur Springs in South Park, is a small hill composed chiefly of trachyte resting directly on metamorphic rocks. Crossing the Platte, and following in a southwestwardly direction, we find a similar hill composed of the same rock, while farther on are several low hills made of basalt resting on a light ash-colored trachyte, which disintegrates readily on exposure. These hills are the northern outliers of a broad trachyte dike, which can be traced in fragments for several miles north from the crossing of the Platte. Following down the river to near its cañon, the trachyte is the prevailing rock on the west side. In one place it rests on a coarse sandstone, which is entirely unaltered even at the line of contact. The plain is covered with fragments of basalt and trachyte, which doubtless reach to a considerable depth, as in the heaps surrounding the burrows of prairie-dogs no other rock is seen. The trachyte in the hills is variable in character—at times lead-colored, not very compact, and weathering white; while again it is blue, weathering red, decomposing readily, and yielding a stiff, red clay. The latter is present in greater quantity than the other, and in weathering loses its crystalline portion first, so as somewhat to resemble pumice in appearance.

Following up Buffalo Slough we soon reach the extensive area of volcanic rock forming the divide between the park and the Arkansas River. The surface is rolling, covered with low, mound-like hills, few of which reach to any considerable height. It is almost destitute of trees, except where some mound rising more sharply than the rest shows a steep northern slope. In such a case this slope usually bears some pines. Along the stream the only rock seen is a basalt, of which the upper portion is reddish, and the lower lead-gray. In many localities it is black and resembles melted tar poured out in successive overflows 8 to 12 feet thick. Not infrequently it is coated with oxide of iron, or a brilliantly-yellow lichen, whose color, contrasting with the gloomy black, renders the scene somewhat suggestive. At one point where the stream forks, the trail passes between two very sharp cones of basalt rising nearly 600 feet above the surrounding country. Here and there the basalt is broken by dike-like walls of coarse syenite, which resisted the erosion of the times preceding the overflows of lava. One of these walls is more than 1,200 feet wide, and nearly 100 feet high.

Beyond the summit of the divide is a peculiar mountain surrounded on all sides by open, grassy meadows, and named by Lieutenant Marshall Basalt Peak. It is represented in the following sketch by Mr. Young:

FIG. 136.—Basalt Peak.

This mountain is composed chiefly of a volcanic breccia, consisting of huge fragments of trachyte held in a basalt, which is very compact, and of high specific gravity. Upon the breccia is a hornblendic trachyte, which weathers into thin slabs. From Basalt Peak to the Thirty-Nine Mile ranch on Currant Creek, the principal rock in sight is the hornblendic trachyte. On the surface are numerous fragments of silicified wood containing chalcedony, while in some of the ravines there are exposures of basalt. Near Currant Creek a small knob of gneiss juts above the volcanic rocks. In former times it was covered by them, for at a short distance Thirty-Nine

Mile Mountain, rising a full thousand feet above it, is composed wholly of basaltic breccia. The basalt of that mountain is brown, with white on the weathered surface, but black on the fresh fracture. Much of it is amygdaloid. Obsidian was found here in small pieces, but not *in situ.*

Southeastwardly from the head of Currant Creek the metamorphic rocks prevail and the volcanic occur only in dykes. Occasional plates of trachyte seen on the tops of hills show that the overflow reached in a thin sheet to no inconsiderable distance in that direction. Southwestward the sheet can be followed unbroken almost to the Arkansas Cañon cut through the range on the west side of South Park. Many dikes cross Thirty-One Mile Creek, a tributary to Currant Creek, and continuing southward lead to the extensive area on the west slope of the Greenhorn or Hardscrabble Mountains, along Texas, Wet Mountain, and Huerfano Parks. These dykes are usually of hornblendic trap. The trachyte on the Hardscrabble Mountains is of some interest, as it contains a number of quite promising mineral lodes near Rosita. In the immediate vicinity of the lodes the hornblendic character is especially pronounced; elsewhere the rock is variable, both in color and texture. Along Texas Creek the trachyte is seen forming a wall on both sides of the stream for nearly nine miles. It is blue to very light-gray, mostly quite compact, but occasionally showing a concretionary structure, and disintegrating quite readily. The rock is not all of the same age, for dikes of the harder material are seen intersecting the softer variety, and not unfrequently standing out, the surrounding soft rock having been removed by erosion. On some large fragments of the harder rock, bowl-shaped depressions were observed, whose surface is very smooth, almost polished. These, which are due probably to the same cause as the columnar structure observed elsewhere, were observed at no other locality east from the Park range of Mountains, though they were seen quite often west from the Arkansas and in the Rio Grande region. In Pleasant Valley, on the Arkansas, dikes are quite numerous, and from the fissures now occupied by them an enormous amount of lava has been poured out, overflowing the sedimentary rocks. This lava consists for the most part of a very soft light-gray rock, with some mica, which weathers readily into cavities and afterward breaks down into a white clay. The junction between it and the Carboniferous sandstone on whose edges it rests is well shown near the head of the valley. The sandstone is apparently unaltered up to the line of contact. A little farther up the river, near the mouth of the cañon through the Park range, the sandstone and trachyte are again seen in contact at a huge dike 150 feet wide, which stands out above the surrounding rocks to a height of nearly 300 feet. Here the sandstone is slightly altered for a few inches from the line of contact. In the cañon a great plate of basalt, about 70 feet thick, rests on the upturned edges of the Carboniferous sandstones. The irregularity of its surface and the depth of its synclinal curves show that it has been subjected to some tremendous distorting force after it cooled and hardened. Above the cañon there are no exposures in the broad park of the South Arkansas, and the spur from the Sangre de Cristo Mountains, striking toward Poncho Pass, shows no rock, but is covered by red *débris*, resulting from decomposition of volcanic rocks. From the cañon up the river to the mouth of Trout Creek the only rocks of volcanic origin are those seen in some low mounds, which belong to the soft variety, and on exposure, break down into a white clay.

Along Trout Creek the dikes are numerous but narrow. One of them, 150 feet wide, rises nearly 200 feet above the wagon-road and is beautifully columnar. For the most part these columns are four-sided, though many have five, and a few six, sides. On the eastern side a plate of basalt (*coulée*) covers the tops of the hills. Crossing the range at the head of this creek one comes again into South Park, reaching it nearly twenty miles north of west from the mouth of Buffalo Slough and not far from the salt-works. The hills adjoining these works are covered by trachyte, which seems to be part of a mass projected from the area at the south. This mass reached to the Park range, where it forms the bold double knob of Buffalo Peak, resting on unaltered Carboniferous sandstones. A rock of the same character is traceable in fragmentary exposures along the range from the South Fork of the Platte to near the headwaters of the Arkansas. Between these points, however, are several extensive dikes.

Along the eastern slope of this range the dikes have a trend north-northwest. One of enormous size cuts Mount Lincoln and extends to the Arkansas. On the southwestern face of the mountain it is traceable for nearly 3,000 feet vertically. Near the summit it spreads, displacing the sandstone and forming an intercalated stratum. The trachyte of this dike contains much more quartz than that of any other observed. The quartz crystals vary from one-eighth of an inch to one inch in length, and are terminated on both ends. Some of them have the prism so nearly obliterated that the pyramids appear attached to each other by their bases. The obliteration is not complete, however, in any specimen examined. A mass of closely allied trachyte is seen on the easterly side of the Hoosier Pass, forming a high knob, which rises nearly 1,000 feet above the summit of the pass. Between Fairplay and Hamilton a grand dike thrusts itself well out into the park and rises like a wall, dividing the north portion of the park. Followed northwestwardly, it was found to cross both the Hamilton and the Jefferson pass, diminishing somewhat in width. East from this the dikes are quite numerous until we reach the Kenosha range, where only one was observed. Through this the North Fork of Platte has excavated its channel for several miles. The number and extent of the dikes in the main divide between south Park and the Blue River is partially shown in the following section, obtained in Hamilton Pass, from the village of Hamilton to the summit. The width of the dikes is somewhat exaggerated, as the road crosses them obliquely. Along Clear Creek and Blue River, dikes are frequently seen, but they are quite narrow, seldom more than 30 feet wide. The course is almost invariably north-northwest.

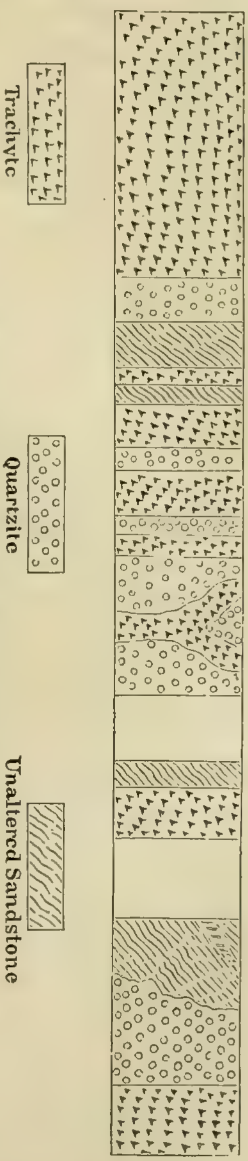


FIG. 137.—Dikes in Hamilton Pass. Scale, 1 inch to the mile.

The diagram shows only such features as were observed along the road in the pass. Efforts to determine the structure, so as to present a section of the mountain, proved unsuccessful. A figure purporting to show a profile of the mountain would be, in great part, imaginary.

Between Blue and Eagle Rivers no igneous rocks were seen, but in the range west from Eagle River and the Arkansas the dikes are numerous and of very large size. The rock is exceedingly variable in character. Some of the dikes are so hard and so capable of resisting the action of the weather that they retain the glacial polishing as perfectly as does the porphyritic granite of the same region. Most of them, however, are composed of either a light-gray micaceous trachyte or a dark pearly trachyte, both of which yield readily to the weather and disintegrate into a loose reddish clay. Red Mountain, near the head of one fork of Lake Creek, is covered by *débris* of this kind, is the southern end of a long line of peaks passing far into the area of the Roaring Fork, all colored in like manner. On the west side of this range the dikes are very numerous, but for the most part very small. One of them, however, is of great breadth, and belongs to a group which assumes much importance near East River, and farther northwest forms a somewhat imposing range of mountains. The great area of eruptive rocks is reached, in this division, between East River and Ohio Creek, where there are several exposures of amygdaloidal basalt. Near the head of East River the trachytes are seen resting on the sedimentary rocks, but no metamorphism resulting from such contact was observed, except at one locality where a dike has turned the black shales of the Cretaceous into slate.

Along the lower portion of Ohio Creek rock exposures are few, as the hills on both sides are low and covered with grass and *débris*, but near the junction of that stream with Gunnison River low cliffs of basaltic conglomerate jut out from the hills and continue along the river to its junction with Tomidgee Creek. How much farther west from this point the volcanic rocks extend north from the Rio Grande divide could not be determined, as this was our western limit. Along the wagon-road from the Gunnison River to the Indian agency the basaltic conglomerate is the predominant rock, here and there removed by erosion so as to expose the metamorphic rocks below, but in the immediate vicinity covering them to the thickness of 1,200 or 1,500 feet. From the agency southward and eastward to the main divide the only rocks in view are those of igneous origin.

Crossing Cochetopa Pass we reach the waters of Saguache Creek. The ridge, which is the third division of the main divide, shows, when seen from the west, a crest almost level from the vicinity of Hunt's Peak to the Rio Grande Cañon. The prevailing rock is a dark trachyte, hard and brittle, breaking with sharp edges and wearing down very slowly. On the east side of the divide this gives place to an ash-gray trachyte, which forms cliffs 40 to 50 feet high, and resembles a coarse irregularly bedded sandstone. Along the valley of this stream, the South Fork of Saguache Creek, the mesa-like hills are composed entirely of volcanic rocks and are capped by a plate of amygdaloidal trachyte, which describes many curves, difficult to follow owing to erosion. On the main stream the rock is again the soft ash-colored variety, soon displaced by a hard form which continues in sight until we reach San Luis Park, and makes up the divide between Saguache Creek and the San Luis River. The broad open space named San Luis Park is covered by volcanic sand, which contains a large proportion of alkaline salts. On the east, the Sangre de Cristo Mountains are seen crusted with the ancient lava to their very crest.

As we approach the mountains on the west side the sand is very coarse, and so open that the little streams sink soon after escaping from the hills. The surface is covered with blocks of basalt and trachyte, and the low ridges jutting out into the park are made of basaltic conglomerate. On Lagarita Creek the basalt is amygdaloid, with many cavities 2 to 4 inches long, filled with chalcedony. Trachyte and basaltic conglomerate seem to alternate, and the total thickness of volcanic rocks on this stream is not less than 2,000 feet. It is sufficiently clear that these rocks have been violently disturbed since their cooling, for they are not only distorted, but faults are not uncommon along Lagarita Creek, where the basalt is seen abutting against the trachyte, which a few hundred feet farther up the stream is seen underlying the basalt.

In a cañon leading from near the head of Lagarita to the South Fork of Saguache Creek the following section was seen:

	Feet.
Basalt, occasionally brecciated	250
Trachyte, light ash-colored, micaceous, soft	80
Basalt, reaching to the stream	30

Crossing the main divide from Saguache Creek we come upon one of the many streams which, uniting below the Indian agency, form Cochetopa Creek. Toward the agency, trachyte in some cases, and basaltic conglomerate in others, is seen resting on the metamorphic rocks. Westward from the agency to Cibolla Creek the prevalent rock is trachyte, of which several varieties occur. Basalt and basaltic conglomerate were frequently seen along the trail, and the following section was obtained:

1. Trachyte, hard, compact, gray, rudely columnar.
2. Basalt and basaltic conglomerate.
3. Trachyte, gray, micaceous, very soft.
4. Trachyte, dull gray, granular, micaceous, tough, but weathers readily, on freshly-fractured surface resembles granite.
5. Trachyte, dove-colored to blue, brittle to tough, weathering into slabs, somewhat micaceous.
6. Basalt and conglomerate.
7. Trachyte, like No. 3.

The thickness of this section is about 500 feet. The most persistent members of the section are Nos. 2 and 3, the former varying little from 150 feet and always accompanied by No. 3 below it. Above the section the trachytes rise several hundred feet at a distance from our trail. On the plateau above the cañon of Cibolla Creek the trachyte is worn by erosion, probably of atmospheric agents, so that the surface is spotted with mounds shaped like a bee-hive. This form is frequently seen. Some of the mounds here are of large size, and closely resemble the *roches moutonées*, resulting from glacial action.

The determination of the thickness of the eruptive rocks in this region is attended with much difficulty, owing to the varying degrees of dip, and the marked similarity of many of the beds. At the head of South Fork of Saguache Creek, a very satisfactory exposure is seen, which gives the information in part. The divide between this stream and the Rio Grande reaches the height of 13,500 feet. Directly under the highest knob is the great "box-cañon" in which the creek heads. Into this we drop, a distance of 2,700 feet, all the way sliding on the eruptive rocks, which show little dip. The thickness here is not less than 2,500 feet. At the head of another fork a vertical wall of eruptive rock is seen 1,000 feet high.

Returning to San Luis Valley, we reach, at Del Norte, the Rio Grande Cañon, which there has opened out into a plain six to eight miles wide, and covered with fine, dusty sand, derived from the eruptive rocks in the vicinity.

Twelve miles above Del Norte the plain contracts and soon after becomes a cañon with high walls, whose crests are almost straight lines. The rock, from this locality to the head of the stream, is trachyte, varying in color from white to gray, lead-colored, blue, and deep green; sometimes hard and brittle; at others almost friable and readily disintegrating under the influence of the weather. Looking east and northeast from the summit of the pass at the head of the Middle Fork, one sees eruptive rocks as far as the eye can reach. The pass is between two great needles of trachyte, nearly 14,000 feet high, while a little eastward is a butte rising from the north wall of the cañon to an equal height. As seen from the pass the south wall is a congeries of sharp peaks and broken mesas, the former terminating in needles, the summits of all being in nearly the same plane.

On the west side of the pass the road descends 2,000 feet in one mile, being cut all the way through volcanic rocks. Reaching the Animas River we find ourselves in a little park, whose walls rise full 3,000 feet above us, and are made up of narrow terraces, with vertical escarpments, in one case 1,000 feet high. Here we have passed beyond the area covered by the eruptive rocks, and have come into a region of dikes piercing sedimentary rocks, which are probably of Carboniferous age. These rocks are completely metamorphosed, and the lavas seem to preponderate. It is somewhat difficult to determine accurately the true nature of many of these rocks by simply inspecting them with the eye, for in some cases the sandstones have undergone such alteration that they bear very close resemblance to trachyte.

Between this and Animas Park but one important dike was seen. Local overflows have occurred in the mountains westward, and many of the peaks are covered with variegated *débris*. From the Animas River eastward to near the base of the Sierra San Juan, no eruptive rocks were seen along our trail, except near the Rito Navajo, where a dull-red trachyte covers a mesa of Upper Cretaceous sandstone. Looking northward from our trail the south wall of the Rio Grande Cañon, which forms the divide between that river and the Rio San Juan, is seen to consist solely of lavas. The thickness must be great, for the Piños, Piedra, and San Juan Rivers show no bowlders on their beds other than trachytic, thus proving that they have not cut through the volcanic rocks.

The San Juan Mountains in their northern portion are completely covered by the eruptive rocks, which reach on both sides of the range quite to the southern line of Colorado. At one locality, evidently not far from the head of the Rito Navajo, these rocks are beautifully columnar, some of the columns being not less than 200 feet long, and of sufficient diameter to be individually distinguishable at a distance of 10 miles, without the aid of a glass. On the east slope the basalts and trachyte conceal all other rocks from the Rio Grande southward to far beyond the northern line of New Mexico. From these mountains eastward, across San Luis Valley to the Spanish Range, one sees nothing but a dull repulsive plain of lava, from which rise the huge basaltic domes known as Ute Peak and Cerro San Antonio. Near Fort Garland there is a magnificent mass of volcanic rock termed Sierra Blanca, of which one peak, Old Baldy, has an altitude of somewhat more than 14,000 feet. In Sangre de Cristo Pass these rocks continue for nearly ten miles, beyond which no more were observed until we reach the outlet of the pass. There we see great mountains of trachyte standing out separate from the Sangre de Cristo, and forming, as it were, a spur. These are the Tetons, and farther south are the Spanish Peaks. Their slopes are rugged and steep, for the most part destitute of soil, and showing few trees.

The volcanic rocks now visible form but a small portion of the original mass, for they have suffered from erosion to perhaps a greater extent than any other rocks within our area. It is exceedingly probable that at one time they covered the larger portion of South Park, filled up the entire region between the Sangre de Cristo and Greenhorn Mountains, and occupied all the space now known as San Luis Valley. It is sufficiently evident from the height of knobs now remaining in the latter region that the thickness of rocks removed thence by erosion could not be less than 3,000 feet, and the ancient mass in Wet Mountain Valley was hardly thinner.

Within the area examined by me no volcano, active or extinct, exists. The volcanic rocks issued from great fissures having, in the majority of instances, a northwest and southeast trend, and now filled with dikes. The greatest of these is an exception in its trend, being rudely east and west. It is of incredible width, and is that along which the Rio Grande has worn out its cañon. This cuts the San Juan axis, whose metamorphic schists are well exposed at the north, a few miles west from the Indian agency, and at the south they can be seen not many miles from the cañon. In each case they are shown at an altitude much above the corresponding point in the cañon, where only igneous rocks occur. The fissure lost its integrity before reaching the Los Piños axis, which crosses the Rio Grande near its headwaters. In crossing that axis it divided into almost numberless branches, which are traceable beyond the Animas River. Everywhere this enormous fissure sent out branches northward into the Grand and Gunnison area, but few into the San Juan region. Whether any direct connection existed between this area and that in South Park I am unable to decide, the information in my possession being insufficient.

The age of these rocks can hardly be determined. It seems quite certain, however, that no extensive overflow antedates the close of the Trias. In the interior they are seen at several localities as great plates [coulées] resting upon the upturned edges of Carboniferous rocks. The facts that trachytes occur as rolled specimens at the base of the Cretaceous near the Arkansas, eight or ten miles above Cañon City, and that the conglomerate at the base of the same formation in South Park has for its cement a volcanic ash, show that some of the rock is older than the Cretaceous. The existence of Tertiary plants on the Rio Grande, in a rock made up entirely of *débris* from the volcanic rocks, shows that the great overflow in the Rio Grande region antedates the early Tertiary, while the sharp folds and frequent faults observed show that the vastly greater portion of the whole mass is not newer than the close of the Cretaceous. Whether any of the rocks are as late as any portion of Tertiary time cannot be told, as they were not seen anywhere resting on Tertiary rocks.

Economic geology of the eruptive rocks.—The older and more compact trachytes forming the dikes in the main divide between South Park and Blue River, have been found by Mr. Alfred Dubois to be auriferous in every case where analyzed. The proportion is too small to admit of working, as it is usually little more than a trace. The same is true of the quartzites, both Silurian and Carboniferous in the same vicinity; but the volcanic rocks are the richer. These rocks are the source of the free gold in several very extensive "flats" where gulch-mining has been carried on. On Tarryall Creek, in South Park, this is most markedly the case, for in the Hamilton Pass, from which the stream flows, the only rocks present are the quartzites and trachytes, the latter predominating. In former times, this was one of the most important gulch mines, and even now, after having been rudely washed out by the old methods of hand-washing, yields to the hydraulic miner an average of $4 a day for each man employed. On the Blue River side of the divide the placers are still rich, and are worked very extensively by strong companies. In many localities iron pyrites occurs in considerable quantity, and no doubt contributes largely toward producing the variegated tints so frequently observed in the *débris*.

At Oro City on California Gulch, a tributary of the Arkansas, a very valuable auriferous lode, known as the Printer Boy, occurs in a dike, and has a course of west-of-north and east-of-south. It shows a well-marked hanging-wall, with black clay casing, but the foot-wall is obscure. On the upper side the rock is a coarse, dark trachyte carrying more or less manganese in streaks. The crevice stuff, to a depth of 250 feet, is a loose, decomposed trachyte, resembling gray sandy mud, with small grains of quartz scattered through it. The gold occurs in thin leaves, and sometimes in minute crystals. As a whole, the stuff is of low grade, averaging about $25 per ton, but the gold occurs often in very rich pockets from which strings radiate, passing sometimes beyond the decomposed material and into the hard rock outside. These pockets are extraordinarily rich; one, barely 18 inches each way, yielded about eight pounds of gold. It is seen, however, that as the depth increases the conditions change, for at an opening nearly 200 feet below the one already mentioned, the vein-stuff, though still so far disintegrated as to be loose, contains much iron and copper pyrites with some blende and galena, all of which are absent above, where azurite and malachite are the only associated minerals. The gold of the gulch below has certainly been derived from the dikes in this vicinity, all of which contain lodes more or less auriferous.

In the Greenhorn Mountains, a somewhat promising mining-district has been formed. The country rock is trachyte, more or less hornblendic. The gangue is likewise trachyte, but differs from the country rock in that where it is not decomposed it is very hard, tough, and more or less vesicular. The lodes have a nearly northwest and southeast bearing. They are usually somewhat ill-defined, but the Senator, the principal lode of the district, shows very good walls with the casings 2 to 4 inches thick. In this vein the gangue is excessively hard and looks much like massive quartz. The vesicles are lined with the ore, which is principally galena accompanied by iron pyrites and some silver glance. One specimen showed a good deal of brittle silver. In several other veins the hanging-wall alone is defined, and the vein-stuff is a light-gray decomposed trachyte. The ore is present in large quantity, but is for Colorado rather low in grade, averaging little more than $100 per ton. The ease with which the ore can be mined, the low altitude of the mines, and the readiness with which they can be reached, as well as the mildness of the climate and the ample supply of fuel, fully compensate the deficiency in grade. Should the present indications hold out, this district will prove of much importance.

CHAPTER XV.

SURFACE GEOLOGY.

SECTION I.—GLACIAL ACTION.
SECTION II.—ANCIENT LAKES.
SECTION III.—EROSION.

SECTION I.

GLACIAL ACTION.

Throughout a very large portion of our district the evidences of the former existence of glaciers are exceedingly distinct. Along the main divide, especially that portion immediately west from the Upper Arkansas, the glacial operations were on a gigantic scale, and in the northern portion of the Grand and Gunnison area the exhibition is scarcely less magnificent than in the main divide. The evidence is equally clear in the Blue River range, the western wall of South Park, and in the Sangre de Cristo Mountains, while in the eastern range, fronting the plains, the glacial cuttings are manifest, and east from the mountains for miles upon the plains, huge fragments of gneiss and granite, resting on sedimentary rocks, bear ample testimony to the existence, at some time, of moving sheets of ice. The glaciers certainly existed as far south as the divide between Wet Mountain Valley and Huerfano Park, north latitude 37° 58′. Whether or not they reached farther south is difficult to determine from our data. The whole region beyond, to the south and west, is covered by eruptive rocks, in which the operations of ordinary erosion eventually bring about a condition almost precisely resembling that resulting from glacial action. Polished and striated surfaces being absent, no data exist, except in the general shape of valleys, which in this connection cannot be depended upon.

In most instances, as might be expected in a region so elevated, and at the same time descending so rapidly on each slope, the effects of recent erosion have been such as to disguise the results of glacial action to no inconsiderable extent. Yet, in the northern portion, there is little difficulty in determining approximately where the one ended and the other began. The broad, boat-shaped trough, through which the glacier passed, is frequently deepened by a running stream, which forms along the central line, or even at one side, a deep, narrow cañon; but, capping the walls of this cañon, the glacial *débris* is usually conspicuous.

The mountain ridges, formerly the seat of extensive glacial action, are now surmounted by thin knife-edges, separating deep cavities, more or less crateriform. Viewed from a distance, such a range resembles a grand plateau, crowned with interlacing ridges, giving the top a reticulate appearance, as though it were made up of enormous septaria, long exposed to weathering. These cavities are, as has been said, more or less cup-shaped, but are usually somewhat elongate. They become narrow quite abruptly, and open into troughs, which are generally broad, and with an irregular surface. These often reach to the wide valleys, but in many instances contract suddenly into a close cañon, which owes its origin not to the glacial action but to erosion by running water. In nearly every instance the large cavities are terraced like an amphitheater, the surfaces of the terraces sloping toward the walls. From these flow streams, whose source is found in one or more ponds upon the topmost terrace. The glaciers in all cases were purely local, moving down the mountain slopes. Whether or not they belonged to the glacial period, so well marked farther east, cannot be determined from the material in our possession.

The character of the rocks throughout a large portion of our district is such as to prevent the preservation of glacial striæ, or polishing, or even of the deeper furrows, where they have been exposed to the weather. Gneiss and micaceous schists rarely retain the markings, and, for the most part, the igneous rocks are much worse, owing to their ready disintegration. The sandstones are coarse, and usually soft, while the peculiar mode of weathering into pits, exhibited by so many of the quartzites and limestones, soon removes all traces from their surface. The only striæ observed were upon the fine-grained quartzites of the Carboniferous, and some gneisses, which, until recently, had been protected by a covering of soil. The massive feldspathic syenite of the main divide frequently retains in perfection the beautiful polish originally produced by the moving ice. The chief evidence, then, on which we may depend, are the moraines, the rounded knobs, and the troughs, in which the glaciers originated, and those in which they flowed.

In the eastern range, under which term we may include the Pike's Peak and Greenhorn ranges, our observations were limited, but from our northern line southward to Pike's Peak, along the eastern face, nearly every peak shows the gashing, characteristic of glacial action. The glaciers here must have united to form a sheet, at least toward the southern portion of this line. Everywhere from the southern limit of the Pike's Peak range, up to Colorado Springs, the surface declines, not very rapidly, from the mountains eastward. It is covered for miles from the mountains, to beyond our limit, with enormous fragments of metamorphic rocks, so strewn everywhere, as altogether to shut out the idea of transportation by running water, and to admit of no explanation of their arrangement, except that they were transported by a sheet of moving ice. In the Kenosha range, which belongs to the eastern range, the evidences of glacial action are not abundant, at least in such portions as were visited by our party. About five miles west from Bailey's ranch, on the North Fork of the South Platte, glacial scratches were seen, but the country is so deeply buried under *débris*, that it was found impossible to trace these up satisfactorily. Between the lower portion of Tarryall Creek and South Park there are many rounded knobs of gneiss, which show an even planing off of the different layers, but retain none of the polish. Striæ, exceedingly indistinct, were seen, having a direction of north 25° east. For the most part, however, the operations of recent erosion have been so energetic here as to remove all traces of glacial action.

Farther north the indications are more satisfactory. Chicago Creek, which enters South Clear Creek, near Idaho, has its source in a small lake of the same name, under Mount Rosalia. This lake, somewhat celebrated as a resort for trout-fishers, is at the head of a "box-cañon," hemmed in on three sides by high, almost vertical walls, of massive granite, which, in many places, is neatly polished, but shows no striæ, and but few furrows. This excavation is trough-like, broad, and has but slight fall. The surface, between the walls, is somewhat irregular, imperfectly drained, with much grass and many clumps of swamp willows. About five miles from its head the trough is closed abruptly by a mass of loose material, made up of fragments of granite, varying in size from mere sand to 8 or 10 feet in diameter, doubtless a terminal moraine, marking the last station, of long continuance, during the retrocession of the glacier. The ice-stream, however, reached not less than three miles beyond this moraine, to the head of a narrow cañon, through which flows another fork of Chicago Creek. If, leaving Georgetown, we follow the South Fork of South Clear Creek, along the road to the Argentine Pass, we reach a similar trough, differing only in that its walls are not so abrupt, and the excavation is wider. Under Gray's Peak, on the opposite side of the range, we find the Peru Fork of Snake River, which flows from a deep crateriform cavity, through a broad, open trough, with beautiful meadows until within a short distance of its junction with the Montezuma Fork of the same river. At the head of the latter fork the evidences of glacial action are so distinct that the mountain between its two forks is known, even locally, as Glacier Mountain.

Along Blue River, at the base of the Blue River range, one rides on glacial *débris* from below Breckenridge to near the headwaters of the stream. The great trough, in which the stream heads, opens out several hundred feet below timber-line, having previously, like so many others, contracted to barely half its width. When it joins the long trough, through which the river flows, the flow falls off abruptly almost 60 feet, a condition not owing to recent erosion, but one which must have existed during the glacial times, as is attested by the fineness of the material composing the heaps at and below Breckenridge.

In the vicinity of Mount Lincoln the glaciers were of magnificent proportions. That mountain is almost isolated from the rest of the range by enormous troughs, whose abrupt walls are partitions so thin that, as one looks down on them from the mountain top, they seem incapable of resisting much longer the wear of atmospheric influences. In these grand troughs are the headwaters of the South Platte, the Blue, and the Arkansas.

Immediately under the mountain are the excavations containing the sources of the South Platte and its tributary, Fairchild's Creek. That of the former has a rudely east and west direction, with irregular surface between the walls, until it approaches the village of Montgomery, where it contracts somewhat suddenly, and at the village drops off 20 or 30 feet into a cañon, about one-third of a mile wide. It is highly probable that this cañon has been deepened by ordinary erosion, for at this point the trough of a tributary glacier opens out into the cañon, but at a very considerable height above the stream. At the same time, when we consider the magnitude of the excavation, it necessarily follows that the depth of the ice-stream must have been very great, so that this smaller glacier, whose length was not more than three or four miles, could have united with it, without the formation of deep crevasses. The cañon, narrow at Montgomery, gradually widens, and assumes the broad boat-shape, with irregular, more or less hummocky surface so characteristic of glacial troughs throughout this region. Near the village of Alma, where the glacier came in from the present cañon of Fairchild's Creek, the trough becomes very wide, and soon disappears.

Following up Fairchild's Creek from Alma we soon pass the narrow cañon of the stream, and reach the old glacial trough. Above the town of Buckskin there are many low, rounded knobs or hummocks of rock, which at one time evidently were polished. Half a mile above the town are two little knobs, on which are some indistinct striæ, quite unsatisfactory owing to weathering. Near the Colorado Company's mill, and adjoining the corral, a bench of gneiss is seen, which exhibits striæ still quite distinct, though somewhat defaced by erosion. Not far from this two other benches were seen: one, of coarse feldspathic granite, has evidently been seriously planed off, but is now so roughened by the action of the weather that all evidences except the channeling have been removed; the other, of gneiss, has been, until recently, protected by a covering of soil. It is beautifully planed, quartz, mica, and feldspar alike.* The channelings are broad, and on the surface are numerous grooves from one-fourth to three-fourths of an inch

* For a knowledge of this locality I am indebted to Mr. Alfred Dubois, of Buckskin, who discovered these markings in 1871.

wide. The grooves have a direction of north 80° west, magnetic, which coincides very closely with that of the gorge. Below Buckskin there is a small accumulation of *débris*, which may, perhaps, be regarded as a terminal moraine. It is probable that these glaciers receded very rapidly, as neither in this gorge, nor in that of the Platte above the junction, are there any large accumulations of *débris*. At some distance below Buckskin the bed of the stream falls quite rapidly, and enters a narrow though not deep cañon. The glacial floor, however, can be traced higher up the hill all the way to Alma, near which locality the two streams joined.

Beyond this locality the terminal moraines begin and continue to beyond the town of Fairplay, becoming more extensive as we descend the stream. These form hills in the broad valley, varying from 50 to 75, or even 100 feet in height, and are badly eroded by the river, which has cut out a deep channel-way through them. Near Fairplay an excellent section of the moraine is exposed in the side of a road leading down to the river, where it is seen to be composed of bowlders, some rounded, others sharp-edged, with occasional striations, and varying from 3 to 10 inches in diameter, mingled with much gravel and fine sand. The whole rises to a height of about 60 feet above the river. Farther up the stream, and about 2 miles below Alma, an exposure shows a greater proportion of fine material, the bowlders being scattered through the gravel and sand. The composition of these moraines shows that most of the material was carried on the bottom of the glacier, or pushed along the floor, there being at no place any large fragments such as might be expected from lateral moraines. At the mouth of the upper division of the trough, in each case, the floor falls very abruptly, and in such a manner that an extensive crevasse could not fail to form; and I am inclined to suppose that in the successive crevasses, thus induced, the lateral moraines were thrown to the bottom, where the coarser material was more or less reduced. If this supposition be true it would necessarily follow that no lateral moraines were formed during the progress of the glaciers through the long troughs below Montgomery, and the new town of Buckskin.

A fact of some interest in this connection was brought to my notice by Mr. Dubois. These hills, or fragments of the moraines, are all auriferous, and hydraulic operations are carried on very extensively from two miles below

Alma to Fairplay. The gold is evenly distributed throughout the whole mass, instead of being collected upon the bed-rock, as is usually the case, where the *débris* has accumulated through the action of running water.

FIG. 138.—Ground-plan of glacial excavations at headwaters of South Platte and Fairchild's Creek.

A few miles southwest from Fairplay we come to Four-Mile Creek, which has its source in two little lakes in Horseshoe gulch. This gulch, at its head, is an enormous double excavation, shaped like two horseshoes placed side by side, and is visible from the opposite side of South Park, forming a striking feature of the scenery. The northerly recess is the larger, and contains two small ponds, which at some seasons are connected, forming a lake with an area of about two acres. In front of this recess are two small hills of Silurian rocks, between which passes the little stream flowing out from the ponds. A similar hill faces the wall separating the "shoes." In the southern recess there is but one pond, and a low, rounded hillock of granite is in its front. On its north side the northern recess is bounded by a long tongue extending eastward, and separating Horseshoe gulch from an immense excavation in the southern side of Mount Sheridan, whose lowest point is far below that of the corresponding portion of Horseshoe gulch. All the hillocks in front of the recesses are low and rounded. The metamorphic rocks are exposed at the base of the rear wall of the gulch, but, with the exception of the one in the southern recess, form only a small portion of the hillocks in front.

The rocks in the upper portion of this gulch are not well fitted to retain glacial markings, and especially so where, as here, they are far above timber-line, and exposed to the excessive changes in temperature so common during the summer. For this reason no grooves or striæ are seen, and even the evidences of channeling are questionable. It is very certain, however, that Horseshoe gulch, as well as the enormous cavity directly adjoining it at the north, was excavated by glacial agency, for on the hills fronting the recesses there are large blocks of granite and gneiss, resting on Silurian rocks, 40 feet above the highest exposure of the metamorphic rocks. The ridge dividing the gulch from the adjoining cavity is similarly furnished, as though the glacier had originally occupied the whole area. The floor of the trough below is somewhat irregular, falling off in sudden breaks at varying distances, until the terminal moraine is reached, about one mile below the proposed site for a smelting-furnace. The integrity of this moraine has been destroyed by the stream, which has removed much of the material, and deposited it in terraces on its way through the Park to the South Platte.

The trough near the head of the South Fork of the South Platte, a few miles south from Horseshoe gulch, is due in part to glacial action, but, in its present form, principally to erosion by running water. The stream rises in a beautiful little lake on a bench near the crest of the range, whence the descent is very rapid for about two miles until the cañon is reached. This is a very symmetrical, though narrow trough, bordered by walls of unaltered rocks, on which rests a mass of detrital matter, evidently the load of a receding glacier. The glacial floor is marked by the bottom of the detritus. Its slope must have been quite rapid, as remains of the moraine occur about six miles from the head of the stream.

The eastern slope of the Sangre del Cristo Mountains is literally gashed to the central line by immense glacial gorges, which are closed by enormous moraines extending hundreds of feet into the valley. As one approaches the mountains, while riding up Grape Creek, he finds the ground covered by irregular fragments of rock, from 4 to 16 inches in diameter. At some places these stones are piled in heaps. Nearer the mountains the fragments become larger, and at length loose rocks 6 to 10 feet in diameter are quite common. These large specimens are all angular, and show no signs of wear other than those resulting from exposure to the weather. Still follow-

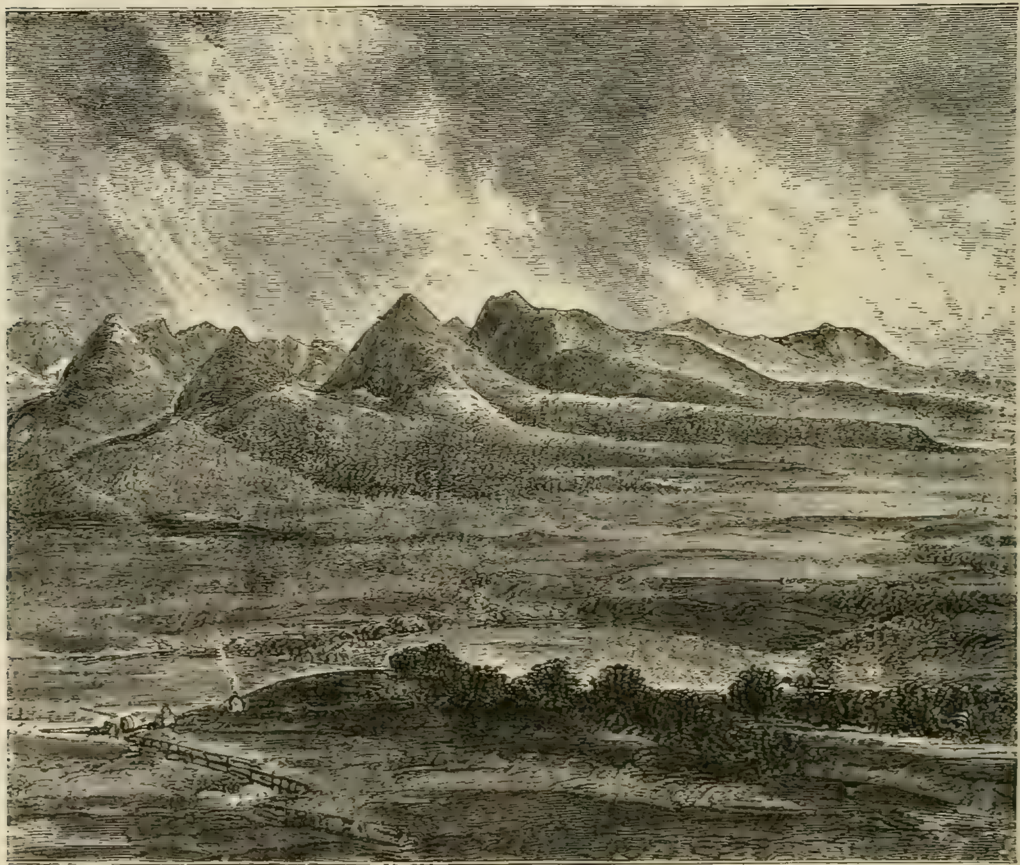


FIG. 139.—Moraine and gorge of Grape Creek, as seen from Wet Mountain Valley.

ing up the stream we reach a long tongue-like hill projecting into the valley for a distance of two-thirds of a mile from the base of the mountain. It is, perhaps, half a mile wide and 600 feet high. Throughout, this is made up of *débris*, and Grape Creek has cut a narrow cañon through it. Climbing the hill it is found to be merely the walls of a great trough, which extends far back into the range, and is closed at its mouth by the mass through which Grape Creek breaks. At the base of the mountain this chasm is 2,000 feet wide, 300 feet deep, and has a direction north 25° east, magnetic. The walls slope somewhat sharply, and the grade of the floor is very slight, but followed into the mountain, the walls become very abrupt, and on the southern side are planed off with the utmost accuracy, while the floor becomes irregular, exhibiting many sudden breaks and numerous hummocks of rock.

This is the most extensive moraine along the range, but is in every way formed like the others. At first it seemed somewhat strange that these moraines, composed of loose material, much of it exceedingly fine, could exist in their present shape, as the valley gives every evidence of comparatively recent origin. But a consideration of all the phenomena renders the matter by no means perplexing. The distribution of detritus along the base of the mountain, and the general shape and character of the valley, lead to the belief that the numerous glaciers, whose troughs in the mountains are in so close proximity to each other, united and covered the whole space with a vast sheet of ice, by which the valley was excavated. It is true that no moraines, or evidence of similar character, can be found on the eastern side of the valley. But this is not to be expected, as the whole section on that side is deeply buried under a deposit of fine material, of which we shall speak in another portion of this chapter. During the recession of the glacier it is natural to suppose that as it approached the mountain the mass would separate into its parts and the individual glaciers would protrude into the valley. Loss by melting would take place on all the exposed sides, and the lateral moraines would build up a wall on the side, while the medial moraines would build up the terminal moraine. Thus a terminal moraine, so to speak, would be built up on all exposed sides of the projecting portion. In this way may be explained the origin of such a trough as is seen along the upper portion of Grape Creek, as well as at many other localities at the west side of Wet Mountain Valley and the basin of Texas Creek.

Passing to the head of the Arkansas, in the vicinity of Mount Lincoln, we find the source of the river in a magnificent trough one-third to two-thirds of a mile wide, about four miles long, and deeply recurved. The craggy walls rise 1,500 feet above the floor, and are deeply scored vertically by recent erosion. The projecting portions are strangely weathered, and at a distance seem to have an imbricated surface. Near the mouth, a

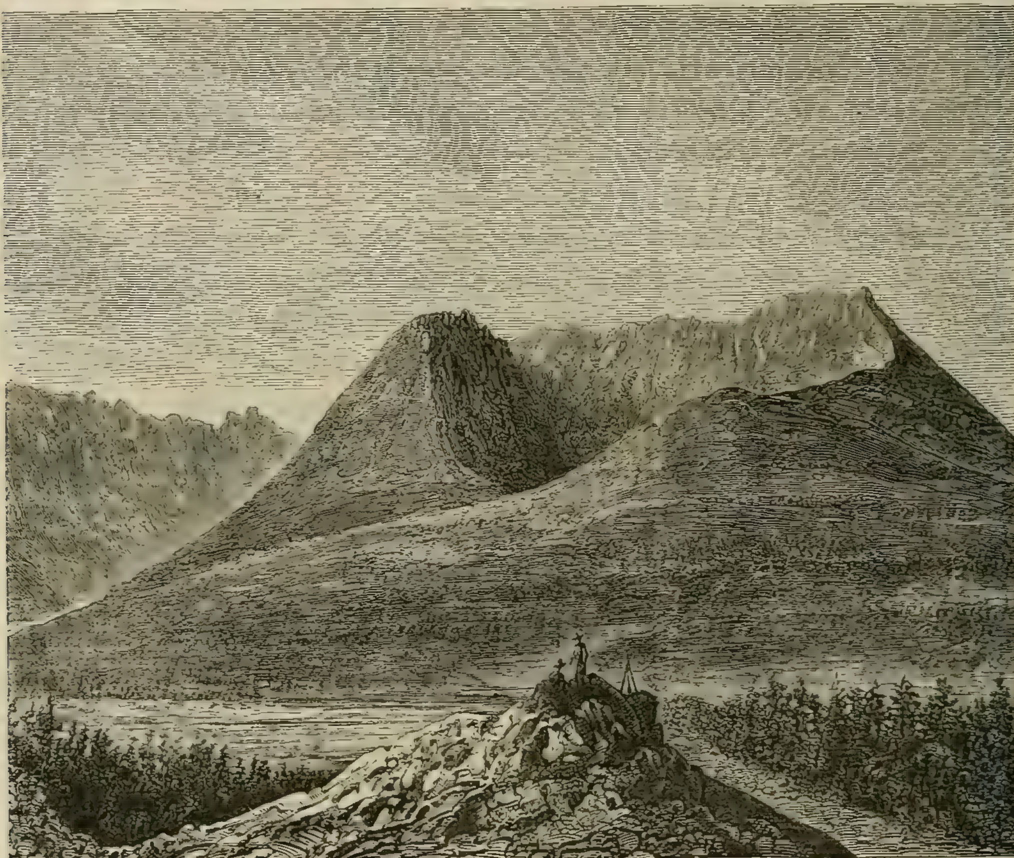


FIG. 139a.—Glacial excavations at headwaters of Arkansas River.

smaller trough enters it from the south, the floor of this being much above that of the main trough. At the outlet the floor falls abruptly. Thence the gorge continues narrow, not more than 300 yards wide for several miles, but the bed has a moderate grade, and is strewn with rounded hummocks made up of *débris*, and covered with fragments of granite, gneiss, quartzite, limestone, and trachyte. At about eight miles from its head, the cañon curves upon itself and the floor falls off sharply 40 or 50 feet to a second plain, which continues for a mile or more without change of grade. The hummocks here have a lineal arrangement, but are badly broken up and covered deeply with *débris*. In the southwest corner is a little lake. At the end of this section another fall occurs in the floor, and the river flows through a group of low rounded hills, rudely conical in shape, 10 to 30 feet high, and having diameters at the base varying from 50 to 200 feet. The gorge is quite narrow here, and the river passes by a cliff of trachyte which is deeply scored, as if by the passage of some hard substance. Below this, to the junction with Tennessee Creek, the gorge widens, but the character of the floor shows little change. These hillocks of *débris* are all that remain of the moraines marking the retreat of the glacier through this cañon.

The headwaters of Tennessee Creek are found in a series of great

FIG. 140.—Glacial excavations at head of Tennessee Creek.

excavations along the face of the range west from Tennessee Pass, which are represented in the following figure. This is by far the finest group of such cavities observed in our whole district.

The glaciers originally occupying these cups were united at no considerable distance from their heads, for their combined moraines form a low mound-like hill extending from near the pass to the junction of Tennessee Creek and the Arkansas, a distance of nearly ten miles. This hill is composed entirely of *débris*, and is covered with blocks of granite and gneiss, with occasional fragments of limestone and quartzite. The surface of the moraine is very irregular, having numerous depressions, many of which are rudely trough-shaped. Not a few of these now hold small ponds of partially stagnant water, surrounded by swamp-grass and frequented by several species of water-fowl. These ponds rarely have outlets, and in most instances the depressions themselves seem to have been the channels of small streams broken up and closed by *débris.*

Crossing the moraine we reach the base of the mountains after a ride of about five miles, so that the area covered by the moraine is not far from fifty square miles. The excavations are very similar in their general characteristics, and the description of one will suffice for all. The most imposing of the group is known as Homestake gulch, deriving its name from a new and rather promising mining enterprise, called the Homestake mine. It is a double cavity, the southern portion being much the larger. From the beginning of the moraine the surface rises westward in successive benches, each of which has in front a smooth escarpment, with a slope of nearly thirty degrees, and occasionally exhibiting indistinct striations. Along the road to Homestake camp striations were seen on every surface of rock from which the soil had been but recently removed. All these surfaces, as well as those of the sloping escarpments, have been planed off smoothly, the different constituents of the gneiss being affected alike. Going upon the upper bench of the southern division of this excavation, we find the surface irregular, somewhat like that of the moraine, there being numerous depressions worn in the solid rock, without intercommunication, and separated by thin, low partitions, which in general outline bear close resemblance to the grand knife-edges separating the large excavations throughout this division of the main divide. These depressions are small and shallow. The surface of this bench has a downward slope to the back-wall, which rises nearly 1,000 feet above the floor, while at its foot are two beautiful ponds, having an extreme depth of about 25 feet. Near the southwest corner of the cup, a narrow gorge cuts into the mountain for about 400 yards and has a very sharply declining floor. At its mouth is a low wall of fine-grained gneissoid granite, about 15 feet high, which has been neatly polished, and even now shows strong grooves, one inch wide and equally deep, coinciding in direction with that of the gorge. Originally these grooves were far deeper and wider, for the rock has yielded much to weathering.

From the junction of Tennessee Creek and the Arkansas, the whole valley to the great cañon below the mouth of the South Arkansas is evidently in its origin a vast glacial trough, and owes in great measure its present form and conditions to the events occurring during the retreat of the glacier northward. As a description of these phenomena would involve matters to be discussed in another portion of this chapter, the whole will be referred to farther on.

About five miles below the junction of Tennessee Creek and the Arkansas, California gulch enters the river from the east, and a little farther on Iowa gulch comes in from the same side. They have the same general character. In each case the stream heads in a deep crateriform excavation, and flows a greater or less distance through a deep irregular gorge on its way to the river. Following down California gulch to new Oro City, we find the banks of the stream composed of clays and fragments of rock. At the city the accumulation is from 7 to 15 feet thick, principally composed of clays, more or less laminated, and containing a few fragments of moderate size. These clays exhibit occasional cross-bedding, always accompanied by more or less of coarser material, as though small dams had formed across the stream. At other places they show curves, sometimes quite sharp, which resulted doubtless from lateral pressure of the detritus farther up the stream. Half a mile below Oro City the clays diminish in proportionate amount and coarse layers come in, containing not merely shingle, but large fragments of rock varying from 3 inches to 3 feet in diameter, and occasional masses are seen having a diameter of nearly 10 feet. None of these are much water-worn.

Along this portion of the Arkansas, one is frequently puzzled to determine the limits of moraines from the smaller glaciers, since by the action of recent erosion moraines are imperceptibly merged into the terraces. But in California gulch the line between terrace and moraine is well marked, and may be seen near old Oro City. Above that locality the gulch owes its present form to the erosive action of the stream and the clays are due to the same agency. The old glacial bed had a more gradual slope, and the glacier itself spread out broadly north and south, as is well shown by the contour of the knobs in the vicinity. It is more than probable that the same glacier at one time occupied both gulches, as the moraine is continuous, covering the dividing tongue with *débris* to a depth varying from 10 to 30 feet. In neither gulch were any striæ seen, as the accumulation of transported material is so great as to conceal the rocks everywhere, except at the very head.

Thirteen miles below the mouth of California gulch, Lake Creek enters the Arkansas from the west, within the cañon, which reaches from the mouth of Box Creek to near that of Cottonwood Creek. The cañon of Lake Creek affords, perhaps, the most interesting exhibitions of glacial phenomena observed along the great range west from the Arkansas. The creek is formed by the union of two large forks, each made up of several smaller ones, all flowing through deep cañons whose abrupt walls are almost entirely free from timber. The sources are found in enormous crateriform excavations, resembling huge amphitheaters, with terraced benches, and opening into the cañons near timber-line, as is so frequently the case in this region. Just as the cañon is reached, the floor of the excavations falls off abruptly. In the upper portions of the cañons the rock is not of a character to preserve glacial marking satisfactorily, being either a brittle granite or a volcanic rock, both of which yield readily to atmospheric influences, but in the lower portion of the main gorge the rock is a hard porphyritic syenite, which resists weathering to a remarkable degree.

Following the southern fork from its head we find the floor exceedingly irregular, ill-drained, and in some places dangerously marshy. At the junction with the northern fork is an enormous mass of *débris*, closing up the cañons and deeply cut by both streams. It is covered by huge blocks of granite, and the surface is pitted with depressions situate between rude hummocks and without intercommunication. Below this junction of the forks, the cañon widens out into a pretty little park half a mile wide, covered with grass and hemmed in by almost vertical walls rising 1,800 feet above the stream. At the end of the park the cañon is narrow, and so continues for about four miles, with a width varying from one-eighth to one-fourth of a mile. Here we reach the hard porphyritic syenite, and on the abrupt naked walls see the result of the glacier's motion. The first object attracting our attention as we descend the stream is a tremendous dike of trachyte, several hundred feet wide, and almost vertical, which, unlike most of its kindred, has entirely withstood the weather. It protrudes into the gorge like a great buttress, dome-shaped on top, and preserving its polished surface for hundreds of feet below. It glistens in the sun as though the polishing had been completed but yesterday. This polishing is everywhere more marked on the northern than on the southern wall, as the latter has yielded more to the action of frost and moisture. Wherever a mass projects into the gorge, the polishing is much more marked on the upper than on the lower side, the effect of the descending stream on the latter evidently having been very slight. Through this portion of the cañon the stream runs close by the southern wall, and the floor between it and the other wall is occupied by rounded hillocks of granite polished as beautifully in many places as though the work had been performed by a lapidary. No striæ are seen here, but instead we find furrows, 2 to 5 feet wide, sometimes in groups like low waves or low abrupt folds, resembling a grand piece of scroll-work. On the northern wall these broad channelings are sometimes visible to the very top, but are rarely exhibited by the southern wall, which, as already stated, has suffered much from recent weathering.

About six miles below the junction of the forks, the cañon contracts to a width of barely one-tenth of a mile. The floor descends a rapid slope for several hundred feet, and suddenly drops off about 20 feet. The cañon then expands into the basin, holding the Twin Lakes, which is nearly five miles long, and varies in width from one mile to one mile and one-half. Before entering this basin the stream dashes through a narrow channel-way, where it is contracted to a width of barely 3 feet. In the jaws of this little gorge a large mass of rock has been caught, forming a curious natural bridge, not altogether devoid of beauty. The basin of Twin Lakes is somewhat celebrated, and justly so, for it is one of the finest scenes in the Rocky Mountains. At the mouth of the cañon the mountains rise to a height of from 12,800 to 13,850 feet, while the approximate line of the lakes is about 9,300 feet. The southerly wall of the basin is abrupt, and its crest slopes gradually downward toward the east, while the northerly wall breaks down abruptly at the mouth of the cañon and rises hardly 400 feet above the lakes. Looking eastward through the narrow valley below the lakes one sees beyond the Arkansas the magnificent range separating the waters of that river from those of the South Platte.

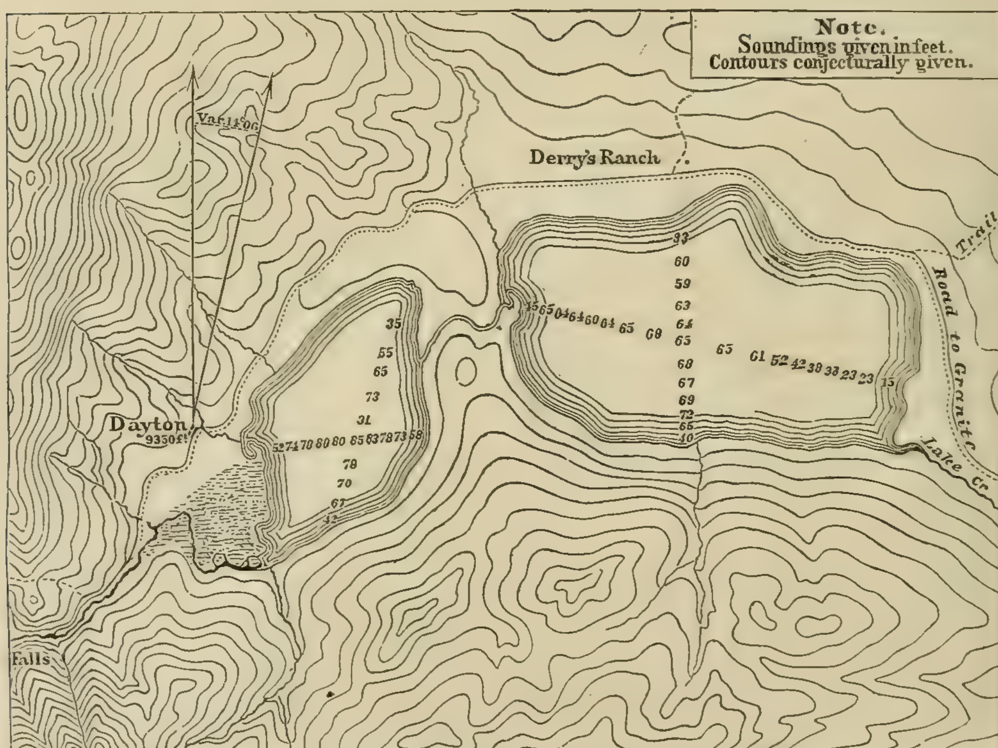


FIG. 141.—Map of Twin Lakes, Colorado.

As we emerge from the cañon at an elevation of about 9,500 feet, we see at a short distance eastward two troughs opening into the basin at about 200 feet above us, one extending in a southerly direction nearly two miles and curving somewhat sharply upon itself, the convexity of the curve being directed to the west, the other much smaller and coming from east-of-south. The southerly wall along the lakes is rocky and abrupt, but on the opposite side the wall breaks down at once at the mouth of the cañon and appears to be simply a mass of *débris*, 200 to 400 feet high, and extending from the mountain round to near the road shown on the map as striking off to the east about two miles below Derry's ranch. On the face toward the lake, this wall is a succession of rude terraces, much broken by recent erosion and littered with large fragments of granite. Its crest, as seen on the road leading north from Derry's ranch, is a grouping of elevations and depressions, the former 10 to 15 feet high by from 50 to 200 feet at the base, and the latter showing a smilar depth and at the top a similar width. The depressions have no inter-communication, but frequently hold small ponds of water during the greater portion of the year. Along this road the wall falls off northward toward Box Creek in a succession of terraces similar to those on the opposite side, but ending in low, rolling knolls covered with angular fragments of granite and gneiss, varying in diameter from 1 to 10 feet. On the crest the fragments are, for the most part, small, and many of them are rounded. Followed eastward, this mass of *débris* rises only 150 feet above the lakes along the road striking off below Derry's ranch, the hill there being rocky. Thence to the river the north wall is rocky, but diminishes gradually in height, and at length almost disappears. Followed below the lakes, the southerly wall soon breaks down into a mass of *débris*, which becomes coarser and lower, so that long before it reaches the river it is little more than a wall of loose rocks.

Below the lakes the stream hugs the south wall closely for a mile or more, and the floor of the cañon for a short distance is filled with low, rounded knolls of granite, but farther on the whole is covered by fine *débris*, through which the creek meanders somewhat sluggishly. On both walls here transported blocks occur, but they are most numerous on the southern side, where there are some of gigantic size. They are granite, gneiss, and trachyte. Many of the last named are small, rounded, and covered with striæ, as though they had been borne along, attached to the bottom of the glacier. The course of the creek does not coincide with the median line of the glacier, but is near the northern edge. No traces of the moraines occur beyond the north wall of the stream's channel-way, but on the south side the wall breaks down, practically, at some distance from the river. At the south of this wall, as well as in its eastern prolongation, the rudely parallel lines of fragments may be seen stretching back more than two miles from the river, marking the old medial and lateral moraines carried down on the surface of a glacier. These are broken, not continuous lines. At varying distances we find small heaps of stone, between which are angular fragments, larger as we approach the river, near which are many blocks of such size, that, at the distance of three miles, they might readily be mistaken for miners' cabins.

An examination of the accompanying map of Twin Lakes and the vicinity, shows that the course of the glacier, after issuing from its cañon above Dayton, must have coincided very nearly with the longer diameter of the upper lake, or rather, with a line connecting the mouth of the cañon and a point about one-eighth of a mile northwest from Derry's ranch. It is more than probable that the glacier once occupied the whole ground now covered by the wall of *débris* reaching from above Dayton to some distance beyond the ranch, while the mass of *débris* piled against the hill, crossed by the left-hand road below the ranch, shows, certainly, that the ice must have reached beyond the limits of the lower lake, or to the line where the basin is seen to contract. The characteristics of the wall on the north side of the lakes have already been given, proving it to be unquestionably a terminal moraine. At the same time we have found farther down, and at the south of the creek, fragments marking both medial and terminal moraines, such as could be left only by the retreat of a glacier formed by the union of several smaller streams. At first sight one is somewhat perplexed to reconcile these conditions, which seem to involve the remarkable phenomenon of a change in the course of the glacier. The difficulty, however, is apparent rather than real. The main glacier moved from the mouth of the cañon northeastward and united with the great glacier of the Arkansas near the line of Box Creek, and not far above the head of the Granite Cañon. It is most likely that the moraines seen just below Lake Creek, near the river, belonged to another glacier, of smaller size, emerging from the mountain east of the lakes, and possibly at one time tributary to the glacier of the cañon above.

Be this supposition respecting the lineal moraines as it may, it is impossible to doubt that the Lake Creek glacier joined the great glacier of the Arkansas above the Granite Cañon, and that, too, until a late period in the glacial history of this region. If we follow the line already indicated as its course, we find it cutting Box Creek not far from where that creek is crossed by the road passing over the hill east from Derry's ranch and leading to Oro City. At this crossing the road is almost level with the surface of the upper lake, while a little farther eastward the surface is nearly level with the deepest point indicated by soundings in the lower lake. If we follow the road striking over the hill just above Derry's ranch, we ride on an undoubted moraine for several miles, almost to Box Creek, which has already been described as littered with enormous fragments of granite on both sides, while, if we take the other road we find the *débris* accumulated against a hill of solid rock, and to a height of not more than 150 feet above the lower lake. The moraine marking the front of the glacier lies then between the mountain by Dayton and the hill crossed by the Oro City road turning off below Derry's ranch. The retreat of the glacier to the line marked by this moraine must have been at a comparatively recent period, for the level of the lakes is the same, or nearly the same, as that of the second terrace on the Arkansas above Granite Cañon. The basin above the cañon was scooped out after the great glacier had retreated entirely from the whole valley below and after the Arkansas River had begun to erode the cañon.

It is not difficult to account for the origin of the plain through which Lake Creek now flows below the lakes. If the glacier during its long halt in the vicinity of Twin Lakes, long enough to admit of the accumulation of its enormous moraine, extended half a mile east from the lower lake, its waters might readily find their way to the Arkansas along the present line of the creek, and so in time wear for themselves a channel. Probably only a narrow wall separated the great glacier from the smaller one, whose retreat was more rapid, and which has left behind it only the lineal moraines seen nearer the river. There is much reason to suppose that this was the actual condition. When our glacier retreated within its cañon it left a basin in the detritus, in which a lake was formed, fed by the waters of the melting ice, and reaching to or near to the top of the moraine or northerly wall. As the channel of the creek deepened, the lake was gradually drained, as shown by the irregular terraces on the northern wall, until at length the level fell below that of the detrital dam now separating the two lakes, and led to a division of the lake. In this way the whole may be readily explained.

Unfortunately I could not accompany that portion of our party which explored the Arkansas from Granite to Cottonwood Creek and ascended the streams between those points. I was enabled, however, to gain some information by means of bird's-eye views obtained from the bluffs overlooking the sources of Clear, Cottonwood, and Chalk Creeks, on the western side of the main divide. In each case the general features resembled those observed in the cañon of Lake Creek. The streams all have their head in little lakes held upon the upper benches or terraces of enormous excavations, somewhat oval in form. These cups contract suddenly at the eastern side, so as to form a broad cañon, which alternately widens and contracts until it opens out into the valley of the Arkansas River.

Passing now to the west of the main divide, we cross the Arkansas Pass and reach the gorge of Ten-Mile Creek. The stream heads in a small cup, almost directly overlooking the headwaters of the Arkansas, which opens out upon the broad summit of the pass. For one-half mile or more the descent is very gradual, the surface is smooth and badly drained, and is covered by a marsh, which stretches wholly across the gorge, and even involves the hill side on the east for some distance. The existence of this marsh, so large, on a slope such as this, is somewhat interesting in its bearing upon some recently announced opinions respecting the origin of the coal series, for it shows that an absolutely level plain is by no means essential to the growth of swamp. The conditions prevailing in the gorge of Ten-Mile Creek, especially in this upper portion, are such as might easily prevail along a shore for any required distance, so that the conditions for the formation of a coal-bed could exist on a moderate slope of 30 feet to the mile, as well as on a level plain.

About one-half mile from the summit the descent becomes more rapid and the plain is broken up into irregular rounded hummocks, on which are many fragments of granite. Amid these is a pretty little lake occupying a depression in the detritus and communicating with the stream. These hillocks continue to a distance of nearly eight miles from the summit, always showing about the same height above the floor, but becoming more regularly rounded as we descend the stream. The floor of the gorge is marshy throughout this distance, although the descent is quite rapid. The branches coming in from the east issue from great cups in the Blue River range, which communicate with the main cañon by means of narrow gorges, marking the path of tributary glaciers. The crest of that range on this side is very jagged, torn into great cavities, whose walls are surmounted by needles. At the base on this eastern side the moraines of the tributary glaciers form a continuous line from McNulty's Gulch to within a mile of the junction with the West Fork of Ten-Mile Creek. They occupy nearly one-third of the width of the main cañon.

The South Fork of Eagle River has its sources in a group of glacial excavations, west from Homestake Mountain, scarcely inferior in grandeur to those of Tennessee Creek, and showing the same general features. The glacier, whose course this stream follows, must have been one of the most remarkable in the region, reaching, as it did, from the vicinity of Homestake Mountain to certainly beyond our farthest point on the Eagle River. For a number of miles the stream flows through a swampy valley, one to two miles wide, and then enters a very close and narrow cañon at whose head it is joined by another stream issuing from a cañon much wider than the one just referred to. The main cañon is about six miles long, and opens up about four miles above the junction with the North Fork, and continues, alternately widening and contracting, until at a distance of about one mile and one-half below the junction it becomes a broad, open valley, one to three miles wide, and extending to beyond our line. Above the cañon the transported fragments are piled in ridges along the side of the plain, while along the middle they are not numerous. The little tongue separating the plain of the main stream from the fork coming in at the head of the cañon is literally paved with great fragments of gneiss and granite. There one granite block, weighing not less than twenty tons, is perched on a shelf of Silurian quartzite.

The head of this cañon marks a station during the retreat of the glacier. It must have been one of long continuance, permitting the grinding out of the valley above the cañon, and the erosion of the cañon itself by the glacial river. The glacier originally flowed along a floor above the top of the cañon walls, in a broad channel, to the end of the present cañon, for fragments of granite are not infrequent upon the mountain side, several hundred feet above the metamorphic rocks, while just below the mouth of the cañon, blocks of gneiss and granite rest on the carboniferous rocks, 200 feet above the stream. At the lower end of the cañon a gorge opens into that of the main stream. It comes down from a mountain nearly 13,500 feet high, which seems to have held glaciers on all sides. Unfortunately, the brief time allowed for the whole of this trip admitted of no extended examination of this most interesting tributary. The gorge is quite wide, and its floor exhibits *roches moutonées*, quite as beautiful as those of Lake Creek on the Arkansas. Its mouth is closed by an immense moraine, through which a stream has worn for itself a narrow channel-way, dividing like a delta. This moraine probably reached entirely across the main gorge, for on the opposite bank of the Eagle, and resting on the terrace, there is a mass of granite weighing not less than one hundred tons. Another tributary gave origin to the lower portion of the gorge through which the North Fork flows. It had its source in the Blue River range, or possibly a spur of that range, and reached the present course of the North Fork about eight miles above the junction. The evidences of its presence are ample. On Red Mountain, four miles above the junction, fragments of granite are found, 400 feet above the stream, resting on the upper sandstones of the carboniferous, while, on the terrace at the base, similar fragments are arranged in curved, rudely parallel lines, as though a glacier had issued from the gorge at the northeast of Red Mountain. Both above and below this locality low hills are of occasional occurrence, rudely conical in shape, whose surface is covered with fragments of gneiss, granite, and limestone, varying in size from a few inches to 2 or 3 feet in diameter. Few of these show any signs of water wear, and many still retain the sharpness of their angles. About ten miles below the junction of the forks another glacial gorge was seen, but no examination of it was made.

The short spur between the South Fork of the Eagle and the Roaring Fork is everywhere interesting. As the main portion of our party did not examine the western side, I have no information respecting that region, further than could be obtained by a visit to the divide between Roaring Fork and Taylor River. At a short distance north from this divide we reach an elevation of 13,000 feet, and stand upon a mere partition separating the headwaters of several little streams, which form the Roaring Fork of Grand River. From this elevation we look down on all sides into deep crateriform cavities, whose walls, rising sharply to a height of from 1,000 to 2,000 feet above the floor, show no break, except the narrow cañons through which the little streams escape. At the west of us, under a massive wall, rising everywhere beyond 13,000 feet, and culminating in Whitfield's Peak nearly 13,900 feet high, are several cups, whose floors rise in a succession of gigantic steps, until they are lost in the ridge; while at the east, and directly under us, is a series of gorges rivaling in grandeur those at the west, but by no means equaling them in eccentricity of outline or wierdness of surroundings. The one nearest us is almost elliptical in shape, with walls inclined at 60°. The floor is roughly terraced, and, below timber-line, is covered with a dense forest of spruces. Its area is not less than six square miles. Entering it from the east is a similar but more elongate excavation, with several branches, all heading up under Red Mountain. The whole area occupied by these cups is more than twenty-five square miles, from which nearly all the rock has been removed, only narrow, knife-like partitions, barely one mile wide at base, remaining. From this group the streams escape through deep gorges, and soon unite to flow through a broad and rapidly-deepening cañon. The sources of the streams are all far above timber-line, but at a distance of twelve miles the main stream flows at a level of 2,000 feet below it.

In the vicinity of Rock Creek the evidences of glacial action are numerous and satisfactory. The examinations here were limited to the upper portion of the stream, reaching not more than seven miles from its head. The effects of ordinary erosion by running water have been such as to deepen the channel-way of the stream, and to cut out a tremendous cañon, beginning really only a mile or so from the source. The glacial floor is found on a bluff of quartzite, overlooking the embryo village of Elko. This was plowed into furrows, from 1 to 4 feet wide, and from 6 to 12 inches deep. It is polished, and shows striæ about one-fourth of an inch wide and deep. These are crowded, and for the most part rudely parallel, though not infrequent crossings of the lines at acute angles tell of slight shiftings in the course of the ice. I was able to trace these striations 300 yards, for which distance they are very distinct. On this easterly side there is evidence of a more ancient floor, 250 feet above the one just described, for, at that elevation, there is a broad bench, with an irregular surface, now covered with *débris*. If we climb the mountain on this side we find it breaking off precipitously on the opposite slope to a great cup, which is separated by a narrow partition from a similar one at the east.

On the west side of Rock Creek a stream comes in, just above Elko, which rises in a cup contracting near timber-line. This is rudely oval in outline, with a longer diameter of about two-thirds of a mile. The floor of its cañon drops down to Rock Creek in a succession of benches, quite abrupt, and from 10 to 80 feet high. On each of these the surface slopes backward from the escarpment, and holds one or more lakes communicating with the stream through sluggish outlets.

Near the head of Slate Fork of East River glacial striæ were seen, similar to those observed on Rock Creek, and it seems to me probable that this whole region was at one time covered with a vast glacier, afterward divided into a number of streams, which excavated in measure the numerous gorges. On East River the moraines are nowhere visible. But well-marked moraines could hardly be expected, since the materials, on which the glacier acted during the greater portion of its existence, were either the Cretaceous shales or the incoherent sandstones of the Carboniferous. Both of these would be reduced to fine powder, and any accumulation of such material would be removed by the streams, and deposited evenly over the surface below. The only trace of such an accumulation is found near the junction of Slate and East Forks, where for miles the former stream is very sluggish, and flows through a marshy plain. Of this circumstance beavers have not been slow to take advantage.

Along Taylor River we find the main divide at the east deeply cut by glacial cavities above the timber-line, and resembling, at a distance, an irregular plateau, covered by peaks and combs. From the headwaters of the forks to their junction the evidences of glacial operations are conclusive. Each little stream, where it issues from the mountains, has been dammed up by a mass of *débris*, through which it has cut down a channel-way. The moraines closing the gorges of the East and Middle Forks are of magnificent proportions. Of that belonging to the Western or Main Fork nothing remains but enormous blocks of granite, some of them weighing two hundred tons. Below the junction of the several forks the surface is quite regular for a mile or more, being interrupted only here and there by a low mound; but beyond, the valley is choked by hillocks, showing no exposure of rocks in place, but composed of detritus, and covered with fragments of rock. Among these are many pot-shaped depressions, containing ponds of water, which seem to be permanent, though their source of supply is not apparent. The hillocks continue for about a mile, and end somewhat abruptly. Along the eastern wall of the park a terrace of fragmental material, little higher than the hillocks, begins near the junction of the forks, and ends quite suddenly about two miles below its beginning. It and the hillocks evidently mark a terminal moraine of the glacier, which, in its greater extent, had ground out the Taylor Park. On the west side the hills, in many places, are rounded, and a low ridge of granite foot-hills line the wall.

Below the line of the hillocks, the park is a broad plain, more or less uneven in surface, with ponds showing neither inlets nor outlets. About eight miles below the head of the park a stream comes in from the east, which has its source on the summit of Lake Creek Pass. Some of its tributaries rise in the most remarkable amphitheater yet seen in our district, and the broad cañon of the pass on this side is not wanting in wild beauty. Its walls are bluff and deeply scarred by weathering. The bold, projecting portions, reaching from the base to the top, resemble the ornamental projections on the walls of gothic churches, so that the walls look like the ruins of enormous cathedrals. The floor of this gorge is narrowed by the high and broad accumulations of fragments broken from the walls. Its descent is rapid for half a mile from the summit, when it suddenly falls off more than 100 feet. The moraine begins about three miles from the summit and continues for not less than three miles, stretching far out into Taylor Park, and broken into hills by recent erosion. In the southern portion of this park, known as Beattie's Park, there are many low, rounded hills, some of naked rock, and others deeply buried by *débris*, which owe their origin to glaciers originating in the mountains in the vicinity and afterwards joining the main glacier in the park.

At the head of Union Park, through which Lottus Creek flows on its way to Taylor River, there is a very pretty illustration of glacial operations. The excavation here is broad, and, unlike all other instances observed, does not contract into a cañon. Descending from the ridge separating the waters of Taylor River and Tumichi Creek, we reach a basin whose area is about eight hundred acres. Its surface is quite irregular, but shows a slight slope backward, and has a low ridge of rock stretching nearly across it in front, like a dam. Here are several lakes, but evidently none are permanent. This bench falls off sharply about 100 feet to below timber-line, where another basin is found, half as large as the former, similarly provided with a rim in front and containing a lake covering six acres, and surrounded by a luxuriant growth of swamp-grass. Below this the floor falls off in a succession of similar benches until it reaches the undulating surface of the park. The rims in front of the benches have been so weathered as to remove all traces of glacial grinding or polishing.

In the southern portion of the Grand and Gunnison area, among the volcanic rocks, the evidences of glacial action are somewhat obscure. At the head of Cibolla and Cochetopa Creeks there are magnificent amphitheaters leading down into broad valleys, the whole closely resembling those eroded by glacial ice in the harder rocks farther north. As one looks down the Gunnison beyond our western line, he cannot fail to be impressed with the remarkable regularity of the slope from the highlands north and south toward the river. Through this broad trough the river and its tributaries flow in deep cañons, and the whole region is thus cut up into mesas, whose upper surface, as already stated, slopes toward the river. This slope has no relation whatever to the dips of the layers making up the mesas. Its regularity over so extensive an area forbids the supposition that it is due to ordinary aqueous erosion, and one can come to no conclusion other than that it was planed off by a sheet of ice, which, originating in the massive range west of the Arkansas, flowed westward, cutting through the anticlinal axes in that direction.

The features of the Upper Rio Grande region, as well as those of the Rio de las Animas and the Upper Arkansas, will be considered in the next division of this chapter.

Along the western side of the Sangre de Cristo Mountains, the evidence of very extensive glacial operations is quite as satisfactory as it is upon the eastern slope of that range. Similar evidence is seen in that portion of the main divide reaching from the South Arkansas to the mouth of the Rio Grande Cañon. At the head of the South Fork of Saguache Creek the amphitheaters are of enormous size and of typical character. It is unnecessary to enter into any details, as that would involve simply repetition of what has already been stated respecting other localities.

SECTION II.

ANCIENT LAKES.

South Park is a basin containing about eight hundred square miles, and is surrounded by mountains rising from 2,000 to 6,000 feet above its lowest point. It is broken into longitudinal valleys by low ridges, which have been so affected by erosion that many of them have lost their continuity and are now merely lines of hills, few of which rise more than 300 feet above the adjoining valley. These, up to a certain height, are naked, but their crests are covered by a growth of cottonwoods and spruces. A similar condition prevails along the margin of the park, there being over the greater portion no trees except above the barren level marked on the hills. Exceptions to this general statement are by no means infrequent, as the trees are advancing downward and everywhere encroaching upon the naked area.

In the northern portion of the park, one cannot fail to be impressed by the remarkable evenness of the surface. Where it has been cut down by the streams the terraces are beautifully regular, except where eroded by rivulets. Along Tarryall Creek, below the village of Hamilton, they are finely exhibited. On the south side the terrace is unbroken and the escarpment is perfect, having an almost straight line for its crest. The terrace on the north side is imperfect, owing to the proximity of other creeks and the consequent washes. The numerous gashes thus produced give frequent partial exposures, which show the structure very satisfactorily. The material is sand, gravel, and water-worn fragments of rock varying from 2 to 15 or 20 inches in diameter. The larger fragments are more numerous near the mountain, and occur chiefly at the base, while higher up there is distinct evidence of sorting and stratification. At one point several miles from Hamilton, and near the end of the northern terrace, the following partial section was seen, which represents very fairly the upper portion:

1. Soil	1 foot 6 inches.
2. Sand, with rolled stones 2 to 4 inches in diameter	2 feet.
3. Fine sand	4 feet 6 inches.
4. Coarse sand with streaks of gravel	4 feet 6 inches.
5. Coarse gravel seen	4 feet.

The gravel consists of trachyte and quartzite, with rarely some gneiss. The thickness of this *débris*, as seen on Tarryall Creek, is more than 70 feet, that being the extreme height of the terrace. From Hamilton down for two miles or more it is quite auriferous, especially near the base, and in the earlier history of the vicinity was the scene of extensive gulch-mining. The gold was derived from the eruptive rocks and the quartzites, there being no other rocks on the eastern slope of Hamilton Pass. Looking west from the Kenosha range, the southern terrace is seen to be the level of this portion of the park. North from Tarryall Creek, the surface is badly cut up by numerous little streams, and shows many knobs of detrital material, which of course vary much in height, but such of them as have suffered least, show a summit reaching to nearly the same level as the terrace, which stretches southward unbroken almost to the Platte.

West and southwest from Fairplay a similar condition exists. From the Platte River the surface rises in a succession of terraces to the mountains, all bearing more or less of vegetation, and covered by fine soil containing much gypsum. Similar terraces are seen on the west side of the river in the southern portion of the park. On the hills the old lake-level is well shown, not only by the line of timber, but also by the slope, which is quite gradual from the valley up to the trees, but above that line becomes abrupt, as if worn by incessant action of moving water. Several of these hills are eroded in a manner which would have been impossible had the lower portion been unprotected, for above the lake-level they are cut down so as to resemble little ridges, while below the level they are intact. On several hills east from the Platte and southwest from the Sulphur Springs, a succession of terraces are seen marking the lowering of the lake as its waters were drained away.

It seems hardly probable that this basin owes its origin primarily to glacial action. The arrangement of the rocks leads to the supposition that here there existed a synclinal trough, deepening southward, which was merely enlarged by the ice. Into this trough the great glaciers from Jefferson and Hamilton Passes, originating in Gilpin's Pillars and Mount Morton, together with those from Mount Lincoln, Mosquito Pass, Horse-Shoe gulch and Stony Point Pass, with others from the Kenosha range, moved down until the whole was full. Those on the east ground the Kenosha range down to a level far below that of the mountains at the west, and doubtless aided in wearing down the partial fissures now greatly widened, through which Tarryall Creek and the South Platte River find their way. The glacier could not have left the park until these gorges had been deeply eroded, for at the southeast the lake seems to have had an extreme depth of only 140 feet. The retreat of the ice was followed by the formation of the lake fed by streams issuing from the numerous glaciers. This was gradually drained as the cañons of Tarryall Creek and the Platte were deepened, until nothing remained but ponds, whose position is marked by patches of alkali. The deepening of the cañons has gone on, until now Tarryall Creek flows 70 feet below the lake-bed, near the old shore-line at the northeast, while the Platte, running more nearly along the line of greatest depth, is but 25 feet below the old bed at the south.

The Upper Arkansas.—From its headwaters to its junction with Tennesseé Creek, the Arkansas flows through a deep and narrow glacial gorge. In like manner from Tennessee Pass to the junction the excavated channel-way is narrow. But below that point the valley widens, and to the head of Granite Cañon maintains a width of from five to eight miles, as measured at the level of the topmost terrace. From the head of Granite Cañon, almost to Cottonwood Creek, the extreme width from base to base of the mountains is little more than one mile, but at the end of the cañon it again expands and soon attains a width of nearly eight miles, measured as before, which continues to the South Arkansas River. The width as here given differs widely from that at first apparent to the casual observer, for the main terrace in some localities projects so far as to render the flood-plain very narrow, while in others it has been so extensively eroded that the plain below which the river flows, as near Chalk Creek, seems to reach completely from mountain to mountain.

The upper basin reaching from the junction of the river and Tennessee Creek to the head of Granite Cañon, a distance of twenty miles, shows an extreme width of eight miles, measured, as has been stated, on the surface of the upper or main terrace. The slope of the basin is very slight, there being but a small difference in level between the mouth of Colorado gulch and the surface of the river at the head of the cañon. The river flows almost centrally through the basin, which is flanked on each side by a magnificent range of mountains. The first terrace at the east is low, only a few feet above the present flood-plain, and extends eastward somewhat less than one mile to the escarpment of the second or main terrace, which here reaches to a height of nearly 200 feet above the river, and presents a front unbroken for several miles, save only where some large stream has worn out a broad, deep ravine. Its upper surface rises gradually for about four miles with a grade of somewhat more than 50 feet per mile, until at old Oro City, where the terrace ends and the moraine begins, the elevation is 420 feet above the river. At one or two points near the mountains there appears to be a still higher terrace, as seen from the river, but this I am inclined to regard as the remains of a moraine, since no terrace was seen in that position, though moraines were. The composition of the terrace is seen near the junction of the river road with that coming down from Stony Point Pass, there being at that locality several minor terraces formed by the tributary creek. The sorting and stratification appear in the alternating layers of fine and coarse gravel. Southward from this place the terrace is much broken by erosion and its continuity is soon lost.

On the west side of the river the condition is very different. The first terrace is of limited extent and is soon lost in the second, rising 20 feet above it. This is the prevailing terrace northward from Half-Moon Creek. Remains of a third terrace are seen near the mountain in the vicinity of Colorado gulch, but they do not become continuous until we cross Willow Creek, where the third terrace is seen, which continues almost to Box Creek, where it has been entirely eroded by the many branches of that stream.

At the lower end of this basin the mountains of the western range, the main divide, jut out into the valley and almost close it. Here we find the gorge in whose floor the Granite Cañon was eroded. The walls of the cañon are in many places vertical, rising 50 to 200 feet above the stream, while the cañon itself is so narrow as to afford barely room for a road alongside of the river. The floor of the main gorge, which for our present purposes may be regarded as continuous between the mountains, is quite irregular, sloping on each side to the central line. Numerous low ridges of rock stretch entirely across and separate small level plains of five to ten miles area. Fragments of rock, many of them of enormous size, are scattered here and there, usually without any order, all of them angular, with no signs of rolling or water-wear. The surface shows a few abrupt descents, but for the most part the slope may be regarded as comparatively regular to near Cottonwood Creek, where the cañon ends and we reach the second or lower basin, which continues to the mouth of the South Arkansas.*

From the end of the cañon the basin opens out on both sides, widening as it descends, until at Chalk Creek it has a width of nearly eight miles. The terraces have been removed almost entirely over a large area in the upper portion, so that in the vicinity of Chalk Creek but one remains. This rises nearly 18 feet above the river and stretches on both sides of the stream almost unbroken to the base of the mountains. Through it several of the larger streams have worn down quite deep channel-ways, with wide flood-plains, which are sufficiently extensive to be the scene of agricultural

* My information respecting the cañon is from other members of the party. I did not visit it.

operations. In several of these secondary terraces occur. This important terrace is persistent, and maintains its integrity to Gas Creek, near which it is interrupted. Below that stream the immediate valley becomes narrow, owing to the presence of a mass of the upper terraces, which by some means has escaped erosion. Here, beginning with the flood-plain, eight terraces can be counted, whose surfaces all slope toward the river. At one locality the whole mass is cut down and exposed in a vertical bluff to the thickness of 40 feet, showing it to be made of stratified sands and gravels with thin layers of argillaceous material, the strata varying in thickness from 3 to 12 inches. Large fragments of rock are altogether wanting, there being no bowlders more than 3 inches in diameter, and few of so large size are seen. In this respect the deposit differs much from the river bed, which is littered with large bowlders, as indeed is the whole escarpment of the lower terrace in which the present flood was excavated. From this relic of the upper terraces to near the South Arkansas only the first terrace is continuous. As we approach that stream the valley becomes very wide, and at last becomes one with that of the tributary. Where the two valleys unite three terraces are seen, which extend up the South Arkansas. They are evidently secondary and owe their origin to that stream.

The material composing these terraces is consolidated into a rock of little tenacity, which yields readily under the influence of the weather. Some of the conglomerate layers are moderately compact and disintegrate less rapidly than the underlying finer layers, thus causing the rock to weather into eccentric forms resembling chimneys, urns, and helmets, very similar to the curious shapes seen along our eastern border in rocks of Cretaceous and Tertiary ages.

Such are the conditions observed in this valley. The history is clearly written. This great trough was excavated by the magnificent glacier of the Arkansas, which once reached, an unbroken sheet of ice, from the headwaters of the river to the Great Cañon below the South Arkansas, receiving noble tributaries from the cañons of California and Iowa gulches at the east, and of Tennessee, Willow, Half Moon, Lake, Clear, Cottonwood, and Chalk Creeks at the west, together with many smaller accessions from each side. Beyond the Great Cañon it never passed after it was separated from the mass which once overspread this whole region from the top of the main divide to South Park. From the junction of Tennessee Creek with the Arkansas, the surface, taking the surface of the upper terrace as the original plane of the glacier's bed, steadily declines to the South Arkansas, so that when the glacier stretched to its extreme southern line, it rested on a rocky floor above the Granite Cañon, whose level was that of the main terrace east from the river in the upper basin. The retreat of the ice-stream to the vicinity of Cottonwood Creek left the lower basin open, and so induced the formation there of an extensive fresh-water lake. At a somewhat later period the glacier retreated to the line marking the southern limit of the upper basin, where it must have remained alternately retreating and advancing for no inconsiderable period, until the upper basin was excavated. Here, too, eventually, a second lake was formed, whose waters escaped into the lower lake through the broad gorge in whose floor the Granite Cañon has been eroded. These lakes, fed by streams issuing from extensive glaciers, of which we find the traces in the cañons on each side of the river, must have existed for a long time, as is shown by the mass of till accumulated in the terraces, and their draining must have been very gradual, as appears from the number and gradual slope of the terraces. This drainage was effected simply by the deepening of the cañons.

The history of the little basin of Pleasant Valley, at the mouth of the Great Cañon, is much the same as that of the Upper Arkansas, but in the valleys of Texas and Grape Creeks some interesting features occur dissimilar to any already noted. These two basins pass imperceptibly into each other, and are doubtless one in origin. Wet Mountain Valley is drained by Grape Creek. It is united on the northwest to Texas Valley, drained by Texas Creek; on the northeast to a somewhat similar park, which communicates with the Arkansas by means of the Dry Cañon, while at the south it is separated from Huerfano Park by a divide much lower than the Sangre del Cristo Mountains. It is probable that the surface of the lake at no time reached above the Huerfano divide, but that the same body of water was continuous over Texas Valley, Wet Mountain Valley, and the little park at the northeast. From this lake there must have flowed to the Arkansas three streams, Grape Creek, Texas Creek, and the third through the Dry Cañon. As the drainage went on, Texas Valley was at length occupied by one lake, and the remaining portions by another, both of which were finally drained by their respective outlets.

An extensive lake at one time occupied the basin through which the Arkansas flows below Cañon City, but our observations are insufficient for discussion of it, as they were confined to the vicinity of that city. Other areas, formerly occupied by lakes of glacial origin, were observed in the interior region along tributaries of the Arkansas, but they are of limited extent and hardly deserve even a passing reference.

Direct evidence respecting the glacial origin of San Luis Valley is almost wholly wanting, and our conclusions must be drawn from the physical structure of the region. In eruptive rocks the results of aqueous erosion so closely resemble those of glacial action that one is frequently unable to determine the agent producing the phenomena in a given locality. But the whole character here seems to admit of no inference other than that the valley is the result of glacial erosion. The valley is a true basin, and its only outlet is southward through the cañon of the Rio Grande. At the south and southwest, somewhat beyond the New Mexico line, the surface is almost as high as the Sierra San Juan, but from those points it slopes gradually toward the immediate basin until within a few miles of an east and west line passing through to Fort Garland, where it falls off quite abruptly. At the southwest, this abruptness is the more marked, owing to the erosion of plazas by the Rio San Antonio and its branches. On the west, the San Juan Mountains descend in a succession of long, low, sloping terraces, and gradually merge into the valley. At the north, the mountains break away so irregularly, because of the numerous streams, that the general slope of the surface can hardly be determined, except by very close survey. At the east, the Sangre de Cristo Mountains rise abruptly from the plain as far south as Fort Garland. Beyond the fort an interesting park exists at the base of the Sierra Rondo, or the southern prolongation of the Sangre de Cristo Mountains, and extends quite to the New Mexico line. It is from one to three miles wide, and is separated from the long, gradually-sloping surface at the west by a sharp, mesa-like wall of eruptive rock. The greater portion of this park is watered by the Rito Culebra, which breaks the wall at San Luis, fourteen miles south from Fort Garland. A low, terraced divide separates the Rito Culebra from the Rito Trinchara, which flows by the fort. The area of the present basin reaches westward to the San Juan Mountains, northwestward to the settlement of Saguache, northward to near the head of San Luis River, eastward to the Sangre de Cristo Mountains, and southward to a line reaching from Fort Garland to the Plaza de los Piños, and having a rudely west-southwest direction. The original area was much greater southward and southeastwardly, reaching in those directions beyond the New Mexico line.

The northern portion of the basin has no outlet for its waters, and is separated from the true area of the Rio Grande by a low divide reaching across the valley and probably not more than 25 feet high, taking the level of San Luis Lake as the base. This northern portion is the true San Luis Valley, the drainage area of the San Luis River. It is divided north and south by a tongue of eruptive rock, which reaches from the main divide almost to Saguache, and separates the waters of Saguache Creek from those of San Luis River. These streams empty into the great marsh known as San Luis Lake. The soil is so porous that many of the streams from the San Juan Mountains diminish rapidly after reaching the plain, and finally sink in the sand before entering the lake. A similar condition exists in the southern portion of the valley, where the Rito Alamosa sinks before reaching the Rio Grande, though when it emerges from the mountains it is a very considerable stream.

Throughout San Luis Valley, both in the present basin and on the elevated slope southward, the surface is covered with *débris* derived from the volcanic rocks of the vicinity. Near the mountains this material is a coarse gravel, with some moderately large fragments, but in the central portions of the basin it is exceedingly fine and affords a soil of remarkable fertility. From the center the surface rises in terraces to the periphery of the basin.

If we examine the elevated slope at the south we find it about thirty miles wide, and nearly midway showing a broad depression, at the bottom of which the Rio Grande flows. Followed southward, this depression becomes narrower, and at length disappears in a deep, gloomy cañon beyond the New Mexico border. Northward, it is separated from the main basin by a short cañon, which begins where the surface falls off abruptly toward the valley.

These general characteristics show beyond a doubt that this whole region, as far south as the New Mexico border, and as far north as the head of San Luis River, was at one time occupied by a great fresh-water lake, covering an area of several thousand square miles and fed by streams coming from the mountain glaciers. To me it seems not improbable that the glacial mass was of equal extent, and that in its retreat northward it delayed for a time, its foot occupying the line marked by the abrupt wall forming the southern boundary of the present basin. The lake must have occupied the subordinate park under the Sierra Rondo, as its outer wall is lower than that portion of the slope directly west from it. The broad trough in this slope marks the narrowing limits of the discharging stream, as the lake-level was lowered by the deepening of the cañon southward.

The main supplies for the lake must have come from the Upper Rio Grande and from the southern portion of the Sangre de Cristo Mountains, while the accretions from the Saguache and San Luis portion were comparatively small. The Rio Grande has been persistent throughout, and the slope everywhere in the southern part of the basin is toward that stream. When the deepening of the Rio Grande Cañon lowered the surface of the lake below the almost imperceptible ridge now dividing the valley, the amount of water coming from the north was not more than enough to overcome the loss by evaporation, otherwise a channel would have been cut through the divide and the northern section would have become tributary to the Rio Grande. As it is, no great lake exists in the northern portion. The supply of water has been so small that the lake has contracted to the limits of the present swamp, its waters having been removed partly by absorption into the ground, but principally by evaporation, as appears from the large proportion of alkali in the soil, and from the frequent occurrence of alkaline salts in white patches upon the surface.

The basin of the *Laguna de los Caballos*, though possibly not due to glacial action, is of interest, as the lake has not entirely disappeared, and as it illustrates directly the drainage by deepening of the outlet channel. It is on the main divide and only a few miles south from the northern line of New Mexico. A short narrow passage through a wall of Upper Cretaceous sandstone, forming the Horse-Lake Pass, leads from the basin to the area of the Rio Chama, and the lower extremity of the lake reaches quite to the pass, which is but little higher than the surface of the lake. Through this pass the surplus waters were formerly discharged and found their way to the Rio Chama. The basin is not large, and is surrounded on all sides by low hills, which are deeply covered by *débris* and have a mammilated surface, as though made up of fragmentary terraces. This structure reaches up to a level with the top of the sandstone wall, through which the old outlet passed. The surface of the lake is now barely 10 feet below the summit of the pass. There being no longer any outlet the water is exceedingly alkaline, and the soil surrounding it is impregnated with salts. At no very distant period it was inhabited by fresh-water mollusks, of which the bleached shells are still to be seen on the shore as well as at various levels, 15 to 20 feet above the surface of the lake.

Along the *Rio de las Animas* we find a series of parks, whose origin can hardly be accounted for on any hypothesis other than that of glacial erosion, though here, as in the case of San Luis Park, the eruptive rocks predominate, and all direct evidence is wanting. From the Rio Grande Pass, of which mention has been made in another chapter, we come down through Cunningham's gulch into a small park on the Las Animas, about seven miles long by half a mile wide. At its lower end this is closed by a cañon, through which the river flows into a somewhat larger basin called Baker's Park. In this lower basin the river is joined by two large streams, Mineral and Cement Creeks, and afterward enters a close, narrow cañon, said to be impassable, which continues for not less than twenty miles to Las Animas Park.

The Rio de las Animas rises in a deep amphitheater, not far from the source of the Rio Grande, North Fork, and flows southward to the Rio San Juan. At a short distance from its head it enters a close cañon, choked with *débris*, in which the stream is almost lost. At the mouth of the cañon the river re-appears in the upper park. Unlike the cañon of the Rio Grande, this park and its neighbor, Baker's Park, are shut in, not by ridges with regular crests, but by mountains, whose irregularity is almost indescribable. These terribly rugged hills show no terraced slopes, but only successive cliffs, sometimes 1,000 feet high, and almost vertical, between which little streams dash down along narrow ravines, their beds sloping at from 30° to 80°. The crests of these mountains are rude knolls, or craggy cones, reaching to a height of 3,000 feet above the river, and in some cases to 13,500 feet above the sea. At the mouth of Cunningham's gulch there is a grand cone, about 13,600 feet high, scarred on all sides by deep ravines, and surrounded for half its height by a vast talus, above which steep bluffs render the top inaccessible to the ordinary traveler.

About one mile below Cunningham's gulch the river enters a narrow cañon, whose walls rise about 50 feet to the old floor of the glacier, which descends with gradual slope, though the surface is irregular, to Baker's Park. Here the mountains are hardly so harsh in outline as those of the upper park, and erosion has so separated them that the scene is more open, and one is less oppressed by the painful feeling of confinement. But the true condition is no better, for both basins together form as terrible a trap in autumn as one can well imagine. Shut in on all sides by mountains 12,000 or 13,000 feet high, with no pass lower than 11,500 feet altitude, this region is practically closed against ingress or egress early in November, and so remains until late in the spring. Midway between the parks, a stream comes in from Little Giant gulch, an imposing amphitheater, whose walls rise nearly 1,500 feet above the floor of the cup.

At the southern extremity of Baker's Park the river enters a deep cañon, whose walls are close, and almost vertical to a height of about 200 feet. At that distance above the stream the gorge widens and presents an appearance similar to that of the country between the two basins of the Upper Arkansas. Of the relation of this cañon to the main Animas Park below, it is impossible to speak, for the oldest wanderers in this region are unanimous in declaring that it is utterly impassable for either man or beast. There can be little doubt, however, of the persistency of this broader portion for a considerable distance, since, two miles below its head, a fine amphitheater is seen, whose western wall rises 1,800 feet above the floor, while its eastern wall is crowned by as fine a nest of crags as was observed during the whole season. Other amphitheaters exist farther below, as far as one can see, so that from the general character, I am inclined to suppose, in the absence of all direct information, that this floor of the broader portion of the cañon reaches quite to Las Animas Park.

An examination of Baker's Park, and the one adjoining it, shows at once that the history of this region differs but little from that of the Upper Arkansas. In both parks we find terraces, which mark the gradual drawing off of the waters. The glacier which, as I take it, at one time occupied the broader and higher portion of the great cañon, halted, in its retreat, at the head of that cañon long enough to admit of wearing out Baker's Park. During the farther retreat of the glacier, the lower basin was filled with water. This retreat was slow, for we find much *débris* upon the rocky floor above the small cañon separating the two basins. In a similar manner the upper park was eroded, and, after the glacier retreated to the long cañon above, was filled with water. The lakes were drained, as were those already referred to in connection with other localities, simply by the deepening of the cañons. Their existence was of short duration, as compared with that of the Arkansas lakes, for the amount of *débris* is small, its extreme thickness, as shown above the stream, being barely 60 feet.

Crossing the high divide from Baker's Park we reach a wide cañon with long, gradual slope, descending southward, and flanked by sharp mesas. At a short distance from the summit a broad cañon opens into the first, from the west, at a small angle, and so likewise farther on, a second, a third, and others, until, at length, we find ourselves in a beautiful park, thirteen miles long, by about one wide, which is Las Animas Park. Continuing southward, the condition is reversed. Low ridges, rudely parallel, and terminating northward *en échelon*, are thrust from the eastern side into the park, so that the open space becomes less and less until it is finally shut off by an abrupt wall at the south. Through this the river passes in a grand cañon, whose sides rise 1,500 feet above the stream, (Newberry.)

Looking northward from Animas City, near the head of the park, one sees a broad floor at a considerable height above the bottom of the cañon and sloping rather gently toward the park. The great cañon, bounded by jagged mountain walls, really terminates at the junction of the river and Cascade Creek, several miles above Animas City, but the broad floor becoming wider reaches quite to that settlement, and is everywhere littered with water-worn fragments of rock. The bed of the river is paved with bowlders of granite torn from the mountains through which the cañon is cut.

At the head of the park two well-marked terraces are seen on the east side of the river, the first rising 5 feet and the second 15 feet above the stream. On the west side these have been removed by erosion so far that small fragments only remain. Following the trail on the east side, we soon rise above the second terrace, and at the height of 80 feet above the river find the surface strewn with fragments of granite, syenite, quartzite, and limestone, mostly water-worn, and resting on unaltered rocks, showing that the river must have flowed at this elevation. Farther down the upper terraces have been entirely removed, and there remains only a long slope stretching from the mountains on each side to the river. Here is the true Animas Park, whose agricultural value has been so highly extolled by those interested in the San Juan mining region. Its surface is covered by stratified sands and gravels, which are exposed in gulleys to the thickness of 20 feet. About ten miles below Animas City, the trail turns off sharply eastward to strike the wagon-road leading to Tierra Amarilla. On this trail we find water-worn fragments of granite and gneiss resting on the dark shales of the Cretaceous, and somewhat more than 200 feet above the river.

The origin of this park cannot well be explained by our observations, which were made in haste. Whether or not the glacier of the Animas reached to any distance in this basin I cannot say. It certainly reached to near its head, for its former existence in the cañon is quite evident. Along Cascade Creek and the other cañons leading into the park no evidences of glacial action could be found. It is very clear, however, that this whole basin has been occupied by a body of water in motion, whose bed originally was many feet above the present stream, as is amply proved by the presence of transported bowlders. The successive depressions of this bed and the consequent narrowing of the channel are shown by the several terraces, on all of which transported fragments, water-worn, and of comparatively large size, were seen. The many cañons, almost parallel, which by their union form the park at its head and the similar series at the lower end, seem to militate against the hypothesis that the basin owes its origin to glacial action. Though somewhat in doubt, owing to imperfect information, I am inclined to regard the whole as due to ordinary erosion by running water. Similar instances, though on by no means so large a scale, occur along the Rito Florida and the Rio Piedra, and are beyond all doubt the result of simple erosion by running water.

The cañon of the Rio Grande, extending from the head of the river to San Luis Valley, is due in its present shape almost equally to both glacial and aqueous erosion, and so should most properly be referred to in this connection. The river is formed by the union of three main forks, each of which flows through a deep cañon. That of the Middle Fork is much broader than the others, and has a somewhat irregular surface marked here and there by small basins connected by shallow cañons. Its walls are exceedingly abrupt, and rise 1,500 feet above the stream, and their crests are weathered into architectural forms of the wildest eccentricity. Toward the junction of the forks it widens and becomes a park, whose surface slopes each way toward the river, which flows near the southern wall. About a mile below the junction the river enters a magnificent cañon, twelve miles long, whose south wall is abrupt, densely wooded, and rises nearly 2,000 feet above the stream. The north wall is equally abrupt to a height of from 75 to 300 feet, beyond which it rises with a slope of 20° to 30°, 400 feet higher to a rude terrace reaching back to palisades, the true wall. The south wall is broken but three times, and then only by tributary streams issuing from cañons as gloomy as the one which they join. Twice the gorge opens out into a very narrow park, occupied by a marsh, through which the river meanders in a succession of horse-shoe curves. It is by no means improbable that at one time the river-channel occupied a depression immediately north from the cañon and rudely parallel to it, through which the wagon-road passes. Of this, however, I am unable to speak positively, as no opportunity was afforded for careful investigation of the matter.

At the mouth of the cañon, the river, turning sharply southward, enters a beautiful little basin known as Antelope Park, which possesses a somewhat melancholy interest, as it was the scene of Frémont's disaster in 1849. It is rudely oval in outline, the longer diameter, two and one-half miles, being in a north and south direction. The river, entering about the middle, hugs the western wall, and a little stream meanders sluggishly through the plain from the east to the river. North from the river the western wall is low and somewhat broken, while southward it is high and very abrupt. There seems to be little room to doubt that in ancient times the river entered the park at its northern end by means of the depression, already referred to, which is traceable to the park. On the eastern side the surface rises gradually from the plain to a height of nearly 350 feet in a distance of not more than half a mile. The face of this ridge-like hill, separating Antelope Park from a long narrow cañon at the east, shows a series of confused benches, evidently the remains of terraces, but now so disguised by erosion that the surface is simply mammilated. In the park itself two distinct terraces exist.

This basin is closed abruptly at its southern end by a tongue extending from the eastern wall, and the river flows out under the western wall through a short narrow gorge into another park, where its course is turned sharply to the east. The southern wall is deeply indented by a broad trough, which is itself cut up into several smaller troughs by low narrow ridges. This trough, covered by water-worn fragments of rock, was formerly the bed of the river. On the east side of the trough we find the eastern wall of Antelope Park, which gradually descends to the park below. Along this portion we find its surface eroded into hummocks, among which are many oval depressions without communication, which at certain seasons of the year are filled with water. When we passed through, the ponds were dry, and the only evidence of their previous existence was the saline incrustation covering the surface. Everywhere along this ridge, the body of which consists of volcanic rocks, one may see the most satisfactory evidence of depression of level in the river-bed, for the surface is covered with water-worn fragments of trachyte, gneiss, syenite, and quartzite, varying from 6 inches to 2 feet in diameter and mingled with gravel and fine sand. None of these is angular, as if transported on a glacier. Many of them must have been brought from the headwaters of the river, as is manifest from the character of the rock.

The cañon lying east from Antelope Park is one of the gloomiest of the many gloomy cañons opening into that of the Rio Grande. It enters the park just below the Little Antelope basin. The principal interest attaching to it lies in the fact that the stream by which it was excavated has changed its channel, and no longer flows through it to the mouth. This stream, which is a very powerful one, has broken through the western wall of the cañon and now empties into the Rio Grande a few miles below Antelope Park.

Below Antelope Park the river valley is for the most part a succession of broad beautiful parks until it reaches the Twenty-nine-Mile ranch, twenty-nine miles above Del Norte. Throughout this distance the surface is quite level and deeply covered by ordinary gravels, which are arranged in only two terraces, both of low height. Thirty-eight miles above Del Norte we find the yellow sandy shales, formed entirely of detritus derived from the volcanic rocks in the vicinity, and reaching up the side of the northern wall for more than 200 feet above the river. This deposit, which is purely local and of fluviatile origin, has been described in a previous chapter. Above the Twenty-nine-Mile ranch the park is very wide, and the mountains on each side rise from the plain with a gradual slope, and for the greater part are free from that abruptness which characterizes the walls above this locality. From the ranch the valley is a cañon for sixteen miles, seldom more than one-eighth of a mile wide, and with harsh abrupt walls rising from 300 to 1,500 feet above the river. At the junction with the so-called South Fork, the valley begins to widen and gradually opens up until at Del Norte it merges into the San Luis Valley.

Beginning, then, with the Middle Fork (Deep Creek) and following the river down to Del Norte, we find the following conditions: On Deep Creek, a broad cañon, becoming a park with irregular, more or less hummocky surface, and closed by a deep narrow cañon, on whose north side is a terrace covered with water-worn fragments of rock. Below this cañon is Antelope Park, the first of a succession, its boundaries terraced and bearing many transported fragments. This line of parks is closed by a deep cañon, which continues to San Luis Valley, which has been described already.

The close resemblance of these conditions to those observed along the Arkansas and the Animas would lead one at once to suspect that this great gorge originated as did those of the rivers referred to, especially as there is no room to doubt that glaciers existed at several localities along the northerly side of the north wall as well as on the Animas in the immediate vicinity of the Rio Grande. I have already stated that glacial and aqueous erosion were equally concerned in the formation of the valley. An examination of the details, however, shows that it is impossible to explain everything without much difficulty.

Thirty-eight miles above Del Norte there is found the local deposit of leaf-bearing arenaceous shales. Possessing an eastward dip of about 3°, and being distinctly non-conformable to the unconsolidated gravel terraces which they under-run, they must date back beyond the existence of the lake on whose bed the terrace materials were distributed. The purely local nature of the deposit, as well as its composition, shows its origin to be due to fluviatile action. The character of the flora, containing, as it does, many specimens of *Platanus*, a genus utterly unknown in the whole region, and, under present circumstances, unable to exist at the altitude where the shale occurs, shows that the time of its deposition must be quite ancient, reaching certainly into the Tertiary, and far anterior to the existence of glaciers. It is evident, then, that during the Tertiary period the locality where these shales are found had been eroded, and that it was filled by a lake into which these leaves were washed or blown from the land. That so extensive a basin could be eroded during the time required for cutting out the cañon below is by no means improbable, for the volcanic rocks surrounding the basin are, for the most part, friable, and yield readily to the weather or running water, while those forming the walls of the cañon below are exceedingly hard. The present park is due solely to the erosive action of running water, which has removed these soft shales.

To my mind it seems quite probable that the glacial agency was not active, or at least long continued, below the junction of the main forks. The gorge above Antelope Park is undoubtedly due to glacial erosion; but if a glacier ever reached to Antelope Park, its stay there and in the long cañon above was of short duration, and left no traces behind. The whole region is covered with bowlders, evidently coming from the headwaters of the river, but in every instance distinctly water-worn, as they would not have been had they been brought down by glaciers.

At the same time I feel hardly justified in positively asserting that glaciers did or did not exist throughout the whole length of the gorge. My opportunities for examining those portions of the country lying off our trail were exceedingly limited, so that, beyond all doubt, many facts of cardinal importance in this connection never came within the range of my observations.

SECTION III.

EROSION BY RUNNING WATER AND ATMOSPHERIC AGENCIES.

In our examination of glacial phenomena we have seen that the ice-stream wore out boat-shaped troughs, usually broad, and with walls more or less abrupt. These troughs expand and contract, frequently showing neat little parks or meadows. The distinction between erosion by ice and that by running water is very well marked. The stream of water becomes less as the erosion goes on, the drainage becoming more rapid, so that the cañon resulting from its agency is wide at the top, and gradually contracts toward the bottom, having a section much like the letter V. This form prevails almost without exception. It is true that where several streams are in close vicinity the walls separating their ravines are thin, and in process of time are worn away so as to produce a basin, especially if the rock be such as to disintegrate readily under influences acting conjointly with that of the moving water. But, even in cases like this, the original V-shaped troughs can be traced without any difficulty, except occasionally among volcanic rocks.

In previous portions of this chapter instances have been given, which show the activity of running streams in modifying the conditions left by the glaciers. Of these, probably the most marked are the Granite Cañon of the Arkansas, and the cañons of the Rio de las Animas, all of which sink below the old glacial floors, which form, as it were, terraces above them. In this section reference will be made to only a few well-marked cañons, in connection with which will be given some illustration of the modification of mountain crests by water and frost conjoined.

Eagle River.—The North Fork of this stream has its source in a narrow basin confined between abrupt, rather low walls, and separated from the

North Fork of Ten-Mile Creek by an almost imperceptible divide. For nearly a mile the surface slopes gradually, and the basin shows many features common in glacial amphitheaters. It soon falls off, and the stream descends quickly, nearly 300 feet per mile, forming a deep, close cañon rarely more than 30 feet wide at the bottom. The left-hand wall rises sharply in a succession of very narrow terraces, which continue almost to the mouth of the cañon, where they disappear, and the wall becomes an unbroken, almost vertical escarpment, about 1,500 feet high. The right wall differs. It rises very abruptly to a height varying from 200 to 300 feet, and there forms a broken, sloping terrace, reaching back several hundred feet to the main wall, whose crest is level with that of the opposite wall. This terrace, whose slope is about 20°, is covered deeply with sandstone *débris*, which is cut into ridges by the many little streams pouring down in early summer. At first I was inclined to suppose that the gorge was of glacial origin, and that this terrace had been the floor, but, examination of the rock in which the cañon has been excavated showed that ordinary weathering is sufficient to account for the terrace. This sandstone, which belongs to the very top of the Carboniferous, is a moderately coarse conglomerate, almost without cementing material, much cross-bedded, and bearing much resemblance to the ordinary terrace material exposed on the Arkansas River. It shows extensive jointing, so that, taken altogether, it is one of the most friable rocks seen in our whole area. Large masses were seen separated by narrow crevices from the main stratum, and crumbling into gravel merely under the influence of the weather. This close cañon ends suddenly about six miles from the head of the stream, and changes into a narrow valley, whose sides slope sharply, so as to form a broad V. Here, as in the cañon above, the left wall is the steeper, showing that during the whole time of excavation the stream flowed closely toward that side. The valley continues for about six miles, and opens into a broad trough of glacial origin at a distance of about eight miles above the junction with the South Fork. The total descent of the stream within twelve miles is 1,900 feet. The coarse sandstone covers the crest of the walls at this point, and has been cut down so deeply that the wall resembles a long row of great buildings, 2,000 feet high, surmounted by Mansard roofs.

The cañon on the South Fork of the Eagle River is about five miles long, and, owing to the harder material of its walls, is much more abrupt than the one of which we have just spoken. It separates two portions of the glacial trough, as is done by the Granite Cañon on the Arkansas, the portion above being broad and deeply excavated like the Upper Arkansas basin. Here it may be well to note that there is no reason to suppose that a lake ever filled this upper basin, but everything tends to show that it was long occupied by the glacier, which remained there, alternately retreating and advancing, until after the cañon had been eroded by its river. The gorge is exceedingly narrow, and its walls rise at a very sharp angle, though perceptibly separating so as to form a compressed V. The height of the abrupt portion is not less than 800 feet, while above this the sides rise with a slope of 35° for nearly 2,000 feet more. The cañon itself is utterly impassable, and the narrow trail on the steep slope above winds along, in most places, not far from the brink. A few tributaries enter the stream in the cañon, and break down the wall. Elsewhere it would be impossible to get down, or, once down, to climb out.

The whole of the Grand and Gunnison area is marked by cañons. Lying, as it does, on the western slope of the main region of upheaval, and stretching westward to the low table-lands, the general slope of its surface is quite rapid, so that deep ravines are formed by the Grand River, and deeper, or, rather, more abrupt ones by its tributaries. The most imposing of the cañons, which owe their origin entirely to the erosive action of running water, is that of Rock Creek, to which indirect reference has already been made. The following sketch by Mr. Young represents the entrance to it below the embryo city of Elko.

This stream is very rapid, descending 2,500 feet in less than eight miles. From the beginning its bed is a succession of falls until, at a distance of three miles, the valley, previously narrow, closes suddenly, and becomes an awful cañon, whose left and right walls rise at angles of 55° and 70° respectively. The direction is nearly northwest for about a mile, where a tributary stream, flowing in a similar gorge, enters from the east, and the course is turned almost westward for a short distance, after which it again changes to northwest. Eight miles from the head of the creek the cañon opens out into a narrow valley. The bed of the stream descends with great rapidity, there being merely falls and rapids, varying from 10 to 40 feet in height, until, four miles below Elko, the creek plunges at one leap almost 150 feet, forming a cascade which, in the middle of summer, when the volume of water is

FIG. 142.—Entrance to cañon of Rock Creek.

greatest, must be quite imposing. Throughout, the cañon is narrow. For two miles it varies in width, at the bottom, from 10 to 30 feet, and is so choked with large fragments of rock, polished by incessant action of the water, that it is almost impassable. No person has succeeded in traveling through it, though several have made the attempt. Once in, one would find the utmost difficulty in endeavoring to scale walls which rise almost 2,000 feet near the head of the cañon, and in many places are precipitous, or even overhanging for hundreds of feet.

The divide between the headwaters of Rock Creek and those of the Roaring Fork is a remarkable example of weathering, and its southern extremity exhibits an eccentricity of outline nowhere excelled within the area of our survey. The crest of this exceedingly narrow ridge resembles a line of ancient castles. Indeed, standing in any of the enormous cavities under this ridge, from which issue the many streams which form the Roaring Fork, one needs little power of imagination to conceive himself within the

FIG. 143.—Whitfield's Peak.

ruins of some majestic cathedral, whose towers, surmounting the massive walls, still remain to attest its pristine splendor. Two of the peaks rise almost to 14,000 feet. One of these I had the honor to dedicate, with the consent of my associates, to Mr. R. P. Whitfield, the distinguished palæontologist, of Albany, N. Y. This remarkable peak, of which the eastern aspect is represented in the following figure by Mr. Young, rises to a height of 13,985 feet, as determined by triangulation. It is pyramidal in outline, composed of sedimentary rocks, varying in color from dark gray to dull red and maroon, and almost horizontal along the face, so that, taken in connection with its surroundings, it is probably the weirdest object in this portion of the chain. On its southern side a similar pyramid reaches almost to an equal height, while adjoining it on the north a long, arched comb gradually rises, stretching to within a hundred feet of the level of its summit. Its northeasterly face is hollowed out so as to resemble a huge pointed scoop, rising 2,000 feet above the glacial cup below. On its western side the mountain shows itself a noble pyramid, whose face rises sharply and unbroken at an angle of 40°, for 4,000 feet above the wondrous crateriform excavation beneath. To complete the ascent of this peak was impracticable. Our indefatigable topographer, Mr. Young, climbed to within 200 feet of the summit, but was compelled to return, as any attempt to move farther along the narrow crest was evidently mere recklessness. This magnificent peak is the most conspicuous object in the whole region, and served as a distinct triangulation point, even so far south as the summit of the Rio Grande divide, eighty miles away.

In the southern portion of this area, and beyond, where the only rocks exposed are of volcanic origin, the conditions are somewhat different from those which we have been considering. The tendency here is to form basins by the rapid wearing away of the walls separating the shallow troughs of the streams. Such we find on Cochetopa and Los Pinos Creeks. There the several cañons have come together, as is evident from their existence now around the basins. But the jointed condition of the rock rendered it very susceptible to the influence of water and frost combined, so that the walls of the cañons have been removed over extensive areas, and the basins are the result. In these, however, the several troughs can still be traced. This process sometimes leads to perplexing conditions, and in the higher regions not infrequently causes the formation of an amphitheater very like those of glacial origin. This is neatly exhibited at the head of a small stream emptying into the Rio Grande about thirty-three miles above Del Norte. There several streams have worn out narrow cañons beginning at the very headwaters. These unite within 400 yards and form one deep, broad excavation, which, were the numerous tributary gorges concealed, could hardly be distinguished from a glacial amphitheater. In course of time the partitions, still separating the narrow cañons, will be worn away, and the form of the excavation will be complete. In such cups, however, one usually finds means to show that they are not of glacial origin. The benches are ordinarily absent, the general form of the floor does not so closely resemble an elongate shallow scoop, and the undulations so characteristic of glacial action are for the most part entirely wanting.

The shales of the Middle Cretaceous, in the San Juan region, have suffered greatly by erosion. The readiness with which they yield induces the formation of many sharp V-like troughs, such as are seen on the tributaries of the Rio Piedra. Such troughs are widened by the joint action of running water and the weather, until they finally become broad, grassy swales, or even parks, with an undulating surface. This erosion must have begun very early in Post-Tertiary times, for most of the broad swales or parks certainly attained almost their present extent before the great cañons of the Rio San Juan or the Rio Colorado were very deeply cut. The deepening of these valleys depended on the deepening of the Colorado Cañon, to which that of the San Juan is tributary. As the result of this deepening and the resulting increased rapidity of drainage, we find the fine terraces along the Florida, Piedra, and Los Piños, and possibly the extensive park along the Rio San Juan above Pagosa Hot Springs. The soft sandstones of the Upper Cretaceous, in the same region, have been affected scarcely less than the shales. The whole country along our trail, from the Rio Blanco to the Laguna de los Caballos, is a succession of beautiful parks eroded from these sandstones, which appear on all sides in the mesas, where they rest on the black shales.

At the eastern base of the Rocky Mountains, we find a series of "hog-back" ridges five to fifteen miles wide, and extending along our whole line from Golden almost to New Mexico.

CHAPTER XVI.

MINERAL SPRINGS.

Pagosa.—On the San Juan River, near the crossing of the old wagon-road which leads from Animas Park to Tierra Amarilla, the cloud of vapor arising from the Pagosa, or the Great Hot Springs, at once arrests the attention of the traveler. The locality seems to have been an interesting one to the Indians from ancient times, for numerous trails, all deeply worn, converge toward it from all directions, and the main trail from New Mexico northward to the White River passes directly by it. The springs are situated at the end of a beautiful park, which extends for several miles up the river, and is closed by a narrow cañon beginning just below the springs. On both sides of the valley the hills rise several hundred feet, and are covered by a dense growth of pines, while northward beyond the park the Rio Grande divide rises gradually to upward of 12,000 feet, and merges at the east into the rugged mountains of the Sierra San Juan. Southward, the surface rises sharply in all directions, and nothing can be seen except the bluff walls forming the cañon through which the river flows. Here and there in the vicinity of the springs are low mesas with steep escarpments, and composed entirely of the deep, black shales of the Middle Cretaceous, the prevailing rocks north from the cañon. Around the springs themselves, is a great stalagmite deposit, whose dull gray color offers no violent contrast to the gloomy black of the shales.

The numerous springs issue from orifices scattered over an area of little less than thirty acres, which is covered by a deposit consisting chiefly of calcium carbonate. In its full extent, this deposit reaches over nearly fifty acres, passing to the opposite side of the river, whose channel has been cut through it. The great mound about the springs is more or less cavernous throughout, with many small openings through the upper layers, from which sulphurous vapor escapes. It is surrounded by a plain, encrusted by calcareous and other salts and bearing a rich growth of grass, which is said to remain green throughout the year. Reaching well up on the mound, this grass conceals many of the openings in the outside crust, and renders the approach to the main springs quite insecure, as these small openings are frequently only "blow-holes" to large cavities roofed by a very thin shell of stalagmite. The principal mound is double. In the lower division no springs were observed, nor indeed was any evidence of activity visible.

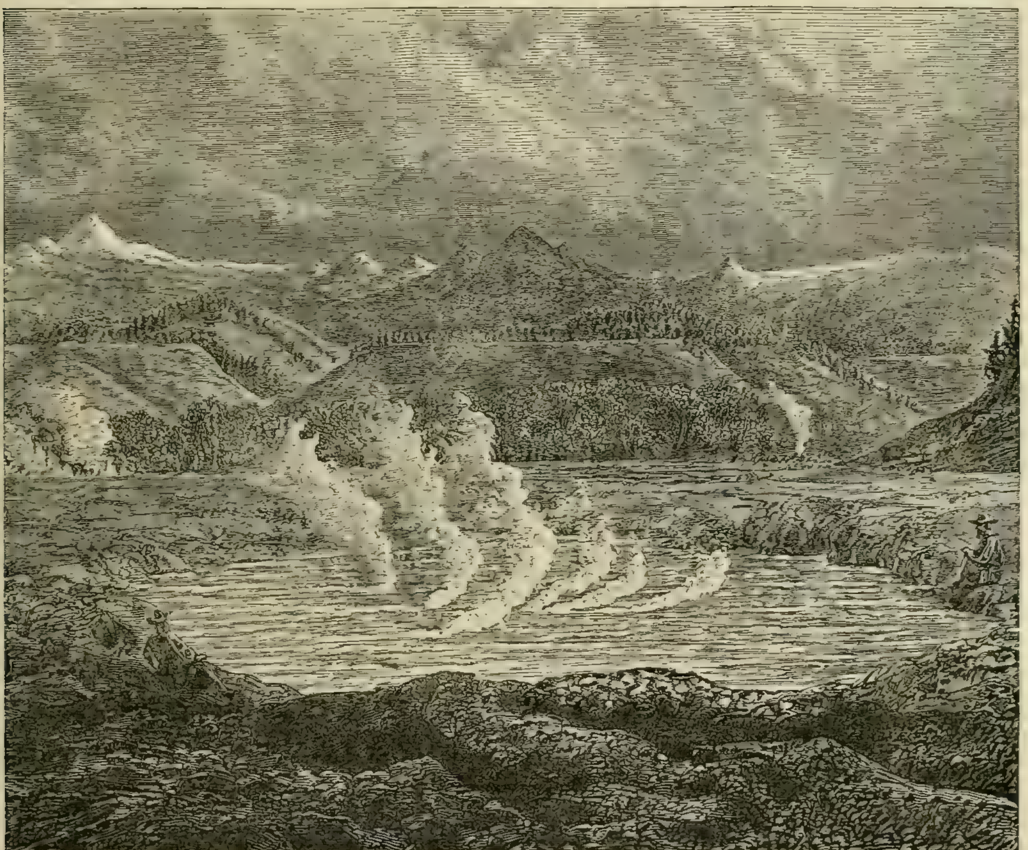


FIG. 144.—Basin of the Great Spring at Pagosa.

At its summit there is a crevice several feet long, 5 feet deep, and 18 inches wide, which no doubt at one time was the crater of an extensive spring, though now it contains much *débris.* From the margin of this division southwest to the river, the surface is undulating, and holds several patches of hot water 10 to 25 feet in diameter, in which the bubbling of the springs is quite energetic. These springs have surface outlets which carry the water directly to the river.

In the upper or northern portion of the mound is the Great Hot Spring. At the summit we find an irregularly oval depression, or crater, 25 by 35 feet, and about 3 feet deep to the surface of the water. It is divided transversely by a partition of stalagmite, reaching up barely to the level of the water, into two areas, one 5 feet by 2 feet, and the other rudely circular with a diameter of about 25 feet. The depth of the larger basin cannot well be determined, owing to the craggy character of its walls, shelves of stalagmite reaching all the way to the center. At one point no bottom was found at 50 feet. Everywhere columns of bubbles are seen rising continually, and the number of the larger columns is more than one hundred. Near the center of this larger basin there are nine principal columns arranged triangularly in three groups, with a low cone of stalagmite projecting above the water near one of the angles. The surface of the smaller basin is like that of a boiling pot, bubbles escaping regularly and continuously over the whole. Around the margin of the crater there are numerous openings in the mound, 3 or 4 feet deep, some of which contain only still water covered by a green scum, while others are actively emitting vapor.

The action of the springs in the larger basin is intermittent. The three groups of columns referred to are continually in operation, but at intervals of from three to five minutes the ebullition becomes explosive. In the northwestern group the water is thrown for a few seconds to the height of 1 foot, and so in the eastern group, which is close to the cone. In the southwest group the ebullition extends over a greater surface, and when most violent produces a flattened cone about 4 feet in diameter at the base and 6 inches high. Near the margin of the crater the temperature of the water is 140°F., but is doubtless much higher near the center. This latter point could not be determined, as the party was not provided with self-registering thermometers. The water is strongly impregnated with hydric-sulphide and carbon dioxide. The solid constituents are carbonates and sulphides of calcium, sodium, and potassium.

The water of the springs in the crater is drained away by subterranean outlets leading to the river, and evidently flowing upon the Lower Cretaceous sandstones on which the mound rests. The outlet farthest up the river is a little rill, 3 or 4 inches wide. The main one is a rapid stream, 1 foot wide and about 4 inches deep, and flows out nearly 5 feet above the level of the river. The volume of water poured out by this stream is very large, but no estimate of the quantity was made. One can easily trace the course of this outlet from the crater to the river bank by means of a line of openings in the surface of the mound, from all of which vapor constantly issues. Some of these holes are simply tubes, 2 to 4 inches in diameter, while others are large cavities several feet wide and almost entirely closed at the top by a roof barely 1 inch thick. Below all the outlets the river is discolored by sulphur, separated by decomposition of the sulphureted hydrogen.

The spring is undoubtedly very ancient. The mound was not less than 12 feet high before ever the river began to excavate its present channel, for such is the thickness of the deposit on the west side of the stream, opposite the springs. How much higher it has been one cannot conjecture, but there is every reason to believe that the whole mass has suffered greatly from erosion. The main portion of the mound long since ceased to increase in height, for the water no longer poured over the rim of the crater after the opening of subterranean outlets. Near to and rudely parallel with the river several large crevasses are seen, beyond which the separated portions lean toward the stream. It is evident that the river is making inroads upon the mound, and it is much aided by the erosive action of the many little streams carrying the water from the crater.

Somewhat less than a mile below the Great Hot Springs, and on the west side of the river, there is a small mound, about 100 feet long, and rising five feet above the surrounding plain. Its surface is almost flat, and shows three small basins, rudely circular, each about 20 feet in diameter, which are arranged along a north and south line. In the center of each of these a small spring issues from an orifice surrounded by stalagmite. These springs do not overflow and the amount of water is inconsiderable. No outlet was observed. The temperature is quite low, barely exceeding 60°. The composition seems to be similar to that of the Hot Springs, except in that the proportion of sulphureted hydrogen is less and that of the alkaline salts somewhat greater. All of the springs in this vicinity evidently hold more or less of iron in solution, as the deposits about them are invariably of a dingy gray color and frequently have a deep ferruginous tint.

At the exit of the main outlet from the crater of the Great Hot Spring the rocks, over which the water flows, are covered with an incrustation, white and mammilated, and with a porcelaneous surface. Small hand specimens can be obtained greatly resembling the paved floor of a drum-fish's jaw. On twigs or jutting portions of rock this sediment is seen in the earlier stages of deposition, moss-like, in tufts of flexible fibers, one or two inches long, which eventually become united by a reddish substance, after which the deposit becomes compact. In the crater the process is somewhat different, and then the successive steps are more clearly shown. A thin scum forms on the surface of the water in small patches, seldom more than one-eighth of an inch wide at first, which combine to form pieces of varying size, sometimes an inch thick and several inches broad and long. This material seems to originate in the films of the bubbles, and occurs in thin, almost transparent laminæ. The larger pieces are porous, the laminæ being loosely packed, so as to give the mass a spongy structure. This scum forms for the most part around the border of the basin, where the ebullition is less violent, and the bubbles do not burst so quickly as they do nearer the center. In the vicinity of the principal groups of columns I could see no formation of such scum during an hour; though no doubt it does form there, but in fragments so small, that they do not appear until, approaching the border, they unite to form pieces of larger size. This material is reddish-brown in color, very soft and of pulpy feel. It probably consists largely of sulphur.

Being much lighter than water, it floats on the surface, continually receiving accretions from the bursting bubbles. At length, fastened to the shore, it acts like the twigs seen at the outlet; calcareous matter is deposited on it and through its pores, until, becoming heavier than the water, it sinks and forms part of some craggy shelf projecting from the sides of the basin. Under the water this pulpy matter is always present, but elsewhere in the substance of the mound it seems to be absent. If present, it is so mixed mechanically with the calcareous material as not to be detected by physical signs. Sometimes large fragments of pulpy matter become cemented together, and, hardened by the deposit of calcareous matter, may form the lid to a cavity several feet wide. Such a mass is seen in the southeast corner of the crater, and has an area of nearly 60 square feet.

The material composing the mass of the mound is compact, as though deposited not in this manner, but rather by overflowing of the water in thin sheets; and some layers are seen closely resembling the beautiful calc-tufa so plenty at Niagara Falls and along the Genesee River in New York. At the lower end of the mound, where the many springs are drained by superficial outlets, the process by which the mound was formed is clearly exhibited. The water running here over the surface has been entangled among the grass, which in many portions is very prettily incrusted. Such incrusted branches soon form little bars, over which the water flows, and the little pools back of them are gradually filled up with the calcareous deposit. The water is thus spread out over a broad surface in a very thin sheet, and is compelled by every obstacle to deposit some sediment, until at length a succession of broad shallow steps is produced, like that made by the flowing of a thin sheet of water over a regular surface during a very cold day. In this direction the mound is rapidly extending, and eventually it will cover all the swamp to the river bank.

From the marked resemblance of the deposit at Pagosa to that observed at the Mound Soda Spring, I am inclined to believe that the spring comes from the metamorphic rocks. The sulphureted hydrogen is doubtless obtained during the passage of the water through the underlying Triassic and Carboniferous, several limestones belonging to the latter being exceedingly fetid.

Mound Soda Spring.—Nine miles below the head of Currant Creek, a tributary of the Arkansas, this spring is seen in a little cañon on the north side of the stream. The mound surrounding it is rudely elliptical in section, with a longer diameter of 60 feet and a height of 20 feet. The lower layers are composed of white travertin and are loosely packed. Some of them have a surface bearing some resemblance to brain-coral. Toward the top the rock becomes less compact, and shows several extensive cavities reaching for a long distance into the interior, which may have been outlet channels in earlier times when the spring was probably much more energetic than now. This upper portion is not white, but is deeply colored by iron.

The spring issues from an orifice on the summit of the mound, about 3 feet in diameter at the surface, but rapidly contracting below to about 15 inches. The only outlet for the water is a small gutter leading from the edge of the orifice along the surface of the mound. The amount discharged at the time of our examination did not exceed three gallons per hour, and, judging from the size of the gutter, it is probably not greater at any time. Though the quantity of water is so insignificant, the ebullition is so violent that one would suppose the discharge to be very great, and be led to suspect an outlet below the surface. This ebullition, however, is due solely to the escape of carbonic acid gas, which comes off in immense quantity.

No analysis of this water has been made. The proportion of carbonate of lime is evidently large, and iron peroxide is present certainly to the extent of one-half of 1 per cent. Some soda or potash is held in solution, as is evident from the slightly alkaline taste. The temperature is the mean. The flavor is agreeable, being much the same as that of the carbonated waters of the shops. In many features the spring closely resembles those at Manitou.

The spring comes from the metamorphic schists, there being no other rocks in the vicinity. Hot springs occur on Chalk Creek in the Upper Arkansas region and in the northern portion of the San Luis Valley. These were not visited by that portion of the party to which I was attached, and no notes were taken by members of the other division.

South Park.—The Sulphur Springs are near the road leading from Fairplay to Colorado Springs, and are about five miles above the cañon of the South Platte River. They are resorted to by many invalids during the summer. In August as many as two hundred persons have been encamped in the vicinity seeking benefit of the baths. Doubtless were there satisfactory hotel accommodations, or proper conveniences for bathing, the number would be greatly increased. The springs or rather orifices are eleven, but clearly proceed from one stream, for the proprietor stopped up six, and the remaining five discharge as much as eleven did. The water is strongly odorous of sulphureted hydrogen, and has a strong alkaline taste, so that the predominant salts are probably the alkaline sulphides. The little stream running from the springs leaves the ground covered with sulphur derived from decomposition of the salts. The springs issue from the lower portion of the Middle Cretaceous.

On the South Fork of the South Platte, and about two miles above its junction with the river, a strong *hot spring* occurs in the bed of the stream directly under the bank. The temperature is about 130° F., being kept low by the influx of water from above. Held directly amid the escaping bubbles the thermometer indicated 160°. A slight odor of sulphureted hydrogen is noticed in the vicinity of the spring, but none is perceptible when the water is held to the nose. The water is tasteless and odorless, so that the gas escaping in bubbles must be only vapor of water. There are nearly forty orifices from which bubbles issue. The quantity of water discharged is very great, and so elevates the temperature of the stream that in winter it remains unfrozen to a distance of more than half a mile below the spring.

The *Salt Springs* have been noticed in another connection.

Idaho Springs.—These are on a small stream entering South Clear Creek near the village of Idaho. Owing to the romantic scenery in the vicinity, as well as to the cleansing properties of the water, they have attained no inconsiderable reputation, and are resorted to during the summer by many hundreds of visitors. There are three important springs, all of which have a temperature above blood-heat. The upper one is a carbonated spring, with an appreciable proportion of iron and a temperature of 98° F. The water has an agreeable flavor, and is much employed by invalids for drinking. The lower springs show temperatures of 105° and 107° respectively. The water is strongly alkaline, and is especially for bathing purposes. It was analyzed by Dr. J. G. Pohle, of New York, with the following results:

Carbonate of soda	30.80
Carbonate of lime	9.52
Carbonate of magnesia	2.88
Carbonate of iron	4.12
Sulphate of sodium	29.36
Sulphate of magnesia	18.72

Sulphate of lime	3.44
Chloride of sodium	4.16
Silicate of soda	4.08
Chloride of calcium	Trace.
Chloride of magnesium	Trace.
Total grains solid residue per gallon	107

These springs issue from the metamorphic rocks.

Colorado Springs.—These springs, situated on the Fontaine qui Bouille, near the village of Manitou, and six miles from the city of Colorado Springs, have long been celebrated for the magnificence of the surrounding scenery, as well as for the medicinal value of the waters. They attracted the attention of Captain Frémont during his second expedition, and received a somewhat glowing description in his report.

There are five springs above Manitou, which readily arrest the attention of the traveler. The upper two are small, one of them much used for drinking, and the other, a chalybeate spring, not used for any purpose. A few yards below the latter, which is on the right bank of the stream, are two large springs, one on each bank. That on the right side is close to the road, and is surrounded by a mound of stalagmite several feet thick. At the summit of the mound is an oval opening through which the operations of the spring can be observed, for the water no longer overflows the mound, but passes by an insignificant outlet below into the creek. The ebullition is exceedingly violent, but the small amount of water discharged shows that it is due entirely to the escape of gas. The spring on the opposite bank is surrounded by a similar deposit, but evidently yields a much larger quantity of water. The fifth spring is opposite the post-office, and is surrounded by an extensive deposit reaching quite to the bank of the stream. The ebullition is quite violent, but I was informed that the quantity of water discharged is comparatively small.

In Frémont's report the following analysis of the deposit about the springs is given:

Carbonate of lime	92.25
Carbonate of magnesia	1.21
Sulphate of lime Chloride of magnesium Chloride of calcium	0.23

Silica	1.50
Vegetable matter	0.20
Loss	4.61
	100.00

In a circular obtained at Manitou I found the following analysis of the solid residue obtained from the water of one of the springs:

Chloride of sodium	36.69
Chloride of potassium	10.01
Bicarbonate of soda	24.01
Bisulphate of soda	4.78
Carbonate of lime	15.62
Carbonate of magnesia	8.89
	100.00

Though issuing from the unaltered rocks, these springs bear such marked resemblance to the Mound Soda Spring, both in their action and in the character of the deposit, that I am inclined to believe that they are of deep-seated origin, and have their sources in the metamorphic rocks below.

CHAPTER XVII.

STRUCTURE AND AGE OF THE ROCKY MOUNTAIN SYSTEM.

In this chapter much must be said which may not fully bear the test of investigation, (complete in all its details.) The area in which my observations were made is little more than two hundred miles in length north and south, and at no point is wide enough to include all the axis of elevation. While it is sufficiently extended to embrace all but two, and these, in one sense, the least important, still it reaches northward only a comparatively short distance along the chain, so that no information was obtained north from the parallel passing through Denver, and only the southern extremity of most of the axes could be carefully examined. For this reason I shall give only my own observations and such conclusions as seem most naturally to flow from them, leaving to others to collate my observations with those which may be obtained hereafter, in order to elaborate fully the structure of this remarkable chain.

STRUCTURE OF THE SYSTEM.

From the Missouri River westward the whole country gradually rises at an average grade of barely 10 feet per mile until west longitude 105° 30′ (approximately) is reached, when the Rocky Mountains rise abruptly from the plain. From this line the ranges extend to somewhat beyond west longitude 108°, where they rapidly fall off to the great plateau, separating the Rocky Mountain region from the broken ranges of Utah and Nevada.

The ranges composing the great system under consideration appear to be in two series; the first comprising the two complex axes of elevation, the front or eastern and the Sangre de Cristo, whose trend is from north 10° west to north 30° west, while the second is made up of the San Juan, Los Piños, La Plata, and San Miguel, which have a trend of north 30° west to north 45° west. Each series shows a parallelism of its ranges, and the whole system terminates *en échelon* southward, most of the axes ending within Colorado. The observations of Dr. Newberry and Mr. Gilbert show that minor axes occur in New Mexico. These are apparently independent of each other and of the main axes in Colorado, but it is by no means improbable that future examination will disclose some more intimate relation than has been suspected.

The *Eastern range* consists of several subordinate axes, closely packed together, and almost accurately parallel to each other. It rises sharply from the plains and attains its greatest altitude near our northern boundary, where several of its peaks rise to a height of more than 14,000 feet. The axes within our area are seen terminating *en échelon* at Colorado Springs, Cañon City, and Huerfano Park. The Kenosha range, the eastern boundary of South Park, is evidently only a portion of the western axis, which, under the name of Greenhorn or Hardscrabble Mountains, extends to Huerfano Park. This group is cut by the Arkansas and South Platte Rivers. The former breaks through only the western axis, while the latter passes through the whole group and reaches the plains about twenty miles southeast from Denver. Near our southern boundary the width is not far from forty miles, at the cañon of the Arkansas it is barely twenty, while southward from that line it dwindles rapidly to its termination. The several axes terminate abruptly, and the unaltered rocks are seen in each instance curving round the base.

This range is composed of metamorphic rocks, which are badly fissured by dikes of lava, and not infrequently capped by overflows of the same material. The schists are much torn and faulted, and sidethrows of mineral veins are by no means uncommon. In some of the cañons which cut deeply into the flanks of the mountains a compact granite, more or less syenitic, is seen, which seems to prevail along the median line of the axes, having been observed near the head of Clear Creek Cañon, as well as in the walls of the amphitheater containing Chicago Lake. The sedimentary rocks occur as "hog-backs" along the eastern base and curve round the southern termination of the several axes. They pass round the Greenhorn Mountains into Huerfano Park, where they are more or less concealed by the great overflow of volcanic rocks.

Along the eastern face of the range the disturbance was variable in its effects. Toward our northern border it was so violent that one can obtain no satisfactory information respecting the stratigraphical relation existing between the rocks of different ages, but as we go southward beyond Colorado Springs the conditions are better defined. On the Little Fountain Creek, where it issues from the "hog-backs," we find the red sandstones and gypsum marls of the Trias inclined at an angle varying from 40° to 60°, while against them abut the Cretaceous rocks dipping from 10° to 20°. Farther southward, toward Cañon City, the Jurassic and Cretaceous are seen resting unconformably upon the Trias, while at a little distance beyond Cañon City the Cretaceous overlaps and conceals all the underlying formations. On the western face of the range the Trias and Cretaceous are unconformable in Huerfano Park; farther north the Cretaceous abuts against sharply inclined quartzites of undetermined age, its own dip being barely 5°. Still farther north the unaltered rocks are wanting, and the axis becomes a great fault, for the sedimentary rocks belonging to an outlier of the next range west abut against the schists of this at the northern boundary of South Park.

The dips in the metamorphic rocks of this range are, for the most part, northerly, either northwest or northeast, and no satisfactory anticlinal or synclinal structure could be made out.

Between the eastern range and the one next westward, there occurs a series of parks separated by outlying spurs from the mountains. In South Park the Cretaceous rocks rest directly upon metamorphic rocks, and are themselves more or less altered. At no locality were they seen resting upon any sedimentary rocks older than themselves. In Wet Mountain Valley the unaltered strata are concealed, and in Huerfano Park the Cretaceous rocks are the only ones observed, except around the border, where they abut against the Trias.

The *second* range, which may be termed provisionally the *Sangre de Cristo* axis of elevation, is in the main almost parallel with the Eastern range, but is much more complex in its structure. It is divided longitudinally by the Arkansas River, which, turning eastward, breaks through its eastern slope. Northward, beyond our area, it is cut by the Grand River. In its northward extension, within our area, it is known as the Blue River range;

farther south, where it forms the western boundary of South Park, it is the Park range; in its southern extension it is called Sangre de Cristo and Spanish range; while beyond our limits, to Santa Fé, where it ends, it bears several names. The portion lying west from the Arkansas River and corresponding to the Park range on the east may be termed the Arkansas or Saguache range.

Owing to the effects of erosion upon the topography the intimate relation of these several ranges is not at once apparent, but with a little care the whole can be traced out quite readily. Beginning at the New Mexico line with the Spanish range, we follow the ridge to Sangre de Cristo Pass, beyond which to Poncho Pass it is known as Sierra Sangre de Cristo, the whole forming, within our area, the divide between the Arkansas and the Rio Grande. If now we follow the eastern slope along Wet Mountain and Texas Valleys we reach the Arkansas at Pleasant Valley. Ascending the river from this point we soon enter the cañon cut through the east face of the Sangre de Cristo Mountains. Passing through this long cañon we emerge into Arkansas Park at the mouth of the South Arkansas and on the *west* side of the Park range. No break occurs in the cañon, so that the Park range is merely a continuation of the east slope of the Sangre de Cristo. In this park the continuity is clear.

On the west side of the park a line of broken hills stretches to Poncho Pass, where they are broken down completely. Beyond Poncho, however, they again begin and soon develop into that grandest of mountain ridges, the Arkansas or Saguache range. To one standing in the park there seems to be every probability that the Park and Saguache ranges are one with the Sangre de Cristo; but, fortunately, one is not left to reason upon probabilities, for the evidence from structure is ample to prove the unity of the whole. On the eastern slope of the Park range the Paleozoic rocks reach quite to the crest, and are traceable from the Sangre de Cristo to our northern line. Underlying these are the metamorphic schists and gneisses, which are seen in the deep cañons along the eastern face, while on the western slope they extend from the river level almost to the crest, and are exposed all the way from the South Arkansas to the mouth of Tennessee Creek. Beyond that point the natural range is divided, as will be shown hereafter.

From the mouth of Box Creek to near that of Cottonwood Creek, the valley of the Arkansas is very narrow. This is the place of the Granite Cañon. Here, granite and gneiss, both metamorphic rocks, are continuous from the park to the Arkansas range, being broken only by the close cañon. Starting from the west base of the former range, we go by the side of one of the many high ridges of metamorphic rocks until we reach the river. Crossing the stream and climbing the steep granite wall of its cañon we follow a similar ridge until beyond Twin Lakes, where we find the porphyritic syenite, which forms the heart of the axis. Passing the crest, the metamorphic rocks are again seen on the west side, and on them rest the ancient quartzites dipping sharply westward. The high ridges of metamorphic rock, thrust out from each side of the Arkansas gorge, demonstrate the continuity of the whole and give a satisfactory succession, unbroken anywhere, save by the cañon.

Let us now ascend the Arkansas a few miles, to the mouth of Tennessee Creek. At about this latitude a great fault causes a bifurcation of the original range. Following Tennessee Creek to Tennessee Pass, upon the eastern slope of the spur produced by the great fault we see, on the eastern side of the stream, hills covered by sedimentary rocks, which are traceable across the Arkansas, and are seen to be continuous with those covering the eastern slope of the Park range. If, instead of proceeding directly to the pass, we ride westward across the moraine of the ancient Tennessee glaciers to the amphitheaters at the head of the creek, we find strewed over the moraine numberless fragments of Silurian quartzites with some of Carboniferous limestone. These must have come from the west, where now only metamorphic schists occur. It is impossible to suppose that they came from the East, for the transporting agent moved from the West. It is clear, then, that the paleozoic rocks, the same with those found on the Park range, at one time reached unbroken from South Park to the Arkansas or Saguache range. How terrible was the erosion which not only cut away these rocks but also tore out and removed the metamorphic rocks to a depth of 6,000 feet along this valley of the Arkansas. If we cross Tennessee Pass and go down to the Eagle River, into a region where only narrow cañons have been eroded, the succession of the rocks is clear at a glance. Beginning with the mountains, a continuation of the Arkansas range, the Silurian rocks are seen resting on the schists and succeeded by the Carboniferous rocks, which reach within our area to the edge of the great fault along Ten-mile Creek and the upper portion of the North Fork of Eagle River.

It is evident, then, that the Sangre de Cristo and its extension, the Spanish range, are but the southern portion of a magnificent group which once covered the whole region from East River to South Park. The width from South Park to Taylor River is about twenty-five miles, but southward it diminishes, being barely twelve miles at Sangre de Cristo Pass. Beyond that pass the range becomes broken and irregular. As it passes beyond our line into New Mexico it is so involved in eruptive rocks that it can be worked out only with some difficulty.

In the Sangre de Cristo portion no spurs are set off, but northward from the South Arkansas River the general structure becomes very complex. Near the head of Chalk Creek a very important spur sets off, with a trend at first almost west, but soon changing to northwest. This extends almost to our northern line and is the divide between Taylor and East Rivers, as well as, farther north, between Roaring Fork and Rock Creek. From this are thrown off the strangely complex spurs, if they may he so called, forming the Elk Mountains. Near the head of Taylor River, another spur strikes out from the main range, and apparently unites with the one just referred to. A third spur is produced by the great fault, and becomes well defined for the first time near the head of the Arkansas. The first and third spur seem to extend to about the same distance northward and to disappear before reaching our northern line, so that the country there is merely a broken table-land.

The intimate structure of this group is very complicated and exceedingly difficult to unravel. No exploration of this region has yet yielded results sufficient to give even a partial solution of the problems involved. Only a few isolated facts, therefore, can be given here.

The Sangre de Cristo portion, in its southern extension, is made up apparently of several axes of fault, most of which have a northeast and southwest trend, but these seem to disappear northward, as they were not observed in the long deep cañons opening into Wet Mountain Valley. In the Park range the faults are very numerous, there being two seen in the cañon of the South Fork of the South Platte River, and one very extensive one occurs in Horse-Shoe gulch. These have a northwest and southeast trend. Another, with similar trend, is seen farther north, which is traceable across the gorge of the Arkansas River, above the junction with Tennessee Creek, and becomes more extensive as it goes northwest. On the east side of the cañon of Ten-Mile Creek is a wall of metamorphic rock more than 2,000 feet high, while on the west side the very highest strata of the Carboniferous form the wall. For the most part the dips in the Park range are toward north of east, but near the head of South Park there is a strange spur, which includes some of the grandest peaks in the whole chain, among them Gilpin's Pillars and Mounts Lincoln, Bross, and Morton. Here the dips are sharply toward the southeast. In the spur produced by the great fault, the dip is toward the fault or northeast. In the Arkansas portion no dips or faults were satisfactorily made out in the metamorphic rocks, but over the crest, on the Taylor River side, the dip of the quartzites is toward the south of west.

The first great spur on the west side is very perplexing. It is clearly an anticlinal from Chalk Creek to the head of Taylor River, but is badly broken by extensive faults. In this portion, on the eastern slope, as seen in Taylor and Beattie's Parks, as well as on the divide between Taylor River and Tumichi Creek, the dip is eastward in a succession of faults, some of which are very sharp, the dip in two instances being reversed. The spur is quite narrow here, not more than six or seven miles wide, the whole structure being exposed on the West Fork of Taylor's River. Near the junction of the forks the dips are all eastward, but near the head of the west fork they are all westward. At the latter locality the rocks are very sharply curved, the rate of dip changing from 70° to 10° within less than fifty yards. Along the "Old Miners' Trail," from Taylor to East River, the faults are well exposed, and the Carboniferous limestone is seen three times standing almost on edge and dipping westward. In the portion lying between Rock Creek and Roaring Fork the derangement is excessive. Probably no other portion of our continent shows such cross-faulting as does this little area. The rocks dip toward all points of the compass, and one whole group is compactly folded on itself and pushed over. Enormous dikes and overflows of igneous rocks are numerous and do not aid in simplifying the conditions.

In the main portion of this second group no rocks occur of later date than the Carboniferous, which, with the underlying Silurian, may be traced along the eastern face to the Blue River. In the southern portion the relations of the Cretaceous to the Paleozoic rocks was not ascertained, but along the Blue River they are unconformable. In no portion of the main axis do we find any rocks more recent than the Carboniferous, the Trias being entirely absent. Nor do any occur until in the Elk Mountains we reach the ancient synclinal trough which lay between the second group and the next one westward. There the Cretaceous rocks are involved in the great fold exhibited near the head of Rock Creek. This fold evidently deepens northward and disappears southward. Near Elko, on Rock Creek, the dark shales of the Cretaceous are folded upon themselves so as to be but one stratum, and are inclosed by Carboniferous rocks, which are not only folded but faulted. Followed southward along the wagon-road across the divide to East River the fold rapidly disappears, so that, before reaching the mouth of the cañon on Upper East River, the shales are resting unconformably upon the quartzites below, and are dipping at only a small angle. In the narrowest part of this cañon, through which the road winds on a shelf, the quartzites describe two shallow curves, which do not involve the shales above. At the junction of the forks of East River the shales are almost horizontal, and at the mouth of East River the Lower Cretaceous rests on the metamorphic schists, with almost inappreciable dip. This whole line of Cretaceous marks the northern portion of the ancient synclinal valley between the Sangre de Cristo group and the San Juan.

Between the second and third great axes of elevation, we find at the south the San Luis Valley, a broad, open plain, extending from the New Mexico line northward to Poncho Pass. It shows no rocks except those of volcanic origin around the border, and the surface of the valley is deeply buried under volcanic sand. Followed northwestwardly, the intervening region is so filled with eruptive rocks, that were it not for the occasional exposures of the underlying strata, one would hardly suppose that this had been a great synclinal trough. The eruptive rocks describe broad curves, both anticlinal and synclinal, as though they had been subjected to great lateral pressure. In several localities they are seriously faulted.

The *third* great axis or line of elevation is the *San Juan*, so named because in its southern prolongation it forms the Sierra San Juan. It reaches into New Mexico, and ends not far from Abiquiu, somewhat farther north than the termination of the *Sangre de Cristo* axis. To trace out this axis is no simple task, for, excepting along its western flank, near the New Mexico border, it is almost entirely concealed within our district by an enormous deposit of volcanic rocks. By means of a few fragmentary exposures, it was followed northwestward to the one hundred and seventh meridian. It is cut by the Rio Grande dyke about thirty-three miles above Del Norte, and reaches the one hundred and seventh meridian on one of the forks of Lime Creek, and almost due west from the Indian agency. Not far north from Tierra Amarilla, in New Mexico, a spur sets off in a northwest direction, which is cut by the Rio Navajo and the Rio San Juan. How far northward it extends was not ascertained. It was not seen along the Rio Grande, and north from that river no observations were made west from the one hundred and seventh meridian. It makes an angle of about 12° with the main axis.

As already stated, the main axis is, for the most part, buried under a great mass of volcanic rocks, which conceals those of sedimentary origin. In Northern New Mexico the western slope is bare for a number of miles, and near Tierra Amarilla the exposures show very marked unconformability between the Carboniferous and the overlying rocks. The older formations are inclined at a very high angle, while the Cretaceous and Triassic (?), which are conformable to each other, have a very small dip. The spur is crossed by the Rito Navajo within two miles of the wagon-road, (Macomb's trail,) and by the Rio San Juan at a short distance below the Pagosa Hot Springs. The extent of the spur is unknown. Its dip increases somewhat in sharpness northward. As far as followed this sub-axis involves the Cretaceous rocks, which describe a beautiful curve where the Rito Navajo breaks through. The dip is somewhat steeper on the west than on the east. No rocks of older date than the Cretaceous were observed along the spur.

The next great axis toward the west is the one termed by Dr. Newberry the *Los Piños* (apud Macomb, ined.) and is in part the divide between the Rio de los Piños and the Rio Piedra. It is crossed by the Rio Piedra near Macomb's trail, which follows along the southwestern slope for several miles. The line terminates quite abruptly a little way south from the trail, and before reaching the southern line of Colorado, the whole country southward being a broken mesa, whose strata have a barely perceptible dip. Followed northward, it is found crossing the Rio Grande near the head of the Middle Fork, and is cut by the Rio de las Animas in the long cañon leading from Baker's to Animas Park. The trend is almost due northwest. The dip is comparatively sharp near the southern extremity, being 10° toward the northeast and 12° to 15° toward the southwest. Farther north it seems to be much less.

The only rocks seriously involved in this anticlinal are the Carboniferous and probably the Silurian, though the latter were not satisfactorily recognized. On each side of the fold, which is not more than five or six miles wide, the Cretaceous rocks are seen forming mesas and dipping only two or three degrees.

The next axis, termed *La Plata* by Dr. Newberry, forms in part the divide between the Rio de la Plata and Rio de las Animas. Our route followed for barely twenty miles along its northeastern slope. For the most part, it lies wholly west from the Animas River, but is cut by that stream in Animas Park, near the middle of which the axis terminates quite abruptly. Along the trail from Baker's to Animas Park one rises twice to the altitude of 11,500 feet, whence the general structure can be seen. The course of the uplift is almost northwest and the dip is very gentle, not exceeding 5° where the strata have not been locally disturbed by the bursting forth of lava and the consequent formation of dikes. The only rocks involved are the Paleozoic, against which the Triassic and Cretaceous abut at an angle of barely 2°. This anticlinal, as well as the *Los Piños*, has been much broken by eruptions of volcanic rocks, which in many places have overflowed and formed a thick cap on the hills.

According to Dr. Newberry there is another axis still farther westward, which he terms *San Miguel*. This terminates farther north than the *La*

Plata, and, like it, involves only the Paleozoic rocks, those of Mesozoic time forming mesas around it. Beyond this, as appears from a section made by Dr. Newberry, the country is a plateau of Cretaceous rocks, which separates the Rocky Mountain System from that of the Great Basin at the west.

In general, respecting the dips, it may be said that the prevailing direction is east-northeast and west-southwest, and the western dips are for the most part somewhat steeper than the eastern. The most extensive faults are on the eastern slopes and cross the easterly dips. The most marked effects of the convulsions occur in the eastern lines, the first and second axes, which are characterized by extensive faults and sharp dips. Crossing westward or southwestward, the dips diminish in steepness, until in the *La Plata* they are comparatively slight.

Of the several axes, the *Sangre de Cristo* extends farthest south. Those lying west from it have their terminations successively farther and farther north, while the eastern group ends at a considerable distance north from the New Mexico line.

Age of the Rocky Mountains.

From the facts given, it is sufficiently evident that the Rocky Mountains are not the result of one grand upheaval,* and that the several axes are not wholly synchronous in origin. Indeed, one cannot resist the conclusion that the area now occupied by this great system has ever been made up of lines of weakness in the earth's crust, along which at varying intervals there have occurred elevations and depressions of the mass. The sections obtained in the deeper gorges of the *Eastern*, *Sangre de Cristo*, and *Los Piños* axes of elevation show that along the median line of each there is a peculiar syenitic granite, more or less porphyritic in structure, upon each side of which the metamorphic rocks lie. There seems to be no room for doubt that the doctrine of granitic axes is a good one in this region, though it may or may not be satisfactory elsewhere.

The general diminution in disturbance westward, as shown by the

* Dr. J. L. Le Conte came to this conclusion respecting the eastern group in 1868. See his notes on the Geology of the extension of the Union Pacific Railway, Eastern Division, 1868.

diminishing steepness of dip, together with the general trend of the various axes, shows that the disturbing force was propagated from the east or east of northeast.

The relations of the strata of the several periods give us the story of successive elevations, and enable us to determine the era and comparative energy of each upheaval. Along the Eastern range no Carboniferous rocks were exposed at any locality visited by me, but they have been seen elsewhere by others. They must be quite unconformable to the Trias, as it overlaps them very greatly. The unconformability between Trias and Cretaceous is extreme, there being a difference of about 40° in the dip. The Tertiary rocks in the same region rest unconformably upon the Cretaceous, and have a dip of not more than 5°. It is worthy of note that the Tertiary rocks on the Rio Grande have nearly the same dip.

In the interior no rock of more recent origin than the Carboniferous is involved in the main axes. The Paleozoic strata occur high up on the flanks of the whole group, and the Cretaceous (the Trias being absent) everywhere abut against them around the base of the mountains. The one exception to this is found in the Elk Mountains. In the southwest, around the southern extremity of the system, we find the Trias and Cretaceous forming mesas abutting against the Paleozoic, and perfectly conformable. One instance, the spur from the San Juan, has been referred to as involving the Mesozoic strata. Everywhere throughout our area the Silurian and Carboniferous are conformable.

The conformability between the Silurian and Carboniferous seems to imply that during the long period of their deposition the conditions must have been the same, either comparative quiet or continued subsidence, while the marked want of conformability between these and the Mesozoic rocks is ample evidence that elevation began at the close of the Carboniferous. The fact that these Paleozoic rocks alone occur on all the interior axes of elevation, with no Mesozoic rocks either overlapping or resting directly on them, shows that the elevation there was permanent, but the extensive overlapping of the Paleozoic by the Trias along the face of the eastern range is proof of a subsequent depression along that line. *The first great epoch of accelerated disturbance in the Rocky Mountain region, resulting in permanent elevation of the*

PART V.

REPORT

ON

THE GEOLOGY OF PORTIONS OF NEW MEXICO AND ARIZONA,

EXAMINED IN

1873.

BY

G. K. GILBERT, A. M.

COMPRISING

WASHINGTON, D. C., *October* 19, 1874.

SIR: I have the honor to submit to you my report of geological examinations in the field-season of 1873, together with drawings for illustrative wood-cuts. It includes, besides the result of my own work, a portion of the information gathered by Mr. E. E. Howell, and by Dr. O. Loew, in the same year. My first examinations were made in the vicinity of the Fort Wingate rendezvous in the latter part of July. Thence, to Camp Apache my route was the usual wagon-road, with the exception of an excursion to Inscription Rock, and a detour of three days, eastward, from the bridge of the Colorado Chiquito. From Camp Apache I made three side-trips; the first with your own party to the Sierra Blanca country, the second up the North Fork of the White Mountain River, and the third to the junction of the main forks of the river. Thence to Camp Bowie, the most southerly point touched, my route was identical with that of Lieutenant Tillman and the topographer, Mr. Schmidt. We diverged from the traveled road to explore the South Fork of the White Mountain, and the Prieto and Bonito Rivers, and to ascend Mount Graham. To Camp Bayard we followed the road *via* San Simon and Ralston. At that camp I joined the division under Lieutenant Russell, for the sake of uniting my route more closely with that of Mr. Howell, and with him I followed, first, the Mimbres, and then the Gila River to its source. Continuing northward, by way of Luera Spring, the Tres Hermanos, Acoma, and Cebolleta, we reached Agua Azul, not far from the point of starting, late in November. The notes of that portion of Mr. Howell's route which lies within this circuit were placed by him in my hands, and his material has been combined with mine so intimately that it has been impracticable to give him full credit in the places in which it has been used. The invertebrate fossils gathered in the progress of the work, and which have now been intrusted to Prof. C. A. White for thorough study, were previously inspected by Mr. F. B. Meek, and upon the authority of his determinations are based the names which I have enumerated in describing the relation of the fossils to the stratigraphy.

The subject matter of the report falls naturally into three categories already recognized in the report of my earlier work, and it happens that, in this field, the areas characterized by the several types of geological constitution are so massed that, in adopting a logical division of my material, I have at the same time chosen a geographical division. I am confident that the omission of details will meet with your approval. Wherever the facts at hand have appeared to warrant a general statement, that has been given in preference to the individual facts, in the belief that, even though it shall require future modification, it will be more readily available and in every way of greater service to geological science than the enumeration of the local details that were the subjects of direct observation.

Very respectfully, your obedient servant,

G. K. GILBERT.

Lieut. GEO. M. WHEELER,
Corps of Engineers, in charge.

CHAPTER XVIII.

THE RANGE REGION.

In a former report (Part I of this volume) I have had occasion to dwell upon the distinction that is marked in Utah and Northern Arizona, between the plateaus of the Colorado Basin and the ranges of the Great Interior Basin. The explorations on which that report was based showed the persistence of the distinction as far south as Middle Arizona, but left doubt whether the plateau belt ran southward into Mexico or found limit within our own territory. In 1873 the southern extremity of the belt was ascertained to be approximately in latitude 33° 30′, and the entire border, at the south, between the areas of great and slight corrugation, was found to be blanketed with lavas. These facts have led to the discrimination in the description of the region explored in 1873 of three provinces, which form the topics of as many chapters. The present chapter considers the mountain ranges visited in Southeastern Arizona and Southwestern New Mexico; the next, the broad area of volcanic rocks everywhere encountered in passing to the north; the last, the plateau country which stretches from the lavas northward beyond our field.

In the region of mountain ranges we intersected the route explored by Lieutenant Parke in 1855, and I was enabled, by direct comparison with my notes of a number of localities, to recognize the fullness with which Dr. Antisell, the geologist of that expedition, has described the phenomena of his route.* Entering the field from different sides, and with different preconceptions, and closely coinciding in route for but a short distance, it is not surprising that we fail to agree in our generalizations, but at our common points of examination I have almost no amendments to propose to his descriptions. The majority of our differences of interpretation it will be unprofitable to discuss until the array of facts shall be less meager.

* Vol. VIII, Pacific Railroad Reports, Part II, chapters 20–23.

In latitude 32° it is possible to group the mountain ranges of Arizona and New Mexico in two systems, distinguished by difference of trend. In the vicinity of the Rio Grande del Norte the ranges trend nearly north and south, and their northward prolongations swerve somewhat to the east. One hundred and fifty miles to the west the Chiricahui range trends northwest, and its prolongation in the Pinaleño, Pinal, and Mazatzal ranges holds the same direction for nearly two hundred miles. The space between these divergent lines of structure is filled at the north by plateaus, and at the south by a series of ridges parallel to the Chiricahui, but disappearing northward under the lavas that fringe the plateau region. West of the Chiric ahui Mountains are others with the same trend. In a general way, we may say that east of the Mimbres River is a mountain province, in which the trend of the axes of corrugation is north, and west of that river another province, in which the trend is northwest. The mountains of the eastern province are the southward continuation of the Rocky Mountains of Colorado, and with them constitute the eastern boundary of the Colorado plateau region. When the western mountain system is traced northward it is found slowly to lose its northwest trend, exchanging it for a more northerly, and finally coalescing, without discernible break, with the Basin Range System of Nevada and Western Utah. Regarding it as one with that system, it constitutes the western and southern boundaries of the Plateau region. Whether this classification, based upon trends, corresponds with, and will lead to a classification based on the more important character of age, cannot yet be told.. The general tendency of the evidence at hand is to give the principal uplift of the western or Basin Range System an earlier date, but there is no final proof. In Nevada, Mr. King announces fossiliferous Triassic strata older than the Basin ranges, and refers the birth of the latter to Jurassic time; but in Arizona and New Mexico there are not grounds for equal confidence. The newest rocks there recognized by fossils are Carboniferous, and these are folded components of the ridges. In the valley of the San Pedro, (Southern Arizona,) Antisell found strata newer than the adjacent mountains, and which he regarded as Cretaceous. If it could be proved that they belong to that system, the age of the mountains would be locally established as between the Carboniferous and the Cretaceous, but the only evidence adduced is lithological, and such proofs, always untrustworthy, are in this case especially questionable, from the fact that the beds pertain to a small estuary, or perhaps lake, where the character of deposits must depend on local causes, and be independent of such wide-spread conditions as alone can give value to lithological coincidences. West of the Mimbres, on the other hand, the facts gathered by Messrs. Marcou, Newberry, Shumard, Jenney, and Howell, though not entirely concordant, appear to show that, while the north-trending chain had a pre-Silurian existence, its present proportions were acquired, after a long period of quiet, in post-Cretaceous time. But, whatever the value of the distinction as an element of ultimate classification of mountains, it is convenient to recognize it in the description of the ranges touched by the season's exploration, and those of northwesterly trend will be first mentioned.

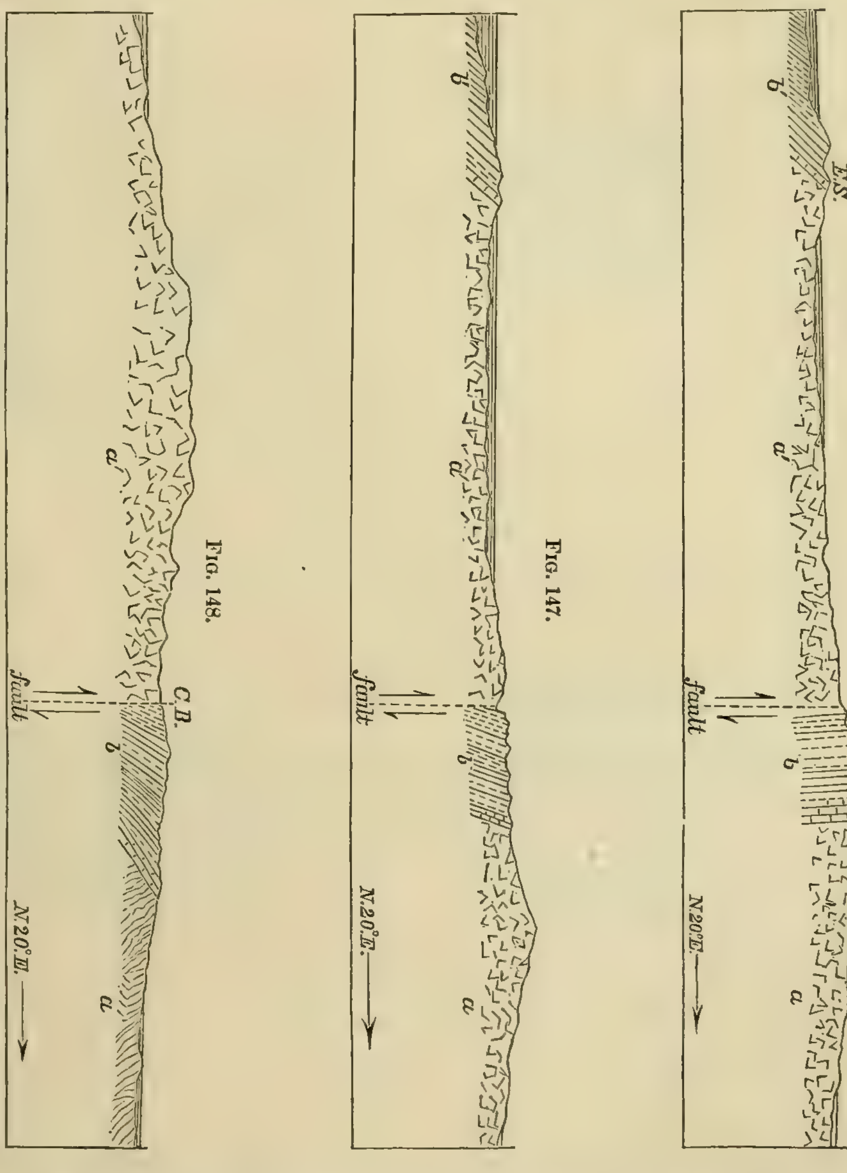
Taking them up, in order, from west to east, the first to consider is a long line (for which there is no comprehensive title) of ridges, succeeding each other in the same trend, and known in different portions as the Mazatzal, Pinal, Pinaleño, and Chiricahui ranges. Of the geology of the Mazatzal nothing is known. The Pinal Mr. Marvine crossed in 1871, and found to be constituted of granite, overlaid in part by sandstone and limestone, that are probably Paleozoic, and in part by acidic lava. The Pinaleño includes three titled peaks, Saddle-back, at the north, Mount Turnbull, and, at the south, Mount Graham, the highest point of the region. At and in the vicinity of Saddle-back Peak, Lieutenant Emory (Reconnaissance of 1846–'47) noted the occurrence of granite, sandstone, and limestone; and in the same vicinity Carboniferous fossils were discovered by Lieutenant Whipple, (quoted by Mr. Marcou in his "Geology of North America.") In the same neighborhood, and especially to the southeast, about the mouth of Aravaypa Cañon, the sedimentary beds are overlapped by great eruptions of trachyte. In the vicinity of Mount Turnbull Dr. Loew noted granites and schists as predominant, but with some quartzite and limestone, and lava. Mount Graham I ascended from the northeast, finding upon that face only gneissic rocks, and a syenite that, viewed in large masses, betrayed a trace of structure. The chief mass, and not improbably the whole of the mountain, is metamorphic. It is of imposing proportions, rising 6,000 feet from its eastern base (and nearly as much from its western) so abruptly that it is difficult of ascent. To the southeast the crust gradually descends, until in Railroad Pass it is buried by the valley detritus. The Chiricahui Mountains, beyond the pass, are inferior in magnitude to Mount Graham, and less simple in structure. My examination of them was confined to the northwestern extremity, from the peak Dos Cabezas to a point six or eight miles beyond Camp Bowie. In this region they are constituted of syenite, schists, Paleozoic strata, and porphyry. The relation of the syenite to the schists was not made out, but they are both overlaid (the schists unconformably) by the Paleozoic. The syenite is not uniform in kind, but a large portion is characterized by crystals of orthoclase from one to two inches in length. The schists are thoroughly foliated, and, in large part, fall under the denomination of gneiss. In the vicinity of Dos Cabezas they contain magnetic iron ore, probably in quantity to give it economic value. The Paleozoic strata, where best displayed, show 3,500 feet of limestone, shale, and sandstone, with Carboniferous fossils near the top of the series, and Lower Silurian near the base. The porphyry overlies all the other rocks, and is probably inferior to all in mass, although it constitutes Dos Cabezas, the highest peak in this portion of the range.

The break between the Archæan schists and the Paleozoic beds is strongly marked. The Archæan sediments were foliated, were tilted, and were lifted above the ocean and eroded before the Paleozoic were laid down. Or, to give the data instead of the inferences, the contrast in degree of metamorphism of the two systems is conspicuous at their contact, the one showing complete foliation, while the other retains ripple-marks and fossils. The angle of discordance in dip is as great as 65°; and the lowest bed of the upper system is a coarse sandstone, spread over a plane and originally level surface. If the syenite is older than the schists, then the degradation of the Archæan mountain was carried so far as to expose the former also to the waves of the Paleozoic shore.

Later revolutions have thrown the rocks into a new system of ridges, in which the Paleozoic strata are inclined at all angles, even passing the vertical. Subsequent denudation has so far removed them, that their areas of outcrop are now inferior to those of the Archæan; and their metamor-

phism, though far less than that of the older system, is marked by the crystallization of hornblende and andalusite in certain shales, and by the local conversion of limestones, elsewhere fossiliferous, to marble. The

Fig. 146. Fig. 147. Fig. 148.



Sections of the Chiricahui range, Ariz. Scale, $\frac{1}{12000}$. Base line = sea level. Fig. 146, section nine miles east of Camp Bowie. Fig. 147, section three miles east of Camp Bowie. Fig. 148, section at Camp Bowie. *E.S.*, Ewell's Spring. *D.C.*, Dos Cabezas Peak. *C.B.*, Camp Bowie.

trend of the structure lines of the later corrugation is north 65° west, and the original strike of the schists was determined, at a single point, to have been due north.* The structure of the range is exhibited in figures 146, 147, and 148, which give sections transverse to the strike at intervals of three and six miles. The rocks are divided into two principal monoclinal bodies, *ab* and *a′b′*, by a fault; and each of these bodies displays a belt of Archæan at the north, and one of Paleozoic at the south. Camp Bowie stands close to the line of fault. The Paleozoic rocks of the northern belt are there little inclined, but in tracing them northward they were found to gradually increase their dip, until, in the vicinity of Dos Cabezas, it is more than 90°. The porphyritic overflow constitutes the crest of the range from Dos Cabezas eastward nearly to the line of the second section, and near it the strata are more altered than elsewhere. The southern Paleozoic belt exhibits two parallel ridges, that figure as southern, and in part outlying, foot-hills of the range. From Ewell Spring they run east-southeast, with constant form and trend, for six or eight miles, and then sink out of sight. In the opposite direction they curve toward the north, and are less persistent.

It will be seen by the following sections that both Lower Silurian and Carboniferous fossils were found, but the horizons were not sufficiently numerous to define the relative thickness of the two formations. If the upper horizon of the Ewell Spring section be regarded as Subcarboniferous, then the Silurian does not exceed 1,000 feet in depth.

Section of strata exposed at Ewell Spring, in the Chiricahui range, twelve miles west of Camp Bowie. The lowest bed rests on Archæan syenite.

	Feet.
1. Massive gray limestone, with little chert, [*Pentremites*, (like *P. melo*,) *Syringopora*, *Zaphrentis*, *Favosites*]	125
2. Unseen; soft	450
3. Dark, bedded, arenaceous limestone, with much chert, [*Euomphalus* (like *E. trochiscus*)]	325
4. Vitreous, bedded sandstone; gray, weathering brown; conglomerate at base	260
Total	1,160

* At a point two miles northeast of Camp Bowie, where the junction of the strata is clearly seen, the Archæan strike north 20° east, and dip at 60° to the east; and the overlying beds strike north 70° west, and dip at 30° to the south. Assuming that the last flexure had its axis parallel to the strike of the upper beds, it follows mathematically that when the upper beds were horizontal, the lower had a strike north 4° east, (approximately,) and a dip of 64° to the east.

PEBBLES, CARVED BY SAND. COLORADO RIVER.

HELIOTYPE

Section of strata exposed at Camp Bowie, in the Chiricahui range. The lowest bed rests on Archæan schists.

		Feet.
1. Massive limestone; dark blue to white, in places changed to marble, [*Productus semireticulatus, Athyris subtilita?, Spiriferina, Zaphrentis*]		850
2. Quartzose rocks:		
a. Quartzitic schists, alternating with black slates, the latter containing andalusite	525 feet.	1,325
b. Quartzite and quartziferous slate, bedded and of dark colors	600 feet.	
c. Dark gray, calcareous, vitreous sandstone or quartzite	200 feet.	
3. Limestone:		
a. Arenaceous limestone	150 feet.	420
b. Massive, sectile limestone, laminated with blue and white	15 feet.	
c. Marble	80 feet.	
d. Bedded, rust-colored limestone, with geodes of quartz and calcite, and obscure fossils, [*Lingula*]	75 feet.	
e. Bedded limestone, dark on fracture, but superficially banded with blue-gray and ash	100 feet.	
4. Shale:		
a. Pale gray, argillaceous shale	55 feet.	215
b. Black, argillaceous and calcareous shale, interlaminated with black limestone	150 feet.	
c. Pale blue, calcareous shale	10 feet.	
5. Massive, pale gray limestone		35
6. Massive limestone; mottled with gray and ash-color. The mottling is in part coralline in form. Fifty feet below the top is a zone of chert, from which the bed is otherwise free. At base is a gradual transition to the next bed		305
7. Dolomitic beds:		
a. White, massive rock, composed of dolomite and some quartz	20 feet.	160
b. Gray, calcareous shale	80 feet.	
c. White, massive, crystalline dolomite	60 feet.	
8. Bedded quartzite and quartzitic schist, gray to brown		310
Total		3,620

The Peloncillo range, next northeast of the Chiricahui, is of less magnitude. Its trend is northwest, and is prolonged beyond the Gila by the Gila range, (the "Sierra Carlos" of Emory.) It is built chiefly of trachytic lavas, but at the two points at which I crossed it a sedimentary nucleus was detected. Opposite Pueblo Viejo the southwestern base of the Gila range is of quartzite, in which are cupriferous veins. Over this is a gray rock, made up chiefly of feldspar and hornblende, and possibly of eruptive origin. Above are nearly 1,000 feet of trachytes and trachyte conglomerates, unevenly bedded, and surmounted by basalt. These are all exhibited in section on the southwestern face, which is steep, while the opposite face is constituted by the upper lavas, which, dipping in that direction, are continuous to the Bonito River, five miles away. The range is at this point a monoclinal mass of bedded lavas, whose eruption took place before the dislocation that produced the ridge, and the same structure probably continues to the northwest for fifteen miles. Forty-five miles in the opposite direction, at Peloncillo Peak, (Steen's Peak of some maps,) Antisell noted only volcanic rocks, but at Gavilan Peak, ten miles beyond, the sedimentaries are once more exposed. They comprise limestones and sandstones, and are probably of the Paleozoic series observed in the Chiricahui range. Carboniferous fossils were seen in their *débris*. The strata dip at a high angle toward both flanks of the range, and upon their upturned edges rests the granite which constitutes the peak. The circumstances admit of no question that the granite in this case is eruptive, and was extruded after or during the disturbance of the Paleozoic strata. The limestones, at their contact with the granite, are converted to white, coarsely-crystalline marble; and the same metamorphism is to be seen along the margin of a heavy dike of granite in the vicinity. The granite is fine-grained, and consists chiefly of quartz and albite. Its body is traversed in one place by a dike of quartz-porphyry.

In the Pyramid range, of which we visited the northeast end, I failed to discover any save eruptive rocks. Basalt and trachyte flank and overlap a more ancient lava, which is proably referable to the propylite of Richtofen, and which contains the quartz veins of the Virginia (Ralston) mining district. The whole range has an appearance of great antiquity, being reduced nearly to the level of the surrounding plain by an erosion, the present progress of which is of exceeding slowness. The appearance is doubtless due to the easy disintegration of the ancient lava. The purest quartz veins, resisting the destructive agents by which the country rock is degraded, project above the ground surface in long, ragged walls. Other veins less conspicuous, but more attractive to the miner, contain, in the quartz, argentiferous ores of lead and copper, and, with the building of the Southern Pacific Railway, may become of economic importance. For the present, however, all mining operations are suspended by the proprietors of the veins, because too expensive for profit in so sterile and remote a place.

The Burro Mountains are of greater magnitude, and are comparable in structure with the Chiricahui. Mr. Howell, crossing them in a northeasterly direction, from Ash Creek to Silver City, found their chief mass Archæan granite, lying in two bodies, the first and smaller of which bears bedded trachytes with a northeast dip, while the larger is overlapped by Paleozoic strata with the same dip. The range is thus, in a general way, monoclinal in structure, the inclination of the rock masses being to the northeast, and the latest disturbance having occurred after the extrusion of the trachyte. The Paleozoic limestones and shales contain the argentiferous veins mined at Silver City, and have likewise been intersected by dykes of a peculiar gray feldspathic porphyry. From one of the limestones, in close proximity to silver mines, Mr. Howell gathered a suite of fossils of Cincinnati age, including *Leptæna sericea*, *Strophomena*, (type of *S. planumbona*,) *Rhynchonella*, (like *R. subtrigonalis*,) *Fenestella*, *Favosites*, and *Stromatopora*, and from the same vicinity Lieut. A. H. Russell brought a block with several specimens of *Zaphrentis*, marking the presence of Carboniferous rocks also.

Fifty miles northwest of the Burro Mountains, and possibly in the same line of trend, the parties which descended the Prieto and San Francisco Rivers found islands of Archæan and Paleozoic rocks—the crests of a mountain almost completely hidden by the deep floods of the lava-field. The most conspicuous rock is a deep red granite, against which rest a system of sandstones, limestones, and shales, lithologically similar to the Silurian and Carboniferous rocks of the neighboring ranges. The only fossils discovered are of Carboniferous age, but it is nevertheless probable that the base of the stratified series is Silurian. The chief of these islands, lying between the two rivers, contains the Clifton mines. It is possible that other peaks of the same character jut through the lavas on the line between Clifton and the Burro Mountains, but none of them were visited.

Next east of the Burro Mountains lie the Santa Rita, a range defined for only a short distance. In the vicinity of Fort Bayard and the Santa

Rita copper-mine its axial rocks are displayed for a few miles, but to the south they are covered by the rhyolite of the Kneeling Jesus mesa, and to the north by the similar lava of the Diabolo range. The axial rocks are

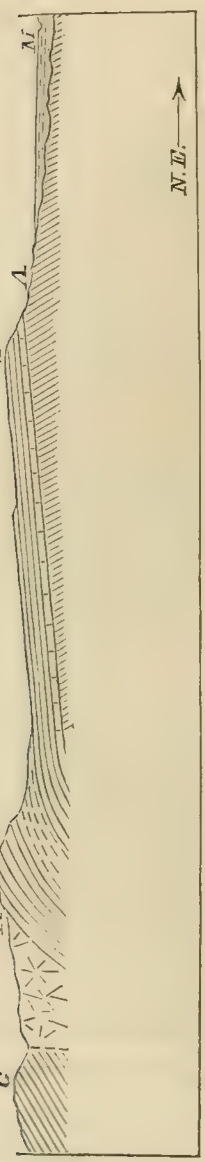


FIG. 149.—Section of Santa Rita range, New Mexico. Scale, $\frac{1}{12000}$. Base line = sea level. *CC*, Carboniferous. *S*, Silurian. *A*, Archæan. *R*, Santa Rita copper-mine. *M*, Mimbres Valley.

Archæan schists, and Silurian and Carboniferous sandstones, limestones, and shales. The schists were seen only at the northeastern base, near the Mimbres River, and at their contact with the Silurian their discordance of dip is 75°. Resting upon them are, in order, sandstone, limestone, with Silurian fossils, shale, and limestone with Carboniferous fossils. The strike of the whole is northwesterly, and the dip gently to the southwest. The weathering of the shale has opened a valley between the outcrops of the two limestones, leaving the lower as the cap to a line of hills near the Mimbres River, and the upper as the crest of the main ridge farther to the west. The surface of the western slope of the range is made up of the Carboniferous limestone and a feldspathic porphyry that has risen through it, and in part overrun it. From the foot of the slope, westward to the Burro and Bear Mountains, the foundation of the plain is of this same porphyry. Fort Bayard stands upon it, and the roads thence to Pinos Altos, Silver City, and Lone Mountain cross little else. Pinos Altos Peak is a granitic, and presumably Archæan, island, bounded on one side by overlapping porphyry, and on the other by the still newer eruptions of the Diabolo range. Lone Mountain, also an insular butte, is bathed at foot on three sides by valley gravels, and to the north by the porphyry flood. It consists of two principal ridges, both short, trending northwest, and composed of strata with a northeast dip. I visited only the more easterly; but, from the descriptions given me by gentlemen engaged there in mining, I am led to believe that the rock series of the whole is identical with that of the

Santa Rita range, the Silurian outcrop being, in this case, at the west instead of the east. The eastern ridge is of limestone, with Carboniferous fossils, including *Productus semireticulatus* and *Spirifer lineatus.* Porphyry, such as floors the country at the north, breaks through the limestone in dykes, and in the same neighborhood are calcareous veins and deposits, with argentiferous galena.

The section of strata exposed in the eastern face of the Santa Rita range is as follows, beds 1 and 2 being estimated in thickness, the others measured by barometer:

	Feet.
1. Gray, massive limestone, [*Spirifer cameratus*, *Productus*, *Orthis*]	200+
2. Gray, argillaceous shale	100+
3. Gray limestone; massive and bedded, with much chert, [*Strophomena (alternata,?) Orthis lynx* (var.,) *O.* (like *O. testudinaria*,) *O.* (type of *O. sinuata*,) *Rhynchonella* (like *R. subtrigonalis*,) *Murchisonia,? Modiolopsis, Favosites*]	90
4. Unseen; shale	25
5. Gray sandstone, in part calcareous	10
6. Unseen	30
7. Heavy-bedded limestone, with coralline mottlings; in part arenaceous, [*Conocoryphe*]	200
8. Vitreous sandstone and conglomerate, red and white, resting unconformably on Archæan schists	80
Total	735+

This closes the list of ridges with northwest trend. It may be said of them, in general, that their axial rocks are Archæan and Paleozoic, there being no evidence of sediments newer than Carboniferous before their uplift. Their age can be defined no more closely than is expressed by the term post-Carboniferous. There is proof of an antecedent—pre-Silurian—corrugation of the same region, the axes of which did not accord in trend with those of the later disturbance. The ridges of earlier formation were mostly, if not all, obliterated by pre-Silurian and Silurian denudation, and the existing ridges are referable to the later—post-Carboniferous—action. Our examinations have demonstrated no anticlinal structures, except as minor features. The usual structure is monoclinal, demonstrably due to faulting in the Chiricahui and Pinal ranges, and presumably so in all the others. Taking the ranges in order, from southwest to northeast, the inclined masses dip as follows: (The ranges given on the same line are considered continuations of each other.)

Chiricahui, SW.
Peloncillo, at Gavilan Peak, synclinal. *Gila, at Pueblo Viejo*, NE.
Pyramid, unknown; axis not seen.
Burro, NE. *Clifton*, SW.?
Lone Mountain, NE. *Pinos Altos Peak*, unknown.
Santa Rita, SW.

In this succession no symmetry is discernible. All the ranges show post-Carboniferous eruptive rocks, and these have no common character, unless it be the preponderance of feldspar. They include granite, feldspathic porphyry, propylite, ? trachyte, and rhyolite, with basalt, quartz-porphyry, and other rocks in minor masses.

The geological distribution of the metalliferous veins warrants no generalization further than that it is not narrowly restricted to rocks of particular age or composition. In the Chiricahui range a siliceous vein in syenite has been wrought for gold. In the Gila range are cupriferous veins in Archæan (?) quartzite. In the propylite (?) of the Pyramid range are quartz veins with argentiferous ores of lead and copper. Near Clifton, gold and copper have been obtained, the former from placers, the latter from lodes in limestone of Paleozoic, and probably Carboniferous age. At Silver City, argentiferous galena in calcareous gangue is taken from Silurian limestone and shale. At Pinos Altos are mined quartz veins, traversing Archæan granitoid rocks, and containing compounds of iron, copper, and lead, together with an economic percentage of gold. At Lone Mountain, calcareous veins and deposits, with argentiferous galena, are found in Carboniferous limestone. On the western slope of the Santa Rita range, in the Santa Clara mining district, plumb-argentiferous ore is obtained from Carboniferous limestone; auriferous and cupriferous, from veins in feldspathic porphyry. The celebrated Santa Rita mine, near the crest of the range, lies on the contact between the Carboniferous limestone and the porphyry. The Upper Mimbres mines, on the eastern slope, are in Carboniferous limestone, and afford argentiferous galena.

Passing now from the ranges of northwesterly trend to those of northerly, we pass, at the same time, from the southern border of the Plateau region to its eastern border, and have to consider a chain of ranges of remarkable persistence, that coalesces northward with the Rocky Mountains of Colorado, and southward, crosses the Mexican boundary. Through the labors of Messrs. Marcou and Newberry, in the vicinity of Santa Fé, and of Mr. Shumard and Mr. Jenney in the El Paso Mountains, it is established that this chain, while it consists mainly of Archæan and Carboniferous rocks, with Silurian at the south, bears upon its flanks Cretaceous and other Mesozoic strata, which have shared in the disturbances that produced the chain. A comparison of the Cretaceous strata upon both sides of the chain, as described by those authors and by Mr. Howell, suffices, when taken in connection with the manner of their disturbance, to indicate that the Cretaceous sea occupied the present site of the chain, with the exception, at most, of a few islands, and possibly without exception; so that the last great upheaval of the chain cannot have begun before the end of the Cretaceous epoch. The discovery, by Dr. Loew, of a Pliocene deposit in the valley of the Rio Grande, at San Ildefonso, assures us that the data for the closer determination of its age are accessible. If these Pliocene beds shall prove to be undisturbed and non-conformable to the Cretaceous, the date of the first uplift will be defined as early Tertiary. If they prove to be conformable, then they ante-date the birth of the Santa Fé Mountains, and presumably of the whole chain.

The *Mimbres range*, in the portion that I examined, belongs to the great lava field, but as its sedimentary nucleus is not entirely concealed, it may be mentioned here, also, as a member of the ridge system. From the town of Upper Mimbres to the Cañada Alamosa, a distance of sixty miles, its western slope is a continuous sheet of trachytic lava, of wonderful uniformity of texture and habit. The opposite face I did not see, but it was skirted by Lieutenant Tillman and Dr. Loew, and from their descriptions, taken in connection with my own observations, I am led to consider the range a great monoclinal uplift, with westward dip, composed in chief part of lava, which constitutes the entire crest, but revealing the underlying sedimentaries (Paleozoic) along the eastern base. Farther south the sway of the lavas is broken, and the sedimentaries rise to the crest.

The *San Mateo* and *Ladrones Mountains* were seen only from a distance. They are huge piles, that would rank among the lofty summits of the land, if they stood on some high plateau, instead of springing from the low valley of the Rio Grande. Their shapes are jagged and alpine, contrasting strongly with the lava forms to the west of them, and indicating a complex structure, with certainly stratified, and probably Archæan, rocks predominant.

Of the mountains that lie east of the Rio Grande, the only ones touched by our parties are the Zandia and Santa Fé, and our observations add nothing to the knowledge of their general geology. The collection of Coal-measure fossils made by Mr. Keasbey, near Santa Fé, is of value to the paleontologist, not from new forms, but from the exceptionally good condition of its specimens, which will enable an intimate and thorough knowledge of some species heretofore but partially described.

The spectacle presented by the Zandia Mountain is a peculiarly impressive one. It overlooks the Rio Grande from the east with a bold, mural front, even and straight, and little gashed by cañons. From the water to the crest the rise is 7,000 feet. Except the crest, the whole front is Archæan, but from end to end there is a cornice of Carboniferous limestone a few hundred feet thick, that by its continuity shows the whole was raised in a single unshattered mass. The eastern face is of easier slope, but is less regular. The limestone band that forms the persistent and almost level line of the crest, is the edge of an eastward dipping bed that is succeeded in that direction by superior Carboniferous and Mesozoic strata, all dipping from the mountain. But going *westward* from the Archæan belt the unaltered rocks are not found in the same order. The tough Carboniferous limestone, that holds its own so valiantly on the summit, does not appear at the west, as it should if the structure of the mountain were anticlinal; but the first strata seen after passing the valley gravels, which bury the base of the Archæan wall, are of Cretaceous age, and they dip toward, rather than from, the ridge. I conceive that the mountain is a great, but simple, monoclinal mass, bounded on the west by a profound fault, along the line of which is the river valley. The difference of level between the Carboniferous strata on the crest of the mountain and the dissevered fraction of the same strata, buried far below the Cretaceous rocks in the valley, is not less than 11,000 feet, and something greater than this must have been the throw of the fault that separated them.*

There are two general facts in regard to the geological history of the great West that deserve especial mention, for the reason that, while some of the individual instances on which they depend have long been known, it is only recently that they have been announced in such number, and with such distribution, as to dissipate all doubt that their meaning is general rather than local. The first is that the pre-Silurian stratigraphical break is as complete and as universal in the West as it is in the Eastern States and Canada. Its existence has been determined in Nebraska, Montana, Idaho, Wyoming, Colorado, Utah, Nevada, Texas, New Mexico, and Arizona, and its general features are everywhere the same. There is, first, a *wide* nonconformity, demonstrating the tilting and erosion of the Archæan beds anterior to the deposition of the Silurian. And, second, there is always, at the contact, a contrast of condition as regards metamorphism, the Silurian rocks being, usually, merely indurated, and the Archæan invariably highly metamorphic.

These two characters of the break serve to show that it represents a vast chasm of time, a chasm, the duration of which may have been greater than that of the ages which have since elapsed. A third character of the break, one that is supported by less evidence, but is negatived by none, is that the lowest of the superposed rocks are conglomerates and coarse sandstones. The lowest Paleozoic rocks are Primordial, and the basal portion of the Primordial is everywhere siliceous and of coarse texture. Where the Primordial is absent, and the Carboniferous rests directly on the Archæan, a limestone has been observed at the contact; but this is a local phenomenon, the meaning of which is that certain Archæan mountains were islands in the Silurian sea, and were afterwards covered, or more deeply submerged, by the Carboniferous sea. The conclusion to be drawn from the coarse, fragmental nature of the lower deposits is that the water which

* See J. Marcou's profile from Fort Smith, Ark., to Los Angeles, Cal., in the "Geology of North America;" the same by W. P. Blake, in Vol. III of the Pacific Railroad Reports; and Mr. Howell's section, Fig. 122 of this volume.

spread them was an encroaching ocean, rising to possess land that had long been dry. The recognized interpretation of a wide-spread sandstone is continental submergence, or, what is the same thing, an advancing coast line; and where the formation is important in depth, as well as breadth, we must suspect, at least, that the shore waves sorted, not merely the detritus which they themselves tore from cliffs of indurated rock, but other *débris*, which they found already ground, and which needed only redistribution. The Tonto sandstone of the Grand Cañon, and its equivalent in other Territories, may fairly be regarded as the coarser of the *débris* accumulated by subaerial agencies on the Archæan continent; the continent, that is, which immediately preceded the Silurian sea; and the Tonto shale and its equivalents, as the finer and lighter part of the same *debris*, sorted out by Primordial beach action, and deposited in the stiller water that followed in the wake of the advancing shore. It would, perhaps, be out of place to controvert here the familiar presentation of eastern Paleozoic history as an emergence, beginning with the *uplift* of the Laurentian highlands, but it may confidently be asserted that western Paleozoic history is the reverse of this. There was a time when Archæan highlands constituted islands in a Paleozoic Sea, but this condition was produced, not by the emergence of these islands, as the *nuclei* of a growing continent, but by the submergence of the surrounding area, and the consequent abolition of a continent. And, so far as we can judge of the remoteness of shores, and of the depth of water, by the relative importance of calcareous and earthy—soluble and insoluble—deposits, the *general* movement of land through the entire Paleozoic age was a subsidence. Of the extent of the pre-Silurian continent we know absolutely nothing. No portion of its shore is determined, nor the position of any reservoir for the reception of its waste. The break which its existence made in the sedimentary history of this portion of the world appears to be absolute; and with its extinction as a continent and division into islands by the Primordial Sea, begins our acquaintance with the early limits of land and water.

The second general fact to which attention is called is the meager representation of the Upper Silurian and Devonian formations, both in fossils and in strata. The geologists of Lieutenant Wheeler's surveys have discovered Lower Silurian fossils at twenty-two different points, and Carboniferous fossils at about seventy-five points, without finding a single specimen of intermediate age. Others have been more successful, but the showing is still meager. Of Upper Silurian localities one is announced by Dr. F. V. Hayden, near Ogden, Utah, upon the strength of a single specimen of *Halysites catenularia;* and some fossils from the Hot Creek mining district, Nevada, are referred by Prof. J. D. Whitney, "without much doubt to the Niagara limestone." Devonian fossils were discovered by Mr. H. Engelmann at Eureka and White Pine, Nevada; and another locality in Nevada, Piñon Station, has been incidentally announced as discovered by the Fortieth Parallel Survey. Dr. J. S. Newberry has received Devonian fossils from Hyko, Nevada, and Mr. R. P. Whitfield refers to the Devonian some specimens collected near the Emma mine, Utah, by Prof. S. Tenney. Trilobites, that indicate either Upper Silurian or Devonian, were announced by Prof. Whitney, from Silver Peak, Nevada, and by Mr. Engelmann, from Egan Cañon, Nevada. To compare with these ten localities of the two faunas, there are known at the west more than thirty localities of Lower Silurian fossils, and probably one hundred and fifty of Carboniferous.

Of the absolute thickness of these beds nothing can be said at present, as their limits have nowhere been definitely ascertained; but there is indication that they are thin as compared with the other Paleozoic formations. At White Pine the Devonian fauna is said by Mr. A. Hague to extend through "several hundred feet" of strata, (Geology of Fortieth Parallel, Vol. III, p. 415.) At Ophir City, Utah, the interval between the lowest Carboniferous fossils and the highest Silurian is 350 feet; and in the Grand Cañon of the Colorado it is not more than 1,000 feet. In the Santa Rita range of New Mexico it is less than 500 feet from the Carboniferous to the Cincinnati horizon. Considering the broad distribution of these localities, and that any of these enumerated spaces, which *may* be filled by middle Paleozoic rocks, may possibly be chiefly filled by higher or lower beds instead, it is safe to put the general thickness of the two formations at 400 feet, and compare this with the 2,000 feet and 3,000 feet that may be called the average depth of the Lower Silurian and Carboniferous, respectively, in the same region.

The paucity of Devonian and Upper Silurian strata is not to be explained by supposing that the region was lifted above the ocean in those ages. But a single non-conformity has been recorded within the Paleozoic, and that was seen by Mr. W. P. Jenney in Texas, near the Mexican boundary. At all of the localities enumerated in the preceding paragraph there is apparent conformity, and in the Grand Cañon so many miles of outcrop were examined that the fact of conformity is placed beyond question. In each of the localities, excepting the Santa Rita range, the rocks between the recognized Lower Silurian and the recognized Carboniferous are limestones uninterrupted by shore deposits.

Of the main divisions of the Paleozoic system, the best developed all through the great West is the Upper Carboniferous, and it is characterized by limestones. The Subcarboniferous is unknown in the southern Territories, and has been most frequently noted in Montana; but no one has at any point determined the thickness of its strata. The Devonian and Upper Silurian are known only in Nevada and the adjacent half of Utah; and the Lower Silurian, while universal in its distribution, has its greatest development along the boundary between Utah and Nevada.

CHAPTER XIX.

THE VOLCANIC REGION.

Prior to the expedition of 1873 it was not known that within the borders of Arizona and New Mexico there lies one of the great lava tracts of the world, a continuous area of volcanic products, second in magnitude in our country only to the great northwestern lava field, and fifteen times as large as the classical district of extinct volcanoes in Central France. The geologists who have accompanied the various public and private railroad surveys, have passed, on the thirty-second parallel, to the south of it, or, on the route of the thirty-fifth parallel, have missed the main body and touched only its extended arms. Messrs. Marcou and Newberry, who saw Mount Taylor and Mount San Francisco, two hundred and thirty-five miles apart, had no means of knowing that by a detour to the south they could pass from one to the other almost without walking on other rock than lava, and yet such is the fact. In the rectangle contained by parallels 32° 45′ and 34° 20′, and the meridians 107° 30′ and 110°, more than nine-tenths of the surface is of volcanic material, and from this main body there stretch two chief arms; the one going north-northeast, eighty miles to Mount Taylor, and the other west-northwest, one hundred and seventy-five miles, in Arizona, to the San Francisco group of volcanoes.* At the present stage of completion of the maps of the survey but little beyond the above general statement of the geography of the tract can be made. A general idea of its form and position may be obtained from the crude sketch in Figure 145. Its total area is more than twenty thousand, and probably nearer twenty-five thousand square miles, or about half that of the State of New York.

The lavas which go to make up this district are conveniently classed, for present purposes, in three divisions, trachyte, sanidin-dolerite, and

*The San Francisco group and the belt with which it is connected were examined in 1871, and their description will be found in Chapter VI of this volume.

basalt. The variety of trachyte most widely distributed is of light color, the characteristic hue being pale-yellow, and is usually of light weight. Imbedded crystals of feldspar are nearly always visible, and occasionally quartz, mica, and hornblende. I have rarely detected an iron oxide, but the rock is usually magnetic.

The name "sanidin-dolerite" is used, for merely temporary convenience, to designate a rock of considerable importance in Arizona, which seems to fall without our present nomenclature and deserves the careful scrutiny of the lithologist. Its habit and color are identical with those of the basaltic or doleritic family. It spreads in broad, sometimes thin sheets, and is apt to be vesicular, the bubbles, in such case, being large, and the partitions which separate them, thick. In typical specimens the matrix is dark iron-gray, and the imbedded crystals are of sanidin. It is by these sanidin crystals, which are often a half inch in diameter, that the rock is separated from dolerite. It is further distinguished by graduation, through a change of matrix, into a true trachyte. It is quite possible that when, by the determination of the constitution of its matrix, it is fully defined, it will not appear lithologically entitled to a specific appellation, but the recognition of its individuality finds geological warrant in Arizona.

Under the term "basalt" are included, after Richtofen, all the more recent basic lavas.

The invariable order of superposition is:

Basalt;

Sanidin-dolerite;

Trachyte.

In many places beds of the lower lavas have been faulted or folded by subsequent orographic disturbances, but this has not been observed (except in a single instance) in the case of basalt. The earlier basalts, however, have a considerable antiquity as measured by erosion. The trachytes have at once the greatest mass and the greatest superficial extent. The basalts are, perhaps, least in mass, but stand second in area. The main body of the district is characterized by trachyte, the arms by basalt.

Sierra Blanca has an imperfectly conical form, and, for a mountain of its magnitude, a remarkably low angle of slope. Standing alone upon a high plateau, it is a conspicuous peak, but the maximum depth of its lava is probably less than 3,000 feet. Its summit has no crater, but is composed of massive eruptions of trachyte—a variety of trachyte affiliated with, and passing into, sanidin-dolerite—and comprises a cluster of rugged knobs. From it there stretch, in every direction, long slopes of sanidin-dolerite, that appear to have flowed from side fissures, and spread in successive sheets over the plain. To the east these sheets extend for ten or fifteen miles, and to the west for thirty miles. To the south and southwest the same material is continuous for forty miles, to the borders of the San Carlos and Bonito Valley; but there were probably independent eruptions of it in that direction. Scattered over these broad sheets are rounded cinder cones, not exceeding a few hundred feet in height, and with some of them are associated *coulées* of basalt. North of the main peak is a dense cluster of these cones, associated with basalt flows, that have completely covered the sanidin-dolerite, if, as is probable, it extended there. The line of eruption, of which this cluster is the culmination, runs northwestward toward Mount San Francisco, and is the Sierra Mogollon. Many of the cones are so fresh as to have perfectly rimmed craters, but none so recent as to be bare of vegetation. The depth of the water-worn gorges upon the flanks of Sierra Blanca, attest the antiquity of its chief mass, and in some of these gorges have run streams of basalt. In the valley of the White Mountain River, near Camp Apache, are vestiges of three distinct lava flows, which entered at as many different epochs in the progress of the excavation of the valley, and have been successively cut through by the stream.

The *Natanes Plateau* is the southern continuation of the Sierra Blanca sheet of sanidin-dolerite, to which allusion has just been made. It is imperfectly tabular, narrow, and elongated in a northwest and southeast direction. Its northeast face, looking toward the South Fork of the White Mountain River, and Prieto Park, is abrupt in its general character, but is broken by numerous cañons. The southwest face, overlooking the headwaters of the San Carlos and Bonito, is an abrupt escarpment, exhibiting in section the lava-beds that constitute the plateau.

The series consist of:

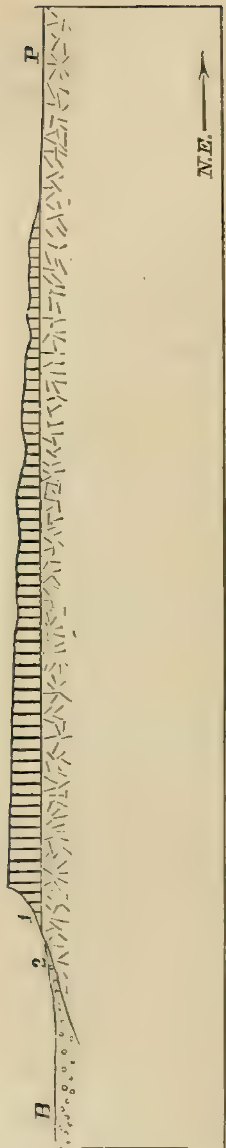


FIG. 150. Section of Natanes Plateau, Arizona. Scale, $\frac{1}{72000}$. Base-line = sea-level. 1. Sanidin-dolerite. 2. Trachyte. *B.* Bonito and San Carlos Valley. *P.* Prieto Park.

		Feet.
1. Typical sanidin-dolerite; in beds 20 to 50 feet thick, and remarkably continuous		1,000
2. Silicic trachyte, (rhyolite:)		
a. Pale pink to white, lithoid, light, somewhat brecciated	110 feet.	460
b. Dark brown, brecciated and amygdaloidal	30 feet.	
c. Purple, hard, fine-grained, brecciated; base not seen	320 feet.	
Total		1,460

The same trachyte was seen at the opposite base, and is doubtless continuous underneath, as represented in the diagram. The southwest escarpment of the plateau is not the work of erosion. Lava-topped tables, with precipitous edges determined by the erosion of softer substrata, are of frequent occurrence in the vicinity of Sierra Blanca, but their contours have a peculiar character, that is here absent. Instead of the scalloped figure, made up of convex curves, that results when erosion controls, we have a straight line, interrupted only by angular embayments, where it is intersected by water-ways; and the steepest cliffs, instead of overhanging the points of most rapid present erosion, are along the rectilinear front, which faces a broad, streamless valley. This character maintains for twenty miles, and is unquestionably due to a fault—a fault of not less than 2,000 feet throw, and which has occurred since the eruption of the sanidin-dolerite. The strike of the fault, and of the plateau, is northwest, strictly parallel to the Gila and Piñaleno ranges, which lie ten and twenty-five miles, respectively, to the southwest; and the plateau should perhaps be regarded as a member of the Basin Range System. If it is so, then it is, in longitude 110°, the most northerly member.

The valley which lies between the Gila range and the Natanes Plateau, deserves mention as an anomaly. A portion of its water, running northwestward, reaches the San Carlos, and the remainder, running southeastward, is the Bonito. The portions of the valley in which the streams flow are rugged and rocky; but the headwaters of the two are not separated by a ridge. The interval is an open plain, level and grassy, of the full width of the valley, ten or fifteen miles long, and drained at its two ends by *arroyos* leading in diametrically opposite directions. So exact is the equipoise between the erosions of the two water-channels, that the plain, which may, with no strained metaphor, be called a lake of detritus, maintains two outlets.

South-southeast from Sierra Blanca, and twenty miles distant, is a tabular mass of lava, to which the name "San Francisco" (with unfortunate duplication) has been attached. It rises a thousand feet above its base, is ten miles broad at top, and terminates rather abruptly on all sides. It was not ascended, but its *débris* to the northward was found to be basaltic, and a distant view from the south showed a horizontal bedding of its material.

From the base of this plateau the Prieto River runs southward in what appears to be an anticlinal valley of trachytic lavas. A rude and unequal bedding, discernible only when a great area is seen at once, betrays a dip in each of the adjacent ranges (ranges without known names) away from the river. In places the valley has been choked by the subsequent eruptions of basalt, and further south the structure proved too intricate to be apprehended in our brief transit; but all the valley and its bounding ridges are volcanic to the junction of the river with the Gila, except that at one place the narrow crest of a granite ridge juts from the tumultuous sea of lava. The same ridge is continued eastward to the San Francisco River at the mining town of Clifton.

Sierra Escudillo, a conspicuous rounded summit upon the common boundary of Arizona and New Mexico and due east from Sierra Blanca, was ascended by Mr. Howell and ascertained to be a massive eruption of trachyte—a cryptocrystalline variety of earthy texture, containing in its larger cavities crystals of quartz. Its summit, although showing no crater structure, has something of the form of a crater, and opens a large *chaldera* or gorge to the east. From this point eastward to Fort Tulerosa, a distance of fifty miles, the same observer found the country floored with rhyolite, horizontally bedded and overlaid in places by basalt, and the same holds for twenty-five miles to the northward, with an increase of the basaltic element. Southward, along the San Francisco River, he detected a great anticlinal fold of bedded trachytes and rhyolites, a fold of which the axis is followed by the river, while the flanks constitute the bordering mountain ranges. The trend of the axis is southwest, or at right angles to the nearest structure-lines of the Basin Ranges, but the Tulerosa mountains, which are constituted by the eastern of the inclined masses, change their trend southward for a more southerly, and finally, in their prolongation the Sierra Diablo, acquire a southeast trend. This entire range, if a mountain mass so irregular in form can be called a range, through the hundred miles of its length, exhibits only volcanic materials. Its chief components are trachytic, and basalt, which is present at many points, is, as usual, in small quantity and superposed. Eastward, to the Mimbres range, a distance of fifty miles, the same lavas are found, and with the same relative position and importance, but they form no great ranges. The country is elevated and rolling, and intersected by deep narrow gorges of the Upper Gila and its tributaries. The building of the Tulerosa and Mimbres ranges separated the basin of the Upper Gila from the lower valleys of the stream, and the way which the waters opened for their escape is a profound cañon separating the Diablo range topographically from the Tulerosa. Before the cutting of the cañon to its present depth that part of the basin which lies nearest the outlet was filled by erupted and transported materials to a great depth and a lake-like plain produced, the proportions of which can still be grasped by a bird's-eye view. It was about fifteen miles by twenty-five in size, and sloped very gently toward the outlet. By the deepening of the draining cañon, an excavation probably connected with a broad continental oscillation to which further allusion will be made in the sequel, the water-ways have been carried below the floor of this plain, and a system of narrow gorges, 500 to 1,000 feet in depth, now traverse and exhibit the filling of the valley. The filling consists of basalt, tuff, and gravel, with nearly horizontal bedding. At bottom are basalt and tuff in alternation, and above, a gravel of basalt and trachyte, in places capped by basalt sheets. In some localities basalt has run into the intersecting gorges since the beginning of their excavation. The tuff is, usually, simply a yellow sand, the volcanic origin of which would escape a casual observation. At the mouth of Diamond Creek it can be seen in a bluff 200 feet in height—a homogeneous, slightly coherent, feldspathic sand, without lamination or bedding. At one point, near the mouth of Gilita Creek, the continuity of these beds is broken by a vertical fault of a few hundred feet, affording the only instance with which I am acquainted of the occurrence of a fault or fold *demonstrably* subsequent to a basaltic eruption.

Sierra Luera, a mass of some magnitude at the northern extremity of the Mimbres range, is composed, like the Tulerosa Mountains, of trachyte and basalt. It overlooks the desert plains of San Augustin, and from its foot a low ridge of more ancient lava runs northward across the desert to Sierra del Datil. The desert is by this partitioned into two parts, the eastern of which is drained (in part at least) by the Cañada Alamosa, while the western is not known to have outlet. Across the low barrier runs a narrow water channel, now long deserted, but once carrying the surplus water of one plain to the other. An attempt was made by Lieutenant Russelland the writer to determine barometrically the direction of the descent of this channel, but without success. A faint trace of an ancient shore-line, however, on an isolated butte near by, marks the western plain as the one that has been covered by water, and records the former existence of a lake that must have been hundreds of miles in area, where now is an absolute desert. If, as the topographical results of the expedition indicate, this lake did not escape by cutting a barrier southward and draining into the San Francisco or the Gila, but lost its water by evaporation, then its record is the record of a climate far more humid than the present—a climate comparable with, and probably contemporaneous with the climate which flooded the basin of Great Salt Lake seven degrees farther to the north.

The *Sierra del Datil* and its eastern continuation, the Sierra del Oso, are the northern edge of the great trachyte district; the lavas which occur farther north are, with the exception of Mount Taylor, basaltic. At the pass near Todo el Mondo Peak the Datil range consists of yellow trachytes, of which hornblende is a constant though small factor, rudely bedded, and dipping to the south. The trend of the range is east and west, and the northern face is precipitous, exposing the edges of the trachyte beds, and showing their relation to the underlying sedimentary beds, which form the foot-hills and extend northward. The escarpment is a cliff of erosion, recording the fact that destructive agents, which the trachyte has been able to withstand, have, beyond its margin, degraded the country more than 1,000 feet. During the progress of this degradation floods of basalt have occurred, which have sufficed to arrest it locally. One of these, arising from the Datil range, a few miles east of the pass before mentioned, has run northward and preserved a spur to the range, and it is probably from this source that the lava was derived, which caps in the vicinity three detached buttes, known as the Tres Hermanos. Farther north the confluent lava from a number of vents has mantled a much larger area, and, by preserving it against denudation, given rise to the Acoma plateau, a table thirty miles long, (north to south,) with an extreme width of fifteen miles, and with an average height of more than 500 feet. Similar tables of unknown but probably smaller dimensions lie to the east of this, between it and the Rio Grande.

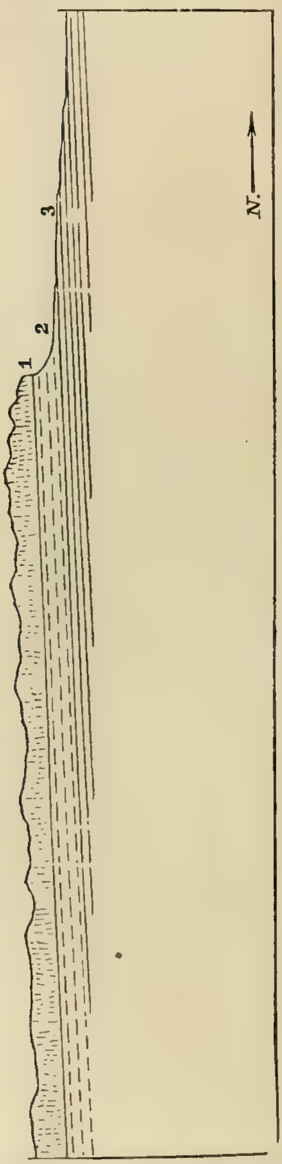


FIG. 151.—Section of Datil range, N. Mex. Scale, $\frac{1}{12000}$. Base-line = sea-level. 1, Trachyte; 2, Soft strata, (Tertiary ?); 3, Cretaceous.

From the Alamocito Mountains, a volcanic group visited by Mr. Howell, and lying west of the Datil, there extends, in a north-northeast direction, to the base of the Zuni range, a line of basaltic cones, thickly set and marking vents, the lavas from which have flooded hundreds, perhaps a thousand, of square miles. For these cones collectively I propose the name of *Marcou Buttes*, in honor of the veteran geologist who first made record of them.* They must be several hundred in number, and are comprised in a belt of moderate

* Jules Marcou: See foot-note to page 22, Geology of North America.

width and fifty miles in length. The principal lava flows have run eastward, but some remarkably long *coulées* have found their way westward. One has reached and passed the Arizona boundary, fifty miles away, following the valley of the Zuni River in the vicinity of Ojo de Benado, and causing a curious duplication of the valley, which has been deepened by later erosion on *both* sides of the lava, (Fig. 152.) Another *coulée*, which ends near the town of Zuni, is referred by Mr. Marcou to the same line of vents, and must be nearly as long. A third fills the monoclinal valley, which, along the southern base of the Zuni uplift, marks the place of the soft Triassic clays between the Carboniferous limestone of the main mountain and the Triassic sandstone of El Moro and companion cliffs. Eastward, the lava-flows cover a continuous area not less than ten miles broad, and bounded by the foot of Acoma plateau. Following the general line of drainage, they have passed, in a broad sheet, northward, around the southeast end of the Zuni range, and eastward, through ten miles of the narrow pass at the head of the San José. It is evident that the entire phenomena of the Marcou buttes are of later date than the Acoma plateau, and some of the *coulées* are certainly very recent. That which passes El Moro is almost bare of vegetation, and is too rugged in most parts to be crossed in the saddle. East and southeast of Old Fort Wingate is one still fresher, and which compels a wide detour of the road from that place to the old Spanish fort at Cebolleta spring. It is a tongue of this which passes the source of the San José, and the convolutions of the viscous torrent, preserved as perfectly as though cooled but yesterday, afford there a wonderful and impressive spectacle. At one point the lava is crossed by a stream of running water, which has not yet removed an inch of its substance.

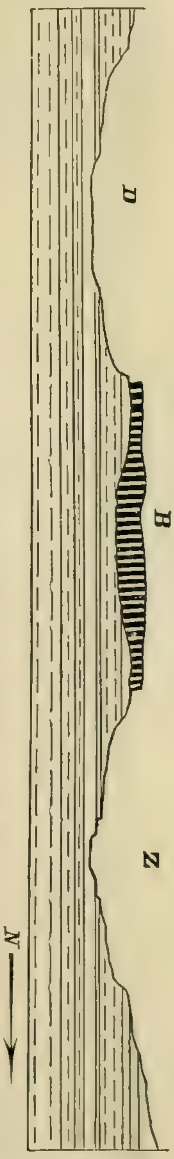


FIG. 152.—Section of Zuni Valley at Ojo de Benado. Scale, 1 inch=1,200 feet. B, Basalt, occupying ancient bed of the Zuni River; Z, Zuni River; D, Dry Valley, tributary to the Zuni.

Mount Taylor was ascended by Mr. Howell, and is described in his report. It is, in nearly every particular, the counterpart of Mount San Francisco—a massive, solitary cone of trachyte, steep-sided, and craterless, and bathed at foot by basalt. Its summit rises 1,000 feet above the timber-line, and is 4,000 feet higher than the floor of Cretaceous sandstone on which the lava rests. On all sides the general surface of the country has been lowered by an erosion which the more enduring lavas have resisted, and the peak, with its surrounding basalt sheets, is left upon a table of circumdenudation, limited in nearly every direction by steep cliffs 1,0C0 feet high. Judged by the amount of subsequent erosion, the Taylor plateau is of earlier date than the Acoma; and the Marcou lavas, which follow the present surface, are almost incomparably newer than either. The accompanying diagram gives a general expression of the relation of the three, although it does not present a section which was actually measured.

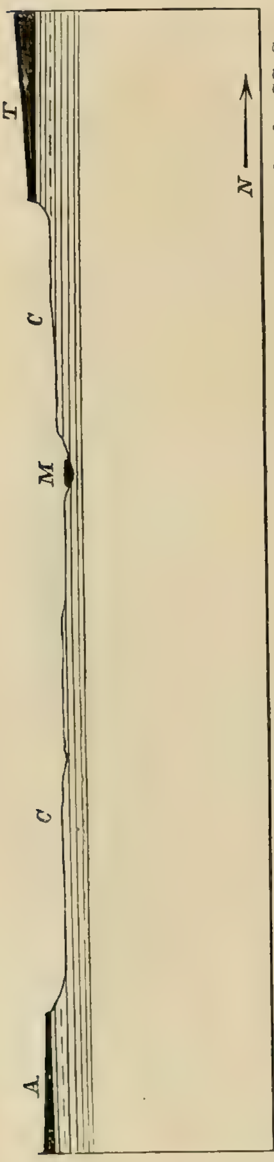


FIG. 153.—Section at the head of the San José River, New Mexico. Scale, $\frac{1}{72000}$. Base-line = sea-level. CC, Cretaceous strata; A, Basalt of Acoma plateau; T, Basalt of Taylor plateau; M, Basalt from the Marcou buttes.

About the base of the Taylor plateau are several localities of later eruption. Near Agua Azul there have run, from a single vent, a number of streams, one of which has reached so far to the southeast as nearly to meet a sheet from the Marcou region on the opposite side of the Zuni range. In the valley of the San José is another lava bed, which, measured by the subsequent lowering of the stream bed, is less recent, and others, of similar character, follow the valley of the Rio Puerco. At Covero, on the San José, is a small butte which affords an epitome of the Taylor plateau. It consists of a lava cone on a pedestal of sandstone and shale. Since its eruption a hundred feet of strata have been removed from the Covero plain, and whatever sheet of basalt surrounded the cone has been undermined and destroyed up to its very base, where the increasing thickness of the cover has retarded the work.*

Several miles to the north of this stands another butte, which represents a later stage of the process of destruction. It is not far from the foot of the Taylor plateau, and its summit is lower than the plateau edge. I conceive it to be the vestige of the flue through which an eruption reached the surface at the time of the flooding of the plateau with lava. The last contents of the flue, congealing within it, formed a pillar of trap, that opposed a stubborn resistance to the atmospheric agents which have destroyed the surrounding strata. It is a cast, in lava, of which the mold was the conduit of a volcano, now not only extinct but demolished. In offering this explanation, it is proper to state that the butte was not directly visited, but that Mr. Howell and the writer, passing it on opposite sides, arrived independently at the same interpretation. In the same way we

FIG. 154.

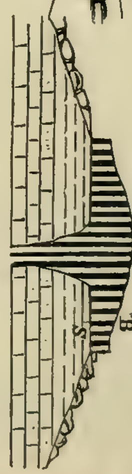


FIG. 155.

FIG. 154.—Lava butte near Covero, N. Mex.
FIG. 155.—Ideal cross-section of the same. B, Basalt; S, Cretaceous sandstone and shale.

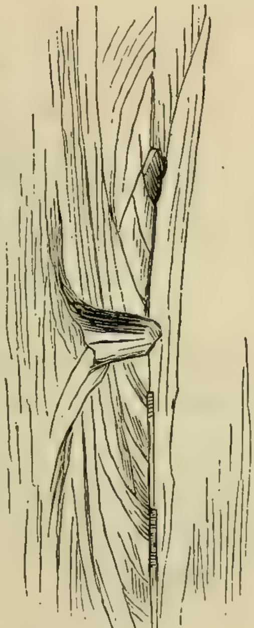


FIG. 156.

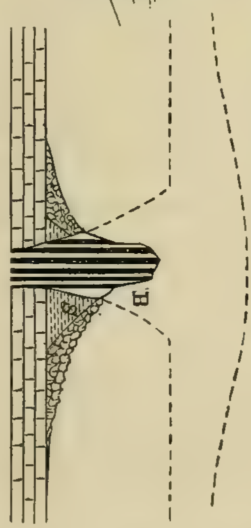


FIG. 157.

FIG. 156.—Black butte north of Covero, N. Mex.
FIG. 157.—Ideal cross-section of the same. B, Basalt; S, Cretaceous shale and sandstone. The dotted lines give a restored section of the basalt.

* Query. Did not the name *Covero* arise from the resemblance of this butte to a pot-lid?

would account for the Cabezon and other similar pinnacles on the opposite (northern) side of the Taylor plateau. Each exhibits a compact mass of lava, nearly as deep as it is broad, and possessed of neither the form nor the structure of a surface eruption. A group of the same character, the largest of which is entitled Kelly's Butte, stand in the valleys of the White Mountain River and its tributaries, west of Camp Apache, and are overlooked in similar manner by basalt-capped tables; but in this case the soft strata, by the excavation of which the flues have been laid bare, are Upper Carboniferous instead of Cretaceous.

Fig. 158.—Diagram to illustrate the manner of disintegration of basalt-capped tables.

The survival of these pinnacles, and the conservation of plateaus by basalt cloaks, depend upon the superior durability of this lava, as compared with most other rocks. Since the lava of the Acoma plateau was extruded, the surrounding country has been stripped of Cretaceous freestones and shales to a depth of more than 500 feet; but the only effect of the elemental warfare that has for the same period assailed the level lava of the plateau, has been to alleviate the rugosity of its surface, and give it a thin soil, adequate to the growth of trees, but hardly to the use of the plow. For the same reason—the endurance of the lava—the undermining of the plateau edge is a slow process; since the lava, when displaced, is not destroyed, but, lying upon the slope, still guards the substrata against atmospheric attack.

The manner in which the reduction of such cliffs is effected is worthy of note. The ordinary structure of the lava is a subprismatic, vertical cleavage, due to shrinkage in cooling; and, determined by this, a vertical face is maintained at the edge of the lava-bed. Except in extreme cases, as where its foot is worn by a stream, the slope below the lava is so gentle, that the fragments of the latter, which are successively detached, do not roll to the base, but slowly settle, without notable horizontal shifting, as the sub-

ROCK CARVED BY THE COLORADO

HELIOTYPE

jacent material is eaten away by percolating waters. Usually, the basalt does not fall away in small fragments, but parts in large masses, which, in the order of their detachment, lie upon the slope. Once separated from the parent bed, they lose somewhat their individual coherence, and become subdivided into smaller angular blocks; and these, in wave-like heaps, make up the surface of the slope. The uniformity with which these undulations succeed each other, where the underlying material is homogeneous, is not exaggerated in the illustrative diagram, (Fig. 158,) and its explanation is an illustration of the principle of rhythm in nature. As, in the process of undermining, the support is gradually removed from the edge of the lava-bed, the force exerted by the weight of the unsupported portion increases, and the point of its application is carried farther from the edge, until, finally, it suffices to overcome the coherence of the bed, and this always occurs, in a given locality, at about the same distance from the edge. Thus arises a rythmic uniformity of result, as nearly perfect, perhaps, as that of the analogous waves of the sea.

The size of these rock-waves depends chiefly on the depth of the bed from which they are derived. Behind each of them, on the slope, is a comparatively level spot, usually covered with soil, and, where the phenomena are on a grand scale, containing a fertile swale, or even a lakelet. Upon the East Fork of the White Mountain River, not far from Camp Apache, a number of such swales are under cultivation by the Indians. Other localities, at which the phenomena were observed upon a larger or smaller scale, are: at Ojo de Benado, twenty miles south of Zuni; on the headwaters of the Colorado Chiquito; at Cave Spring, between Zuni and Camp Apache; on the South Fork of the White Mountain River; at the Tres Hermanos, north of the Datil range; at Cebolleta Spring, under the Acoma plateau; and at Covero Butte.

In this brief sketch of a great lava district an endeavor has been made to render the description as general in its character as the facts at command would permit; and, with this end in view, the presentation of local details has been avoided. The field-notes, however, afford a few special facts which are worthy of record, and these, with the mention of a few others, not of volcanic order, but pertaining to the volcanic district, will complete the chapter.

Buried cinder-cone.—At the junction of the Prieto River with the Gila, their cañons are cut in bedded basalt to the depth of 1,100 feet. On the right bank of the Gila, just below the tributary, stands the ruin of a cone of scoria. It has been so unevenly excavated that the relation of its parts would not be detected by one who stood near it; but a comprehensive bird's-eye view, from the cliff of the opposite shore, revealed its character. It was formed after the compact lava had accumulated to a height somewhat above what is now the level of the water, and was founded upon it. Its height was probably 600 or 800 feet, and it appears to have been completely buried by later outpourings of lava. The erosion of the river has once more brought it to light, and displayed its structure in a rude and uneven section. At a point on the Prieto, ten miles farther north, a similar scoria was seen in the river-bluff, but its manner of occurrence was not recognized. The subsequent discovery of the cone on the Gila led to the surmise that it too might belong to a buried volcano.

Lakes.—The field of this year's exploration is not a region of lakes. A number of playas at the extreme south are inundated in periods of rain, but the list of permanent lakes is exceedingly small. Allusion has already been made to the little basins that arise incidentally in the peculiar, slow process of the demolition of some basaltic tables. Many of these hold water for a short time, and a few of them permanently; and it is supposed that in such a basin lies Apache Lake—a pond near the North Fork of the White Mountain River, that was visited and photographed by Mr. O'Sullivan. The salt lake forty miles south of Zuni, on the shore of which is gathered the salt used by many Indian tribes, was visited by Mr. Howell. He found its basin anomalous in character, and, with present data, its origin is inexplicable. The basin is 100 to 200 feet deep, and is surrounded, on nearly all sides—apparently on all sides—by horizontal Cretaceous strata, over which, for the most part—the chief exception being at the north—there is a capping of recent basalt. A cinder-cone stands at the margin of the lake, and has a crater so deep that it contains water at the lake level. If the basin be really a cup hollowed from undisturbed Cretaceous strata, it is difficult to account for.

Reservoir Lake, at the eastern base of Sierra Blanca, occupies a shallow basin, floored and walled by lava, which lies in the form it assumed in cooling, with little modification by erosion. The water is shallow, and weeds grow to the surface over nearly its whole extent. The area draining to it is small; there is no permanent inlet, and no visible outlet. That the lake is permanent, is indicated by the life it contains; and that it has a subterranean outlet, by the perfect freshness of its water. At the time of our visit, August 22, the area of water surface was about fifty acres; but its maximum is a third greater. Its maximum height is marked by a well-defined beach, three feet above the water-stage which we found. Ten feet higher is an ancient beach, that appears to have been abandoned for centuries. *Siredon*, *Limnæa*, and *Physa* were found in great abundance; and the presence of fish was announced, though none were obtained.

Prairie mounds.—The grassy plains that diversify the pine forests at the eastern base of Sierra Blanca, are dotted with a system of low mounds, in a manner independent of the nature or slope of the soil. They are usually one or two rods broad and less than a foot high, and separated by interspaces several times as broad as themselves. There is frequently a notable difference of soil texture between the level ground and the mound, the mound being, in some instances, the more gravelly, and in others, the less so; and there is some difference of quality, that the eye detects only in its effect upon vegetation. The grass upon the mounds is distinguished by a ranker growth, and, as we saw it in August, by a deeper green. Viewed from a commanding position, the effect is peculiarly beautiful, the green spots dappling the plain like the figure of a carpet. These are not considered geological features, and they are mentioned in this place only to distinguish them from the prairie mounds of California, which, according to Professor Le Conte, are phenomena of erosion.* There is little question that they are the vestiges of hummocks thrown up by prairie dogs, or other burrowing animals. The manner of their distribution first suggested this

* American Journal of Science and Arts, April, 1874, p. 365.

explanation, and it appears to accord with all the observed facts. The subsoil, brought to the surface in the excavation of the burrows, produces the superficial difference of texture; and the looser aggregation of the earth, together, perhaps, with the presence of animal manure, gives the grass a stronger growth. None of the mounds are inhabited, and no burrows, or other sign of recent occupation, were seen. I am acquainted with no colonies of prairie dogs at such an altitude—7,000 feet—and, if the mounds are the work of that species, they may point to a climate, in very recent time, of even greater warmth and aridity than the present. Some of the mounds were seen upon, and on the slope below, the oldest of the Reservoir Lake beaches, showing that the race which built them has given way since the diminution of the lake.

The Gila conglomerate.—A system of valley beds, of which a conglomerate is the characteristic member, are exhibited in section along the gorges of the Upper Gila and its tributaries. The bowlders of the conglomerate are of local origin, and their derivation from particular mountain flanks is often indicated by the slopes of the beds. Its cement is calcareous. Interbedded with it are layers of slightly coherent sand, and of trass, and sheets of basalt; the latter, in some cliffs, predominating over the conglomerate. One thousand feet of the beds are frequently exposed, and the maximum exposure on the Prieto is probably 1,500 feet. They have been seen at so many points, by Mr. Howell and myself, that their distribution can be given in general terms. Beginning at the mouth of the Bonito, below which point their distinctive characters are lost, they follow the Gila for more than one hundred miles toward its source, being last seen a little above the mouth of the Gilita. On the San Francisco they extend eighty miles; on the Prieto, ten; and on the Bonito, fifteen. Where the Gila intersects the troughs of the Basin Range system, as it does north of Ralston, the conglomerate is continuous with the gravels which occupy the troughs, and floor the desert plains. Below the Bonito it merges insensibly with the detritus of Pueblo Viejo Desert. It is, indeed, one of the "quaternary gravels" of the desert interior, and is distinguished from its family only by the fact that the water-courses which cross it are sinking themselves into it and destroying it, instead of adding to its depth. It is in its relation to the rivers that it is chiefly interesting; in the accumulation, and subsequent excavation of the beds, there is recorded a reversal of conditions, that may have a broad meaning. The base of the series in its deepest parts is not exposed, and if we go back to the beginning of its deposition, we have to picture the valleys as deeper than they are revealed at present.* During the accumulation the altitude of the drainage lines steadily increased—their altitude, that is, in relation to the surrounding mountains—and it attained its maximum when the top of the conglomerate was laid; since which time it has as steadily diminished. There is no difficulty in comprehending the present action, for it is the usual habit of swift-flowing streams to cut their channels deeper; but to account for the period of accumulation there must be assumed some condition that has ceased to exist. Such a condition might be, either a barrier, somewhere below the region in question, determining the discharge of the water at a higher level than at present, or it might be a general depression of the region, in virtue of which the ocean (now three hundred miles away) became a virtual barrier. With either hypothesis, a change of more than 1,000 feet must be considered.

* The postulate is not absolutely tenable, since the corrugation by which troughs are produced, and the filling of those troughs by detritus, go forward simultaneously; but it introduces no fallacy in its present use.

CHAPTER XX.

THE PLATEAU REGION.

Since the Plateau region differs from the Range region only in the degree of disturbance, the determination of their common boundary is necessarily to some extent arbitrary, and the difficulties in the way of conciseness are increased in Southern New Mexico by the great lava cloak, which conceals for many miles the structure of the buried strata. But, as the only object for the drawing of the boundary is the graphic presentation of the general distribution of certain structural features, it need not be regretted that the position of the line is indefinite at points, where, in nature, there is a transition from one grade of structure to the other. In 1871 the boundary was traced in Arizona from Music Mountain southeastward to the Natanes Butte, passing to the north of the Black Hills and Sierra Ancha. From Natanes Butte I have drawn it eastward, past the south edge of the San Francisco plateau, and then, east-northeast, over the uncommunicative lava, to the Sierra del Oso. Thence it passes between the Ladron range and the Lucera plateau, to the Rio Grande Valley, and follows that northward to the Nacimiento Mountains. The general contour of the southern part of the boundary is shown in Fig. 145. The portion of the Plateau province included in Arizona has an area of forty-five thousand square miles; and that in New Mexico, of twenty-five thousand. Of Utah it includes fifty thousand, and of Colorado, perhaps, twenty thousand miles; making a total extent of one hundred and forty thousand miles.

Of the volcanic mountains, noticed in the last chapter, the San Francisco group, the Mogollon, Blanca, Escudillo, Alamocito, Datil, Oso, and Taylor, and the Marcou Buttes, are based on the level strata of the plateaus.

The plateaus explored by Dr. Loew and the writer in 1873 are built of Tertiary, Cretaceous, Triassic, and Carboniferous rocks. The presence of Tertiary strata was demonstrated by fossils at but a single locality, and their horizontal and vertical extent are unknown. Dr. Loew, who visited the locality, says: "A mile and a half north of Ildefonso, in some hills of alluvial drift, fossil bones of several mammals were found. These bones were much broken and scattered, leaving no doubt that this was not the original locality where the petrifaction took place." A collection had previously been obtained from the same place by Gov. W. F. M. Arny, and was, by his gift, added to that of the expedition. The joint collection has been placed in the hands of Prof. O. C. Marsh for study; and, in a preliminary examination, he was able to recognize the presence of *Mastodon*, *Rhinoceros*, *Equus*, and *Procamelus*. He pronounces the fauna Pliocene, the equivalent of the Pliocene of the Niobrara region. The bones are well preserved, and the fact that they are not worn by rolling, shows that, if not found in the place of original deposition, they, at least, had not been far removed. The adherent matrix is a coarse sand, closely resembling, according to Professor Marsh, the formation in which the same fauna occurs on the Plains. Among the more interesting of the specimens are a large head of *Rhinoceros*, probably referable to no known species, and a pair of *Mastodon* tusks, characterized by a ribbon of enamel upon one side only, in place of the usual complete envelopment.

The Cretaceous is in area the chief of the formations. Underlying the lavas of the Taylor and Acoma plateaus, its exposure forms a belt around each of them. Overlying the Trias and Carboniferous, which appear in the Zuni uplift, its exposure encircles that also, except where covered by lava. In like manner it flanks the Nacimiento uplift on the west and south. North of the Zuni range and the Taylor plateau, and west of the Nacimiento range, it covers the country to the limit of our survey. South of the Zuni range and Taylor plateau, and thence to the great lava field, it is the only sedimentary formation, except the Trias, by which its continuity is interrupted at two points. West of the Zuni range it forms a belt fifteen miles wide, and with a north-northwest trend—a flat synclinal, limited east and west by the Nutria and Defiance folds. Going due east from the Taylor plateau to the Rio Grande, Mr. Howell found the Cretaceous only, but, both north and south of that line, it yields in part to the Trias. Three islands of Cretaceous were discovered among the basalts of the Mogollon Mountains—

one at Mineral Spring on the road from Zuni to Camp Apache, a second five miles farther west, and a third sixteen miles north of Camp Apache. Not far from the last is a coal opening that is presumably referable to the same formation. The Cretaceous rocks are an alternating series of sandstones and shales, in which the sandstones are yellow, and the shales gray and yellow, with bituminous layers and coal. In the upper part of the series, the sandstones incline to green, and are soft; in the lower, they incline to orange, are harder, and form heavier beds. The coal occurs through the entire series, but, so far as is known, is of economic importance only near the middle. None of the sandstones are known to continue over large areas, but the lower are more persistent than the upper. With the utmost variability of the individual beds, there is combined a marked uniformity of the series as a whole. Characterized by sands, by coal, by rapid alternations, by ripple-marks, and by oysters, it is evidently an off-shore deposit. Lithologically it is a single series, offering no criteria for subdivision. In its entire depth of 2,000 feet, fossil animals have been found, in this particular field, only in the lower 850 feet. The highest fossil horizon, near Stinking Spring, yielded *Inoceramus problematicus* and *Ammonites*. The most prolific localities are near the base. From one of these, a point at the western base of the Acoma plateau, near Cebolleta Spring, were obtained *Ammonites*, (of two species,) *Turritella*, *Gyrodes*, *Anchura*, *Cardium*, *Ostræa*, and *Lingula*, with vertebræ and teeth of sharks, (*Otodus* and *Lamna Texana*.) The same horizon at the Mesa Redonda, near Quelites, New Mexico, yielded, besides a portion of the above, *Cucullæa*, *Gryphæa*, and *Pinna*. A locality sixteen miles north of Camp Apache, and probably near the base of the series, afforded *Ammonites*, *Gyrodes*, *Anchura*, *Scalaria?*, *Cardium*, *Avicula*, and *Inoceramus;* and another twenty-five miles farther north, gave *Anchura?*, *Camptonectes*, *Pinna*, and *Gryphæa*.

In the local sections, which will be found a few paragraphs beyond, the top of the uniform lithological series, to which, with our present knowledge, we must apply the title Cretaceous, is found only in the first. At that locality the familiar Cretaceous characters cease, in the ascending series, with number 3, (section A,) and the upper 1,000 feet of strata are so distinct in character as to permit an easy stratigraphical discrimination.

The superior beds (No. 2) were seen only at this point, and are of so perishable a nature that they would have disappeared but for their volcanic shield. The trachyte that covers them must have been spread before they were greatly lifted above water. They afforded no fossils, and showed no stratum that suggested the possibility that such would be yielded to careful search. The only beds with which I am familiar that resemble them in lithological character are the barren Jurassic clays and sands of Northern Arizona, but they lack the visible gypsum of the Jurassic. They rest, with seeming conformity, upon the Cretaceous. The base of the Cretaceous is included in each of the sections, and there is little uncertainty as to its position. The barren, bright-hued sandstones and clays, that are, by common consent, called Triassic, are known in Utah to be separated from the Cretaceous by strata with Jurassic fossils, and Mr. Howell, tracing the beds by almost unbroken exposures, from Utah to Fort Wingate in New Mexico, has demonstrated the continuity of the Cretaceous and Triassic, and the thinning and disappearance of the Jurassic. His determination defines the base of the Cretaceous as at, or very near, the great lithological change from the heavy homogeneous sandstones to the variable lignitiferous series, and proves—what Dr. Newberry surmised—that the abrupt transition marked a historical break. The lowest Cretaceous bed is, in section A, No. 11; in B, No. 7; in C, No. 8 or No. 10; in D, No. 6; and in E, No. 4.

The best display of coal seen by the writer is near Stinking Spring, twelve miles west of Fort Wingate. It includes four seams of workable thickness, (4 to 5½ feet,) three of which are probably of good quality, (1 *n*, 1 *p*, and 1 *ff*, of section B.) Their position is not here the most desirable for working, as they dip at 70°, and are probably deteriorated by leaching to a considerable depth; but, to the north, south, and west, the same horizon must reach the surface with a gentle inclination, and intelligent search will readily discover favorable localities. The Cretaceous region is characterized by innumerable *mesas*, or tables, the tops of which are sandstone, and the bases, shale. The coal beds are included in the shale, and are usually concealed by *débris*, unless lying close to the sandstone. Hardly an escarpment can be examined without the detection of thin layers of coal, and any of these may develop, at some point, to economic thickness. Whenever there shall be a market for it, coal will be developed in all the indicated areas of Cretaceous outcrop.

About the Zuni range the Trias forms a belt, inside the Cretaceous, and without the Carboniferous, (except where covered by lavas,) and upon the flanks of the Nacimiento range it holds the same position. Southeast of the Taylor plateau it appears in the valley of the San José, as described by Messrs. Marcou and Newberry, and the same exposure extends south and west to the Indian town of Acoma. It is possible, also, that an outcrop in the valley which lies east of the Tres Hermanos and of the southern end of the Acoma plateau, is connected with the same. West of the Marcou Buttes, Mr. Howell found a belt, with east-west trend, passing under the Cretaceous at the north, and separated from it at the south by a lava-stream, and probably a fault. From Fort Defiance, southward and westward; from Zuni Village, westward; and westward from the lower course of the Zuni River, there stretch tracts of Trias, that are probably confluent with each other, and with the belt through which the Colorado Chiquito flows, which is overlooked by the Moquis towns, and which was followed by Mr. Howell from Utah.

Lithologically the "Trias" is a definite system, sharply distinguished from the Cretaceous above, and the Carboniferous below. In Southern Utah it is not sharply distinguished from the superior Jurassic, and, if our stratigraphic nomenclature had been first instituted there, the term "Trias" would probably not have received its provisional use; but, in the absence of fossils, there is no reason to depart from the practice of Messrs. Marcou and Newberry. With reference to the subdivisions there has arisen a variety of nomenclature, dependent on the localities at which different observers have first analyzed the series. Mr. Marcou, who saw it on the Plains east of the Rocky Mountains, made three divisions, to correspond with European formations, as follows:

		Feet.
Upper division, (Variegated Marls.)	500 feet of sandy calcareous clay of brilliant colors. 1,000 feet of massive, white gray sandstone.	1,500
Middle division, (Muschelkalk.)—Red clay, with gypsum, salt, and magnesian limestone		1,500
Lower division, (Bunter sandstein.)—Red sandstone, over red and blue clay		2–3,000
Total		5–6,000

Dr. Newberry, making his examination in Arizona, between the Colorado Chiquito and the Moquis villages, gives:

	Feet.
1. Variegated marl group.—Variegated marls with magnesian limestone and gypsum. Fossil wood near base	1,500
2. Saliferous sandstones, or Salt group.—Red sandstones, shales, and conglomerates	*500
Total	2,000

Of this the section observed in Southern Utah is almost the reverse:

		Feet.
1.	Cream and red, massive sandstone	1,700
2.	Variegated clays, with gypsum	450
	Conglomerate, (the Shinarump of Powell)	50
	Variegated clays	400
	Total	2,600

It is impossible now, and it may never be possible, to find west of the mountains—among the plateaus, that is—the representatives of the several beds of Marcou's section. The necessary full exposures are too far separated, and the transformations of these protean beds are too rapid. But within the Plateau region there are better facilities, and the Utah series is connected with that of the Colorado Chiquito by a continuous outcrop. This outcrop has been followed, through the greater part of its extent, by Mr. Howell, and his observations show that the upper portion of Dr. Newberry's variegated marls is the equivalent of the upper massive sandstone of the Utah section. The beds which Dr. Newberry describes as "red, blue, green, orange, purple, white, brown, lilac, and yellow marls, interstratified with bands of purple, bluish white or mottled magnesian limestone," are, in Utah, one hundred miles farther north, massive, cross-laminated, cream, buff, and red sandstones, with a calcareous cement, and closely resembling the Waverly sandstone as quarried at Amherst, Ohio. The transition is gradual, and there is no reason to doubt the continuity and synchrony of the whole. Dr. Newberry remarks that in some localities the marls "are sufficiently indurated to deserve the name of soft calcareous sandstones;" and the writer, who saw the beds first as sandstones, recorded in his note-

* The thickness of the salt group is not explicitly stated, but is implied. See pp. 74, 77, and 101 of the Geology of the Ives Expedition.

books their incoherent and argillaceous character in certain remote localities. In Western and Central New Mexico, the series is, as a rule, better comparable with its Utah development. As will be seen in the local sections, it is arenaceous at top and argillaceous below, so that Dr. Newberry's titles of "variegated marls" and "saliferous sandstones" are inapplicable; but the sandstone is not persistently firm, as in Utah, and in the most southerly locality it is replaced by a clay. The basal clays are interrupted by a number of thin layers of sandstone, among which the Shinarump conglomerate cannot be discriminated. There is no indication that the lower beds are saliferous. The waters of Nutria, Bear, and Wingate Springs, and of Agua Azul, which rise from it, are fresh; and Stinking Spring, (Salt Spring of Newberry's report,) which affords brackish water in the same neighborhood, rises from the base of the Cretaceous series. At Acoma there is apparently a gradation in point of coherence in the upper sandstone within a single field of view. I say "apparently" because I had not time to ascertain that there was or was not a change of texture, and saw only a progressive change in the character of a long cliff, such a change as would naturally result from a change in the constitution of its material. In the diagram (Fig. 159) the profile at the left is that of the section which was measured, (see section E *sub.*,) and exhibits Cretaceous strata between the points 1 and 4 and Triassic below. The continuity of 1,1,1,1, and *b,b,b,b*, could be traced by their colors as well as by their forms. The right-hand section presents the character of the slope at a distance of six or eight miles, and the others at intermediate points.

FIG. 159.—Cliff profiles near Acoma, N. Mex.

In the subjoined local sections the Triassic rocks are completely displayed only in those of Bear Spring and Nutria. They comprise, in Section A, Nos. 12 to 15, inclusive; in B, No. 8; in C, Nos. 9 to 14; in D, Nos. 7 to 11; and in E, No. 5.

In the sections C and D a few feet of Carboniferous limestone are included at the bottom. The two localities are at northern and western bases of the Zuni range and embody the rocks of its foot-hills. The range itself consists of Carboniferous strata, with a general anticlinal arrangement, along the axis of which is revealed a core of crystalline rocks. Whether Silurian strata appear between the latter and the Carboniferous is not known. Mr. Howell estimates the Paleozoic strata at a little more than 1,000 feet, of which the lower half is siliceous and the upper calcareous. The upper limestones abound with Carboniferous fossils, but the life of the lower beds is unknown. If they are Silurian, then the Carboniferous series is not only far thinner than in Arizona, but thinner even than on the Zandia Mountains, where Mr. Marcou places its average at 700 feet. There is, nevertheless, a strong suggestion, in the presence of a vitreous sandstone, that the lower portion of the series is Lower Silurian. Carboniferous rocks were also observed by Dr. Loew in the Nacimiento Mountains, where the chief characters of the Zuni range are repeated. In Arizona a considerable portion of the plateau to which the title of Mogollon range was given by early geographers, is floored by Upper Carboniferous strata. This region was traversed by Dr. Loew on two lines, and, when adequate maps shall have been constructed, his data, combined with those previously gathered by Dr. Newberry and Mr. Marvine, will give an idea of the form of what must be an extended Carboniferous area.

Local stratigraphical sections in New Mexico.

Section A.

From the crest of the Datil range to the valley east of the Tres Hermanos buttes. Beds 1 to 2 and 8 to 14 were measured by aneroid barometer, the remainder estimated.

	Feet.
1. Trachyte	800
2. Red clays, alternating with pale, incoherent sandstone	1,000
3. Shale, sandstone, and lignite; a series of rapidly alternating sandstone and shale-beds, the sandstone of green-yellow color and soft, and the shale yellow and gray, with fillets of lignite	750
4. Massive yellow sandstone	75
5. Shaly yellow sandstone and gray shale	400
6. Massive yellow sandstone	75

		Feet.
7.	Shaly yellow sandstone and gray shale	300
8.	Massive yellow sandstone, [*Inoceramus*]	75
9.	Gray shale with band of limestone, [*Ostræa*]	125
10.	Soft orange sandstone	20
11.	Gray, green, and blue, argillaceous shale	100
12.	Conglomerate of metamorphic pebbles	10
13.	Red clay	200
14.	Purple-brown sandstone, sectile and laminated	5
15.	Purple clay, base not seen	50
	Total	3,985

Section B.

At Stinking Spring, twelve miles west of Fort Wingate.

1. Shale, yellow sandstone, and coal:

			Feet.
a.	Yellow sandstone	80 feet.	448½
b.	Gray clay shale	25 feet.	
c.	Yellow sandy shale, with thin band of limestone	35 feet.	
d.	Argillaceous and bituminous shale	15 feet.	
e.	*Coal*	1 foot.	
f.	Bituminous shale	1 foot.	
g.	Soft, yellow sandstone and shale	30 feet.	
h.	Argillaceous and bituminous shale	15 feet.	
i.	*Coal*	1½ feet.	
j.	Bituminous shale	1 foot.	
k.	Soft, green shale	8 feet.	
l.	Soft, yellow sandstone	30 feet.	
m.	Gray clay shale	20 feet.	
n.	*Coal*	4 feet.	
o.	Bituminous shale	5 feet.	
p.	*Coal*	5½ feet.	
q.	Clay shale	1 foot.	
r.	*Coal*	2 feet.	
s.	Gray shale	10 feet.	
t.	*Coal*	2 feet.	
u.	Gray shale	1 foot.	
v.	Red sandstone	25 feet.	
w.	Yellow clay shale, with some coal	40 feet.	
x.	Yellow sandstone and sandy shale	50 feet.	
y.	Clay shale, with thin coal seam	8 feet.	
z.	Yellow sandstone	3 feet.	
aa.	Bituminous clay shale	10 feet.	
bb.	*Impure coal*	4½ feet.	
cc.	Pale green clay shale	15 feet.	

		Feet.
dd. Red sandstone	2 feet.	251½
ee. Soft, yellow and gray shale	40 feet.	
ff. *Coal*	4½ feet.	
gg. Clay shale	5 feet.	
hh. Coarse, red sandstone	25 feet.	
ii. Yellow sandstone shale	20 feet.	
jj. Gray and yellow clay shale	25 feet.	
kk. Yellow sandstone	30 feet.	
ll. Soft, yellow, arenaceous shale	100 feet.	
2. Massive orange sandstone		200
3. Soft gray shale, [*Ammonites* and *Inoceramus*]		100
4. Unseen; shale?		500
5. Massive, yellow sandstone		50
6. Yellow, sandy shale		100
7. Massive, yellow sandstone, with some cross-bedding; a fillet of bituminous shale at base, [*Gryphæa*]		100
8. Massive, cross-bedded sandstone:		
a. Soft; variegated with green, sienna, and ocher yellow	400 feet.	1,000
b. Pale red to white	500 feet.	
c. Brick red; base not seen	100 feet.	
Total		2,750

SECTION C.

From Bear Spring, (*Ojo del Oso,*) near Fort Wingatē, northward. The lowest beds are at Bear Spring, and the highest eight miles to the north.

		Feet.
1. Massive, red and orange sandstone		70
2. Arenaceous shale		20
3. Massive, yellow sandstone		40
4. Soft, arenaceous and argillaceous shale		25
5. Shaly yellow sandstone, changing to		90
6. Bituminous and clay shales, [*Gryphæa*]		380
7. Massive, yellow sandstone, with ribbons of coal		40
8. Shale, sandstone, and coal:		
a. *Coal*	1 foot.	30
b. Bituminous and clay shale	8 feet.	
c. Coarse, yellow sandstone	6 feet.	
d. *Coal*	1 foot.	
e. Soft, blue shale	8 feet.	
f. Yellow sandstone	6 feet.	
9. Purple to white conglomerate		80
10. Pink and variegated, arenaceous shales		30

		Feet.
11. Massive, cross-bedded sandstone:		
a. Pale purple; white at top	90 feet.	
b. Pale pink; friable	80 feet.	
c. Cream-colored; incoherent	120 feet.	712
d. Red and white, banded	200 feet.	
e. Crystalline limestone	2 feet.	
f. Red and compact; with white band near base	220 feet.	
12. Red and variegated shales		100
13. Purplish limestone		6
14. Variegated gypsiferous clays, with beds of sandstone:		
a. Variegated clays	450 feet.	
b. Pale purple cross-bedded sandstone	15 feet.	
c. Variegated clays	150 feet.	
d. Coarse white sandstone	25 feet.	
e. Purple and white clays	125 feet.	975
f. Red and purple clays	50 feet.	
g. Coarse brown conglomerate	10 feet.	
h. Red, purple, and white clays	90 feet.	
i. Gray sectile sandstone	10 feet.	
j. Red, purple, and white clays	50 feet.	
15. Calcareous chert		25
16. Massive gray limestone, [*Productus semireticulatus*, *Bellerophon*, *Bakevellia*, *Schizodus*, *Aviculopecten*]		40
17. Calcareous, cross-laminated sandstone; gray on fracture, but red in escarpment; base not seen		75
Total		2,738

SECTION D.

Near Nutria Pueblo. The strata are upturned at the western base of the Zuni range.

	Feet.
1. Yellow sandstone	25
2. Unseen; shale?	50
3. Massive, orange sandstone	20
4. Soft rocks, unseen, (this is the position of the main coal series)	600
5. Massive, red-brown sandstone	20
6. Clay shale, with thin coal, changing below to red, arenaceous shale	110
7. Massive, cross-bedded sandstone, red and white, and weathering brown	535
8. Conglomerate	10
9. Red, arenaceous shale	240
10. Purple, brecciated limestone	2

		Feet.
11. Variegated clays, with sandstone beds:		
a. Purple and variegated clays	800 feet.	1,585
b. Pale red, sectile sandstone	5 feet.	
c. Red clay	70 feet.	
d. Pale red, sectile sandstone	10 feet.	
e. Variegated clays	700 feet.	
12. Massive limestone, [*Athyris subtilita*, *Productus*, *Euomphalus*, *Nautilus*, *Aviculopecten*, *Archæocidaris*]		55
Total		3,252

The variegated clays (11) have apparently a greater depth at this point than at Fort Wingate, (section C, bed 14,) and the difference (1,585 less 975 feet) is so great as to suggest that it is apparent only, and arises from the imperfect facilities for measurement. The strata have in each case, but more especially at Nutria, a considerable inclination, and the position of the clays is marked topographically by a broad flat valley, interrupted only by the ridges that are produced by the interbedded sandstones. Measurements were made horizontally by pacing, and the dip was measured at each of these hard beds; and from these data the thickness of the series was computed. It is possible that the clays, which are here laid bare and relieved from the pressure of superincumbent beds, have, at the surface, expanded, after the manner of the "creeping" of underclays in coal-mines, and, by their expanse, tilted the included sandstones, and thus vitiated the only data available for measurement. The accompanying diagram shows the relations of the beds at Nutria.

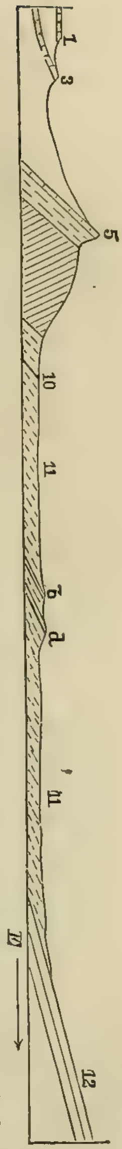


FIG. 160.—Diagram to show dip of strata near Nutria, N. Mex. The letters and figures refer to stratigraphical section D.

SECTION E.

Near the pueblo of Acoma.

	Feet.
1. Massive, cross-bedded sandstone; yellow, stained superficially with red and brown	40
2. Gray and yellow, gypsiferous shale	260
3. Sandstone with fucoids	5
4. Gray and yellow shale, with a foot of coal	15

		Feet.
5. Massive, friable, cross-bedded sandstone:		
a. Pink, weathering brown, soft	30 feet.	580
b. Yellow and firm; pebbly and banded with white near top	250 feet.	
c. Soft; olive-green, with brown band 100 feet below the top	250 feet.	
d. Soft; red	150 feet.	
Total		900

Some general laws of erosion are well illustrated by the region under consideration. The conditions under which meteoric agencies produce the sculptured forms of land are complex, and in special cases difficult of analysis, but there are two general principles everywhere manifested. The first is, that soft material is worn more rapidly than hard, and the second, that high points are worn more rapidly than low—or, more strictly, that steep acclivities suffer more than gentle. The tendency of the first principle is to variety of surface; of the second, to uniformity; and the two are complementary. Insomuch as the Cretaceous areas are, in a general sense, plains, with no conspicuous elevation, and insomuch as the series consists of a quick alternation of soft sandstones and softer shales, the areas are, in detail, variegated with low sandstone tables. Moreover, where the series is covered by lava, the vastly superior hardness of the lava has enabled it to protect the strata, and given rise to such "hills of circumdenudation" as the Taylor and Acoma plateaus. These facts have resulted in obedience to the law of hardness, but it has, at the same time, followed from the law of altitude, that the areas not protected by the lava have been denuded *evenly*, instead of being deeply scored along the chief lines of drainage. The Cretaceous field southwest of the Acoma plateau has been reduced nearly or perhaps quite a thousand feet since the eruption of the Acoma lava, but it has been reduced so evenly, that its surface is now as near level as that upon which the Acoma lava was spread. And the same may be said of the field north of the Taylor plateau, which has been degraded even a greater amount. Standing upon the edge of one of these tables, and viewing a broad stretch of country, from the entire face of which it is demonstrated that a thousand feet of rock have been razed since it has been notably modified by any movement of orographic corrugation, one can appreciate the fact that erosion is the great agent in the production

PERCHED ROCK.

ROCKER CREEK. ARIZONA

of all details of surface, and that the disposition and hardness of rocks are only modifying conditions.

The antagonism and the concurrent result of the two laws of erosion are illustrated by the Zuni range, which is an elongated quaquaversal uplift within the Cretaceous area. From its sides and summit the soft Mesozoic strata have been removed, exposing the tough Paleozoic rocks, and even the Archæan. If the law of hardness only had been potent, the Cretaceous strata would still cover the arch, and the range would rise 6,000 instead of 3,000 feet above its base; if only the law of altitude were obeyed, (which would have been the case if the Paleozoic and Archæan rocks were no harder than the Mesozoic,) there would be no mountain at all, and the uplift would be marked only by concentric annular outcrops of the several strata. There could hardly be found a simpler natural illustration of these familiar principles.

The site of the village of Acoma presents a curious result of erosion. The streams flowing eastward from the base of the Acoma plateau have first opened channels in the Cretaceous, and, farther east, in the Triassic strata. At the point of their descent, where they traverse the clays of the Lower Trias, the yielding of these clays has undermined the overlying sandstones, which are there massive, but rather friable, and opened broad valleys. At the same point the water-courses approach each other, but they recede again as they continue eastward. The lateral extension of the valleys has proceeded so far as to remove, for several miles, the barrier of Upper Trias sandstone, producing, in effect, a single, high-walled valley, traversed, in the wet season, by two streams, which do not unite, but leave it by separate outlets. The removal of the sandstone partition has not been completely effected, but it has been broken through at a number of places, and the intervening fragments, which still stand, are precipitous pinnacles, as difficult of access as Pompey's Pillar. The most westerly of them, and one which is not yet quite isolated, but, by a narrow neck, is joined as a peninsula to the Triassic escarpment, has been chosen as the site of the Indian village. Upon every side except one the spot is surrounded by sheer precipices 200 feet in height, so that for defensive purposes there is need to guard but that single side. At the neck of the peninsula, communication is afforded with the valley below by a natural pathway, no less curious than the citadel itself. The soil of the valley is sand, freed by the destruction of the sandstone; and a portion of it is so dry as to be shifted by the wind. In favored places it accumulates in dunes or drifts, and one of these drifts, 150 feet high, reaches to a point on the neck, from which the summit can be gained.* The upper surface of the peninsula is naturally very uneven, but a portion of it has been partially leveled for the village, and one of the cavities has been improved so as to constitute a cistern, the water of which may serve in time of siege.

Folds.—If the reader will refer to the first chapter of this volume, he will find there a description and discussion of the folds and faults of the Plateau region, as observed by the writer in Southern Utah and the adjacent border of Arizona; and additional material by Mr. Howell will be found in the ninth chapter. What I have to add, as the result of my examinations in 1873, is a mere supplementary contribution of facts,—facts which do not differ in kind from those that have already been adduced, and which, partly from the nature of the country in which they were noted, are less susceptible of generalization than those gathered in the previous year. Only a single fold—the Nutria—was traced for any considerable number of miles, and observations upon others were so scatterred, that the *system* to which they belong was not shown. But of a class of facts so novel it will be profitable to record even isolated examples, and a description of each locality will be given, for the benefit of future investigators in the same field.

The Tres Hermanos buttes stand south of the Acoma plateau and north of the Datil range. Between them and the latter there runs eastward a water-course tributary to Tres Huerfanos Creek. The diagram, Figure 161, represents the structure of the Cretaceous and Triassic strata, as shown on the left bank of the water-course. The proportions were not submitted to measurement, but were estimated and sketched, by the writer from the saddle. A bird's-eye view was afterward obtained from the summit of the tallest butte, and the course of the disturbance traced. From the butte it

*This sand-drift is mentioned by Lieut. J. W. Abert, in his report of "Examinations of New Mexico. House Ex. Doc. No. 41. 33d Congress, 1st session.

runs tén miles northwest to the Acoma plateau, beneath which it disappears. In the opposite direction it could be traced but three miles, its course being directed toward the Sierra del Oso. To the west, for ten miles at least, there is no similar disturbance; to the east, a mantle of basalt prevented observation. The throw of the fold—the difference of level, that is, between portions of the same stratum on opposite sides of the fold—is between 1,500 and 2,000 feet, and is to the southwest. The fold is older than the basalt of the vicinity. The eroded edges of the strata upturned by it support the lava caps of the Hermanos buttes and of the Acoma plateau. The level line of the Acoma lava, shows that the folding has not continued since the eruption, and the antiquity of the eruption is measured by a general degradation of the country of more than 500 feet. The course of the fold, if produced, would carry it to the Nutria fold at Inscription Rock, and it accords with that in the direction of its throw; but these coincidences will not suffice to establish the identity of folds fifty miles apart.

FIG. 161.—Section of monoclinal fold on Tres Huerfanos Creek, New Mexico. Scale, $\frac{1}{72000}$. C, Cretaceous; T, Trias; B, basalt of one of the Tres Hermanos buttes.

Upon the San José, a few miles west of its junction with the Puerco of the East, there is exposed a complex disturbance, constituted of a number of faults and folds, that were not sufficiently studied to warrant an attempt at their representation. The residual throw is to the east, and the trend of the dipping strata, north and south. The basalt of the Lucera plateau, and of the Mesa Redonda, rests on the disturbed strata, and is not tilted with them. Twenty miles further north Mr. Howell crossed the same line of disturbance, finding it manifested by a simple fault, with an easterly throw of 1,000 feet. It is a noteworthy fact that this line of abrupt local dislocation is also a hinge-line for the flexure of broad leaves of strata. If the reader will refer to Figure 122, he will see that, while the strata for thirty miles west of the disturbance have an even dip to the west, they have for an equal distance on the opposite side an easterly dip. In the engraving the vertical scale is made greater than the horizontal, and the angle of dip is consequently exaggerated; but, slight as is the angular deflection, it is still significant that a change, which involves such broad sheets of strata, is made abruptly instead of by gentle curves, and that the line of that change is also the line of a fault, or its equivalent monoclinal fold. The same thing has been observed elsewhere. The East Kaibab fold (see Figures 26 and 29 *b*) is the boundary between level strata at the west and eastward-dipping strata at the east, and the Paria fold (Figure 27) limits this same eastward-dipping mass at the east, and separates it from nearly level strata. Upon the Colorado Chiquito, a low fold, that is probably continuous with the last mentioned, marks a synclinal between tracts of gently dipping strata.* In each of these instances we are shown the same localization of the evidences of disturbance. Stupendous blocks of rock, ten, twenty, or even thirty miles in diameter, and of unknown depth, have changed their relations to other similar blocks, with which they were once continuous, and have themselves remained rigid, all evidence of movement being at the common boundaries of the dissociated blocks. It is difficult to illustrate these features because of the contrast between the magnitudes of the masses and of the movements they have experienced, but in the diagram (Figure 162) the same scale is used for all dimensions.

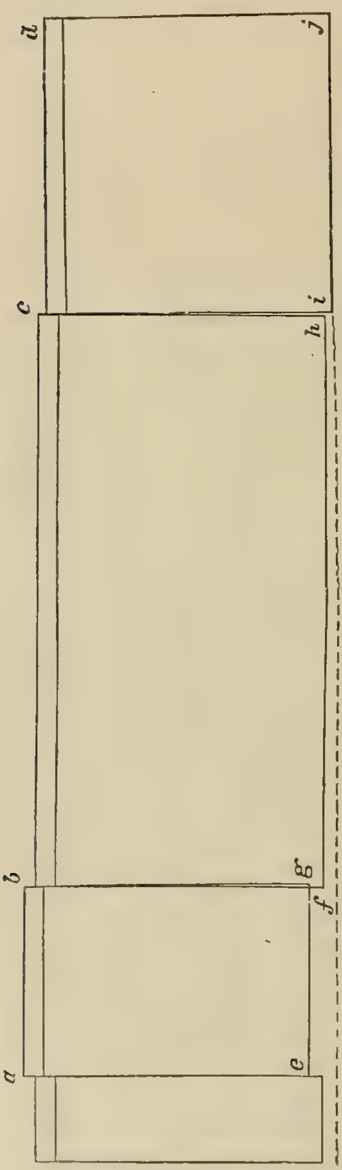


Fig. 162.—Ideal section, by a vertical plane, of a portion of the earth's crust in Northern Arizona.

* In all these instances the general dip of all the strata to the north is discounted.

It represents an ideal section, by a vertical plane, of a portion of the earth's crust in Northern Arizona. The West Kaibab fault, or fold, is at *a*, the East Kaibab, at *b*, and the Paria, at *c*. The distance *a b* is ten miles, and the distance *b c*, thirty. The parallel lines at top include the Paleozoic strata, one mile in depth. They were originally nearly level, and by their present position the changes are recorded. If we suppose, for the sake of a datum, that the block *c d j i* has its original position, then the block *b c h f*, of unknown depth and form, and known to us only by its surface, *b c*, has been lifted two-fifths of a mile at *c*, and three-fourths of a mile at *b*, without any disturbance of the rectitude of the line *b c;* and the block *a b f e* has been, in like manner, lifted a mile and a fourth. To my mind, the meaning of these movements of the earth, in vast but limited masses, is, that rigidity is an important factor in the determination of the superficial manifestations of subterranean movements. The fact that, at the points of differential movement, *b* and *c*, the rocks were not fractured but were flexed, proves that the changes were of secular slowness, and the rigidity that resists secular applications of force is a far different thing to contemplate from the rigidity that can be measured by experiment. It demands for its interpretation that we shall grant to the rigid masses a depth commensurate with their superficial dimensions, and suppose that the forces which move them are seated still deeper.

North and a little east from Mount Taylor, near Willow Spring, a monoclinal fold was noted, with an eastward drop of about 500 feet.

At the head of the cañon in which the San José rises, it is crossed by a fold with eastward drop and a trend north 10° west. At the intersection of the cañon the maximum dip of the flexed strata is 15°. To the north it increases to 30°, and the fold disappears under the Taylor plateau. Southward it flattens and has nearly faded out, when, three miles away, it is covered by the Acoma lavas. In its origin it antedated the basalts of the Taylor plateau.

The Defiance anticlinal was described by Dr. Newberry, in the geological report of the Colorado expedition under Lieutenant Ives, (pp. 91–93,) as it is exhibited along the trail from the Moquis towns to Fort Wingate, and was afterward examined by Mr. Howell upon the same line. Dr. Newberry's description is very full, and corresponds, in nearly every particular, with the section drawn by Mr. Howell.* The arch is a broad one, extending from Fort Defiance nearly, or quite, to the Moquis towns. This line of section, however, intersects it obliquely, and it is improbable that the width is greater than thirty miles. The westward slope is gentle, and the eastward steep, so that the axis of the fold lies close to the eastern base. (See Figures 120 and 121.) The valley in which Fort Defiance is built is a monoclinal of erosion, walled by the eastward-dipping Triassic strata. Forty-five miles to the south (south 20° east) the same fold was seen again, where it is intersected by the Zuni River. Its character is almost identically the same as at Defiance. The arch takes the same form, and the westward slope is so exceedingly gentle, that it might almost be disregarded, and the fold called a monoclinal, with eastern descent. The steepest dip is seen eight miles east of the town of Zuni, and is about 20°. The lowest strata bared by the erosion of the Zuni River are Triassic clays, and upon these the town is built.

Twelve miles east of the Defiance fold, and parallel with it, is the Nutria fold—a monoclinal that, in part of its course, follows the southwestern base of the Zuni range, and is there a portion of the Zuni anticlinal. Its throw is to the west. It was first noticed by Dr. Newberry, who crossed it at Stinking Spring, (Salt Spring of his report,) and, although he failed to recognize it as a fold, his description is the first record, in the Plateau region, of this peculiar form of disturbance. Traveling eastward on level Cretaceous strata, he suddenly encountered a wall of Cretaceous and Triassic strata dipping westward at a high angle, and, passing through it by the gate-way which opens for the Puerco of the West, he found himself on nearly level Lower Triassic rocks, having in one mile, without change of altitude, accomplished a geological descent of 2,000 feet. (See Fig. 164.) It appeared to him that the inclined strata were a dissevered mass, separated by faults from the horizontal portions on either side; but the fuller observations of Mr. Howell and the writer have demonstrated that the inclined and

* Dr. Newberry's text is so full as to leave no question that his observations agree with those of Mr. Howell, but the section and map, published with it, tend to mislead. The section represents the western instead of the eastern as the steeper side of the anticlinal; and upon the map (at least upon two copies of it) the crest of the arch, a tract extending thirty miles west from Fort Defiance, is colored as Cretaceous, while the descriptions of both geologists make it Triassic.

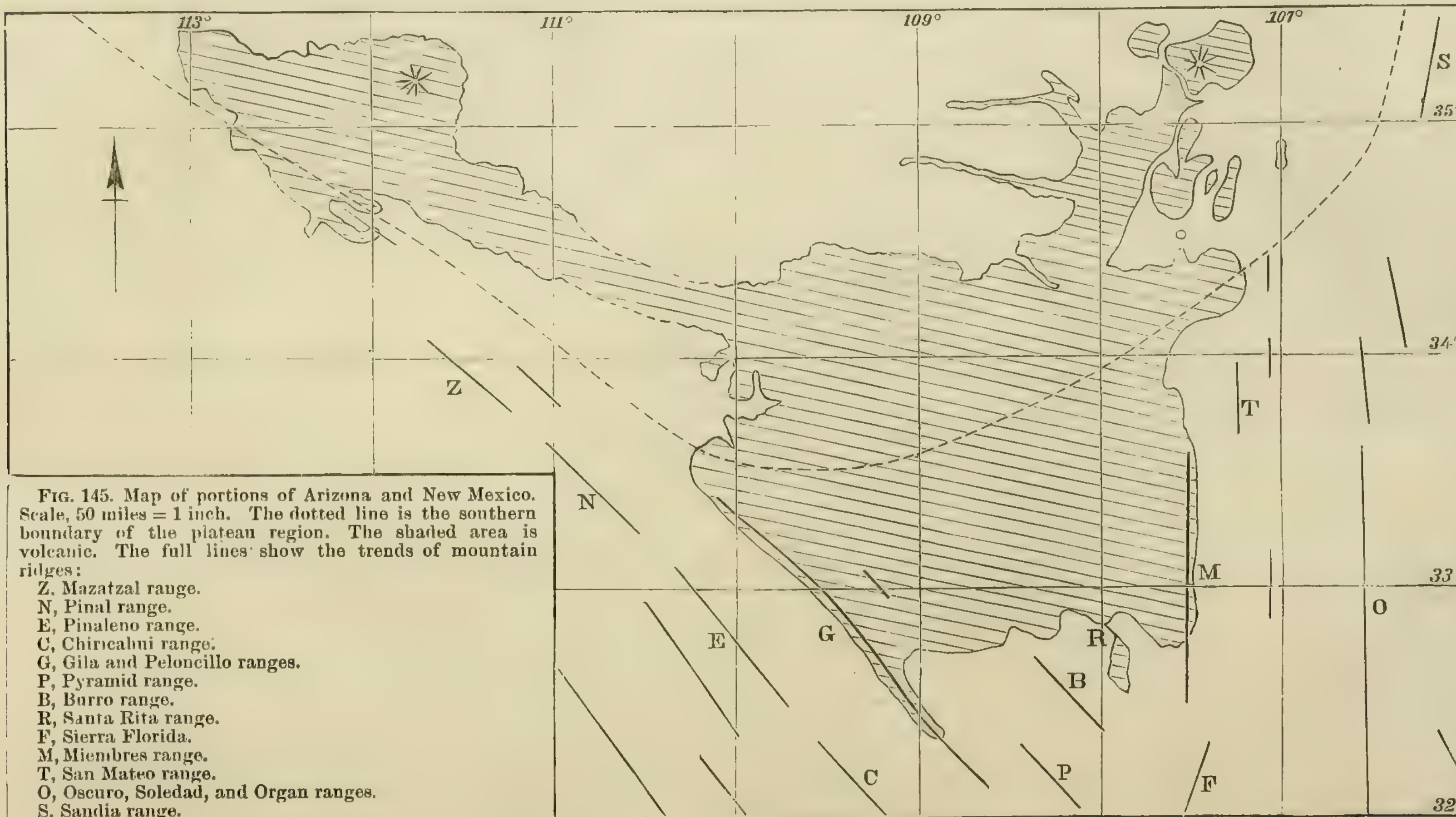


FIG. 145. Map of portions of Arizona and New Mexico. Scale, 50 miles = 1 inch. The dotted line is the southern boundary of the plateau region. The shaded area is volcanic. The full lines show the trends of mountain ridges:

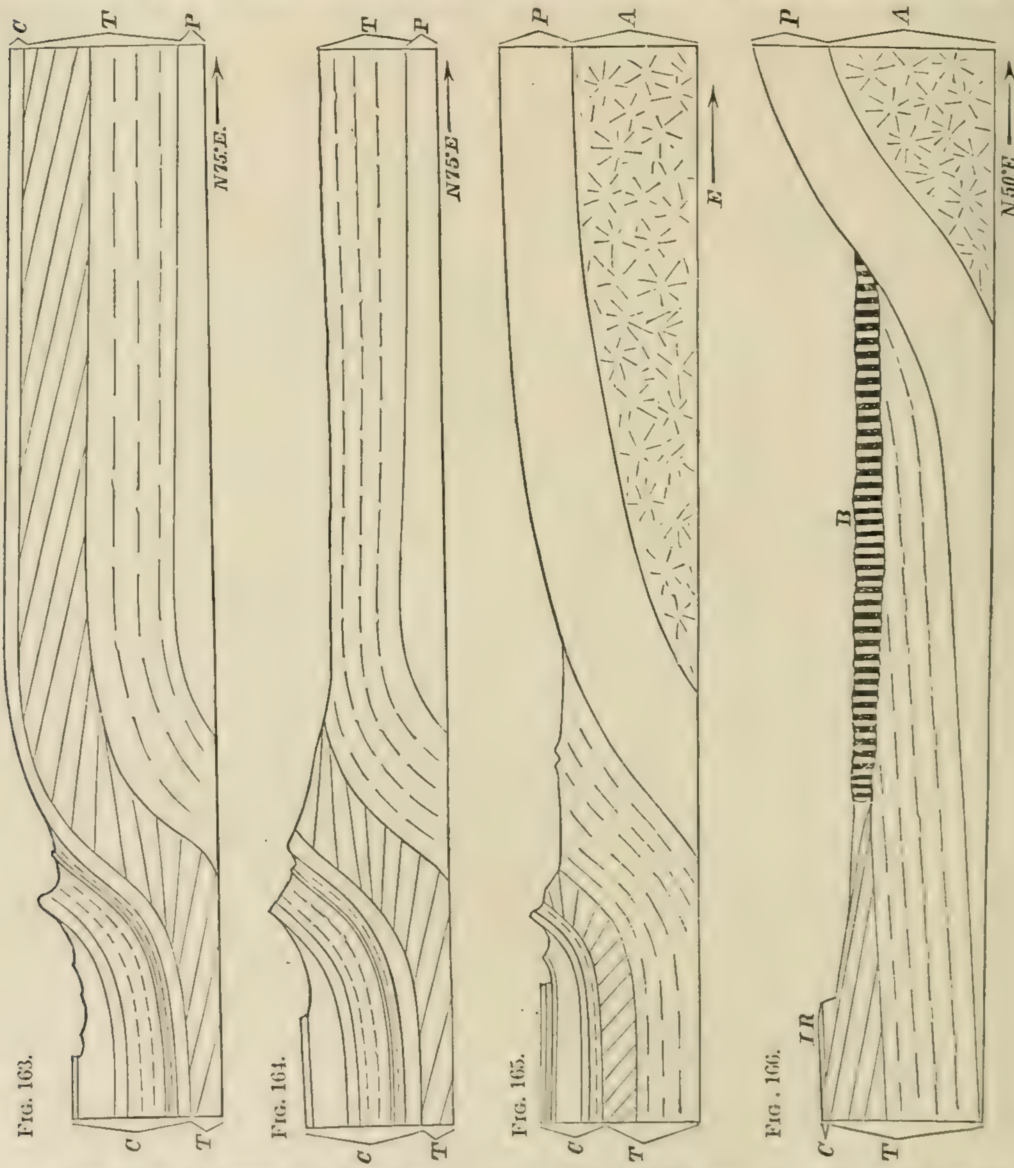
Z. Mazatzal range.
N, Pinal range.
E, Pinaleno range.
C, Chiricahui range.
G, Gila and Peloncillo ranges.
P, Pyramid range.
B, Burro range.
R, Santa Rita range.
F, Sierra Florida.
M, Miembres range.
T, San Mateo range.
O, Oscuro, Soledad, and Organ ranges.
S, Sandia range.

Fig. 167.


Geological Map of the
Nutria Fold and Zuni Range
8 miles - 1 Inch
Cretaceous
Trias
Paleozoic and Archaean
Lava
NUTRIA FOLD
Fig. 163
Fig. 164
Stinking Spr.
Ft. Wingate
DEFIANCE FOLD
ZUNI RANGE
Fig. 165
Nutria
A. Azul
Fig. 166
Old Wingate
Inscription Rock
Zuni

level strata are connected by curved portions, and that the only failures of continuity are due to erosion. From this point southeastward to Inscription Rock, forty miles, the fold has been seen at so many points, that its course can be mapped; and, from a high point near Stinking Spring, it was traced by the eye for about fifteen miles in a direction north 20° west. The general strike of the fold (the bearing of the most northerly known point from the most southerly) is north 30° west, but its course is remarkably flexuous, ranging from north to north 60° west. Through the entire observed length of the fold the rocks are unfractured; it is nowhere converted to a fault. But, while it remains essentially the same, its proportions and superficial manifestations undergo notable changes. At Stinking Spring its throw is about 2,500 feet, and at Nutria Spring it is as great as 4,000 feet. At the former locality the maximum dip of the inclined beds is 70°; at the latter, 50°; and at Inscription Rock it is still smaller, but was not measured. Five miles north of Stinking Spring the level strata at the west and east are respectively Upper Cretaceous and Lower Cretaceous; at Stinking Spring they are Upper Cretaceous and Lower Trias; at Nutria Spring, Upper Cretaceous and Upper Carboniferous; and at Inscription Rock, Upper Trias and Upper Carboniferous. All these peculiarities are illustrated by the accompanying map and sections—Figures 163 to 168. The dimensions were obtained by rough measurement at Stinking Spring and Nutria Spring; and the other sections are drawn from sketches made at a distance. The representation of the fold upon the map is, at the north of the town of Nutria, a plotting of the outcrop of a Lower Cretaceous sandstone, which appears as the crest of a ridge in Figures 163, 164, and 165. South of Nutria erosion has laid bare the Lower Trias, along the line of the steepest dip, and the valley opened by these soft beds has been flooded by lava from the Marcou buttes. The line in that portion of the map has been carried parallel to the margin of the Carboniferous outcrop. For a distance of at least fifty miles the Nutria fold is finely exposed for examination and measurement, and the variety of phase which it exhibits, as dependent on the alternation of hard and soft beds in the rock series involved by it, is well worthy of study.

The *Zuni range*, standing upon the water-divide of the continent, was assumed by the earlier explorers to be a continuation of the Sierra Madre of



Sections of the Nutria fold, New Mexico. Scale, 1 inch = 3,000 feet. Fig. 163, section five miles north of Stinking Spring; Fig. 164, 1 mile north of Stinking Spring; Fig. 165, two miles north of Nutria; Fig. 166, at Inscription Rock. C, Cretaceous; T, Trias; P, Paleozoic; A, Archæan; B, Basalt; I R, Inscription Rock. Fig. 166 is slightly distorted to bring in Inscription Rock; its true position is farther to the left. The relative positions of the sections are shown on the map, Fig. 167. The scale of the map is 1 inch = eight miles.

Mexico, and the name is still retained on many maps, although the range has for some time been known to be of limited extent. Topographically it is forty-five miles long, trends northwest, and extends from Old Fort Wingate to Fort Wingate. Upon most published maps the name is extended so as to cross the Acoma Plateau or the Marcou buttes, but without due warrant. Those elevations are at once inferior in magnitude and independent in character and trend. Geologically, the range, far from deserving to be entitled the mother of a family of mountains, is a lonely orphan, dissevered from all kindred. It stands, in the midst of the Plateau region, a mountain of upheaval; from every side of it the strata stretch in level tables. The nearest uplifted ranges are the Nacimiento, sixty miles to the northeast; the Zandia, seventy miles to the east; and the Ladron, sixty miles to the southeast; and each of these trends with the meridian, while the Zuni trends north 45° west. It is truly a mountain by itself, and in its isolation, in its accessibility, in its simplicity of structure, and in its relation to the fold system of the plateaus, it offers a richer harvest to the geologist, who shall give it a thorough study, than any other single mountain with which I am acquainted. Only its most general features are at present known, and it has never been ascended by a geologist. Mr. Marcou skirted its southern margin and discovered its anticlinal structure. Dr. Newberry passed to the north, from which side its character is not well shown. Mr. Howell and the writer have conjointly seen it from every base, and have been able to add something to the knowledge of it; but, in the following paragraphs, I hope to accomplish no more than to direct attention to its great value as an object of special study.

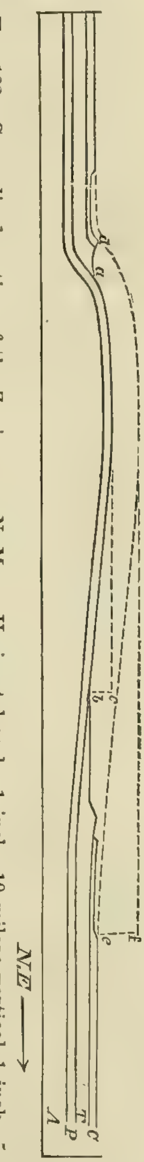


FIG. 168.—Generalized section of the Zuni range, N. Mex. Horizontal scale, 1 inch=10 miles; vertical, 1 inch=5 miles. Base-line=sea-level. C, Cretaceous; T, Trias; P, Paleozoic; A, Crystalline rocks.

The Zuni uplift is an anticlinal or elongated quaquaversal. On every side the strata dip away from the axis, and the soft formations that have been eroded from the dome now outcrop in a series of concentric elliptical belts. (See Fig. 167.) These formations are the Cretaceous and Triassic. The Carboniferous has yielded less to erosion, and probably forms the whole surface of the northern half of the dome; but at the south it has been broken through, and Archæan rocks are centrally exposed. A generalized expression of the structure of the range is given by figure 168, in which the vertical scale is twice as great as the horizontal. Topographically its width is the distance *ab*, and its height *bc*; but as a geological feature its width is the distance, *dc*, from level strata on one side to level strata on the other; and its height is the vertical displacement of the rock system, *ef*. As a mountain range it is forty-five miles long, twenty miles broad, and about 3,000 feet high. As a geological uplift it is seventy miles long, thirty-five miles broad, and 6,000 feet high. It is not to be supposed that the dome ever possessed these geological proportions, for mountains rise slowly and erosion and corrugation proceed in concert; but if we could restore the rock that has been washed away and make each stratum that now encircles the base continuous over the arch, we should then have a mountain mass that would represent quantitatively the magnitude of the upward movement. A rough calculation places that mass at seven hundred cubic miles, and this quantity is an expression of the volume of matter brought by the uplift above the original level surface.

In this instance the circumstances admit of no question that the movement that produced the mountain was an *upward* movement. As a remote cause of the swelling, there may have been horizontal motion of subterranean matter, but the immediate cause could only be an upward motion. This dome, rising in the midst of a geological plane, is as unmistakably the result of upward transfer of subterranean material, as is the volcanic cone of Mount Taylor, which stands by its side. In the one case, the rising rock passed through the superstrata, and, piling itself on the surface, built a mountain of its own substance; in the other, it moved a comparatively short distance, but lifted all above it, and built a mountain by upcurving the superficial strata. In this instance the magnitude of the uplift far exceeded that of the companion eruption; Mount Taylor was produced by the effusion of not more than sixty cubic miles of trachyte. The steeper slopes of the lava, however, and its superior durability, leave it now the taller and more conspicuous mountain.

The southwest side of the anticlinal is the steeper, and its flexure is the

Nutria fold. The typical cross-section (Fig. 168) changes to the northwest by a diminution in height, until, a little beyond Stinking Spring, it has lost its anticlinal character, and is a simple monoclinal—the Nutria fold. The circling of the strata around that end of the anticlinal is finely shown on the plain between Fort Wingate and Stinking Spring, where the curves are marked by the outcropping of the sandy and calcareous beds which interrupt the lower Triassic, clays. At the opposite, southeast, extremity of the dome observation is impeded by lava, but there is reason to suspect that the structure is less simple and involves some local faulting of the strata.

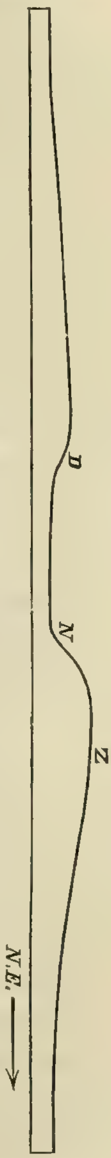


Fig. 169.—Diagram of Zuni and Defiance uplifts. Vertical scale, greater than horizontal. Z, Zuni range; N, Nutria fold; D, Defiance fold.

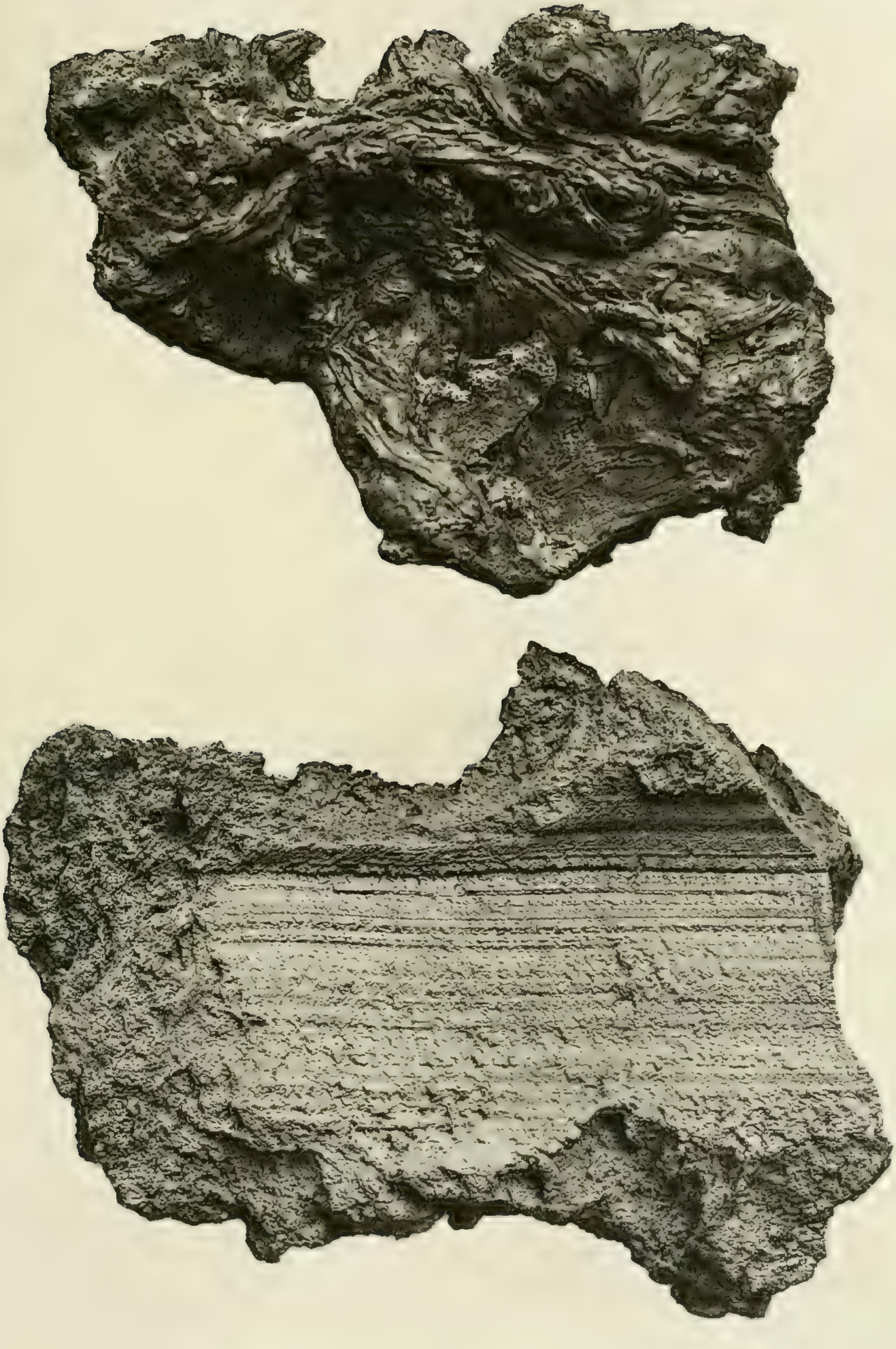
The resemblance of the curves exhibited in the cross-section to the sigmoid curves that have been found to characterize the Appalachian corrugations is conspicuous; but there is reason to suspect that they are not homologous. The unequal anticlinal of the Zuni range passes into a simple monoclinal, and that is the structural equivalent of a fault. (See chapter I.) Moreover, the uniformity in the direction of the steeper slopes, which characterizes the Appalachians, is not found when the Zuni fold is compared with the only known parallel fold of the vicinity. If we trace a single stratum across the Zuni range and Nutria fold, and then southwestward across the Defiance fold, we find its flexures repeated, with inferior dimensions and in *inverse* order. (Fig. 169.)

On the northeastern slope, between Old Fort Wingate and Bacon Spring, there is a broad and generally even sheet of Carboniferous limestone. The rapid destruction of the lower Trias shales, and the stubborn resistance of the underlying limestone, have led to the baring of a broad area of the *upper surface* of the limestone, and this great exposure of a single stratum reveals some details of structure that could not otherwise be comprehended without laborious study. The rock appears to be divided into blocks of such magnitude that their superficial areas would be expressed in miles rather than in acres, and these blocks have been inclined with somewhat different dips and directions, so that at their edges they differ in altitude. So far as my very limited observation goes they are not separated by faults, but are connected by monoclinal flexures. The case may be differently stated by saying that the limestone area is traversed by a number of monoclinal folds, which are usually of small throw, and separated by wide intervals. They are not parallel, but bear toward all points of the compass and intersect each other. It is not unlikely that they exhibit, in epitome, the characters of the fold and fault system of the Plateau region, and their study cannot fail to throw light on the function of rigidity as a factor of orographic corrugation.

If, as is probable, the strata of Carboniferous limestone are continuous across the arch near its crest, as drawn in Figure 168, then the absolute length of the curved strata can be measured and compared with the direct distance between their remote parts; and there is reason to hope that, by a series of such measurements in different parts of the range, an answer can be found to the question whether, in the production of the curve, the remote portions of the strata were brought nearer, or whether the curved portions were stretched. The unbent, or little bent, strata which surround the range, afford a base or *datum* for these and other measurements, such as can very rarely be found in the neighborhood of anticlinals.

The observations of Mr. Howell led him to suspect that the crystalline nucleus of the range had been formed by the metamorphism of lower Paleozoic strata, conformable with the unaltered upper Paleozoic beds; and the specimens he procured show a gradation from compact sandstone to gneissic quartzite and a quartzose granite. This subject, and the question of the presence or absence of Silurian strata, will repay investigation and add to the interest that will attach to the study of the range.

In fine, the Zuni range is so simple a fold, is so little impaired by denudation, and is so little concealed by detritus, that its structure can be made out with exceptional ease, and with exceptional completeness. Its insulation upon a petrographical plane affords exceptional facilities for the quantitative determination of its form. It offers a valuable contribution to our knowledge of the fold system of the plateaus; first, because it is a member of that system, and shows of what sort of mountain the monoclinal fold



is the embryo; and, second, because it includes, as subordinate features, a number of small monoclinal folds conveniently disposed for examination. The study of these latter will involve the study of the relation of rigidity to plasticity of rock masses in secular movements. It hints at an answer to the question whether indurated, non-metamorphic strata may dilate latitudinally. And, in addition to these its proffered contributions to orographic geology, which are its chief attractions, it may afford a valuable study in metamorphism; and it illustrates, with rare simplicity, the relations of altitude and hardness to erosion.

INDEX.

ENGINEER DEPARTMENT, UNITED STATES ARMY.

REPORT

UPON

GEOGRAPHICAL AND GEOLOGICAL

EXPLORATIONS AND SURVEYS

WEST OF THE ONE HUNDREDTH MERIDIAN,

IN CHARGE OF

FIRST LIEUT. GEO. M. WHEELER,
CORPS OF ENGINEERS, U. S. ARMY,

UNDER THE DIRECTION OF

BRIG. GEN. A. A. HUMPHREYS,

CHIEF OF ENGINEERS, U. S. ARMY.

PUBLISHED BY AUTHORITY OF HON. WM. W. BELKNAP, SECRETARY OF WAR,

IN ACCORDANCE WITH ACTS OF CONGRESS OF JUNE 23, 1874, AND FEBRUARY 15, 1875.

IN SIX VOLUMES, ACCOMPANIED BY ONE TOPOGRAPHICAL AND ONE GEOLOGICAL ATLAS.

PART VI.

VOL. III.—GEOLOGY.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1875.

TABLE OF CONTENTS.

UNITED STATES ENGINEER OFFICE,
GEOGRAPHICAL EXPLORATIONS AND SURVEYS,
WEST OF THE ONE HUNDREDTH MERIDIAN,
Washington, D. C., November 11, 1874.

GENERAL: I have the honor to forward herewith reports upon geological data gathered by parties of the survey under my charge for publication, in accordance with the act of Congress, approved June 23, 1874. (See Statutes at Large, Forty-third Congress, First Session, page 224.)

This volume is one of the series of six heretofore proposed for the elaboration of the detailed results of the survey.

The geological assistants have usually been members of the field parties, organized to embrace representatives of the several branches of the work, except during occasions incident to a divergence from the routes of travel necessary to carry on the main or topographical branch.

The obstacles attendant upon researches amid the mountain intricacies, rigid plateau contours, and desert-wastes encountered, have largely added to their undertakings, while their reports will attest the manner in which they have prosecuted the arduous duties intrusted to them.

The nature of the survey has necessarily made geological and other scientific inquiry subsidiary to the main object of the work, which, in view of the great area covered by the survey, consists in the determination of positions and the delineation of the surface of the region occupied. Hence the geologists have not had the same facilities they would have had in parties organized especially for geological work; but notwithstanding these deficiencies and the difficulties they entailed, it is believed that these reports extend and connect our geological information over a wide field, embracing areas in several important basins of drainage of six different States and Territories, including portions of the plateau region, and several prominent mountain ranges heretofore conjecturally known, and will not be without their important values and acceptable as a worthy contribution to our geological knowledge of the territorial domain west of the Mississippi River.

It is believed that the geological matter here presented, when supplemented, as it soon will be, by a series of geological maps and paleontological reports, will answer all the present needs of the Government and of the industries of these partially inhabited areas, in which, for years to come, geological or other scientific examinations will find but few localities where sectional industrial interests may be healthfully promoted with economy to them or to the Government.

The time consumed in office labor, as compared with that in the field, has been somewhat inadequate, yet the results appear in the systematic rather than the itinerary form, which it is hoped will prove advantageous to all the purposes to which they may be applied.

Fossil and other geological specimens have been collected from a wide-spread range, including many well-prospected localities, and their number is large.

Their examination will lead to an extended report upon the paleontology of the area embraced by the survey affording a large number of new forms of the extinct fauna of that region, identifying with certainty geological relations heretofore vague, and defining horizons newly discovered. They have been placed in the hands of Prof. C. A. White, of Bowdoin College, a preliminary examination having been made by Prof. F. B. Meek, a portion of the results of which are incorporated herein. The report upon these collections will form the bulk of Vol. IV of the series. This volume will also embrace, in addition, reports, if they be submitted in time, upon the vertebrate collections of 1874.

The collection of rock-specimens, especially of volcanic varieties, is large and well worthy of special examination for additional evidence, bearing upon lithological characteristics.

The practical or economic features of the accompanying reports will appeal to those interested in the mineral and agricultural industries constantly advancing into these untrodden fields, and that of Dr. Loew, who has, with patient labor, made chemical investigations and analyses in mineral waters, plants, soils, &c., forms an interesting feature of the volume.

Mr. G. K. Gilbert, A. M., geological assistant during three field seasons, contributes more largely than any other to this volume, and besides his purely professional labors, has aided to give form to the work of the geological parties.

Mr. E. E. Howell, geological assistant in the years 1872–'73, presents his individual contribution.

The report of Prof. John J. Stevenson, an assistant with the Colorado party under Lieutenant Marshall in 1873, relates to territory somewhat disconnected from the areas occupied by the others, and treats its subjects in the same systematic manner.

Mr. A. R. Marvine, occupying the position of astronomical assistant in 1871, while on the march to the southward, examined areas contiguous to his route so far as circumstances would permit.

Considering the character and scope of the results from the labors of the geological assistants, the comparative increase of expense attendant upon attaching them to the several parties seems to have been justified, and the advantages of affording opportunities for examinations in this cognate scientific branch are made manifest.

Very respectfully, your obedient servant,

GEO. M. WHEELER,
First Lieutenant Corps of Engineers, in Charge.

Brig. Gen. A. A. HUMPHREYS,
Chief of Engineers, United States Army.

NOTE.—Owing to an omission in the act making appropriation for the publication of the survey reports, the MS. for this volume has been delayed until this date; and meanwhile Dr. Loew has returned from the field and prepared a report upon the mineral springs, of which specimens were collected during the field season of 1874; also a report upon the composition of coal from different localities in New Mexico and Colorado. As both are germane to the subject-matter of his report for 1873, they have been incorporated therewith, not being of sufficient length to justify publication in separate form.

GEO. M. WHEELER,
Lieutenant of Engineers, in Charge.

UNITED STATES ENGINEER OFFICE,
Washington, February 10, 1875.

PART VI.

REPORT

UPON

MINERALOGICAL, AGRICULTURAL, AND CHEMICAL CONDITIONS OBSERVED IN PORTIONS OF COLORADO, NEW MEXICO, AND ARIZONA,

IN

1873.

BY

OSCAR LOEW, PH. D.

COMPRISING

United States Engineer Office,
Geographical and Geological Explorations and Surveys
west of the 100th Meridian,

Washington, D. C., May 20, 1874.

Dear Sir: I have the honor to present herewith a report upon the chemical investigations of soils, minerals, mineral waters, rocks, coals, and plants of parts of Colorado, New Mexico, and Arizona, traversed during the expedition of 1873.

The report is divided into four chapters. The first contains a description of the agricultural capacity of portions of New Mexico and Arizona, with analyses of soils and plants, and remarks on several cosmical conditions; the second treats of the composition of mineral waters and minerals, and contains, also, an investigation of a previously undescribed fossil-resin, which I have taken the liberty to name after yourself,—"Wheelerite;" the third consists of a general geognostical and chemical description of the volcanic rocks of New Mexico and Arizona; the fourth comprises a list of minerals, embracing not only those collected last year, but also the mineralogical data of the two preceding years, by Messrs. Gilbert, Stevenson, Howell, and Hoffman, of the survey.

The tables are arranged after the system of Dana, thus deviating from the usual alphabetic enumeration, which is not well adapted for a scientific report.

Permit me, in submitting this report, to add that, since so many important and interesting questions can find their proper solution only by chemical investigation, it is to be hoped that, as you have been the first to recognize the importance of chemistry as a branch of natural history operations in explorations for survey, its claims will continue to receive favorable consideration at your hands.

Respectfully submitted,

O. Loew,
Mineralogical Assistant.

Lieut. George M. Wheeler,
Corps of Engineers, in charge.

CHAPTER XXI.

AGRICULTURAL RESOURCES: SOIL, VEGETATION, COSMICAL PHENOMENA.

SECTION I.—GENERAL REMARKS ON THE AGRICULTURAL CAPACITIES OF ARIZONA AND NEW MEXICO; THE VALLEY OF THE RIO GRANDE, NEW MEXICO; SOUTHWESTERN NEW MEXICO; NORTHWESTERN NEW MEXICO; COUNTRY OF THE MOQUIS, ARIZONA; BOTTOM LANDS OF THE COLORADO CHIQUITO AND CHEVELON'S FORK; THE MOGOLLON MESA; THE SAN FRANCISCO MOUNTAINS; BOTTOM LANDS OF THE RIO SAN PEDRO; PLAIN OF CAMP GRANT; BOTTOM LANDS OF THE RIO GILA, ARIZONA; GENERAL REMARKS ON THE RESULTS OF SOIL INVESTIGATIONS.

SECTION II.—THE CLIMATE OF THE GILA VALLEY; OZONE REACTIONS OF THE ATMOSPHERE; GEOGRAPHICAL DISTRIBUTION OF PLANTS; LIST OF PLANTS OF MEDICAL OR TECHNICAL USE; ANALYSES OF YUCCA BACCATA (SOAP WEED); OF AGAVE (MESCAL); AND OF EPHEDRA ANTISYPHILITICA.

SECTION I.

GENERAL REMARKS ON THE AGRICULTURAL CAPACITIES OF WESTERN NEW MEXICO AND EASTERN ARIZONA.

The extent of agricultural lands in Western New Mexico and Eastern Arizona is not very considerable, by reason of scarcity of water-courses and deficiency of rain, on the one hand, and on the other, of the rocky, irregular character of the country. A large part of this irregular region, however, is suitable for stock-raising, but a portion, at least, appears doomed, until a change of climate effects an abundant rain-fall. The sections suitable for farming are situated either on the Plateau region at an altitude of more than 6,800 feet, or along the river and creek bottoms. Many of these streams, however, are of but little use for agricultural purposes, being partially or wholly inclosed in deep cañons or flowing through rocky and mountainous regions, termed in New Mexico "*mal pais*," the "*mauvaises terres*" of the Northwest. Among them are White Mountain Creek, Salt Creek, Rio San Carlos, and Rio Bonito, tributaries of the Gila in Arizona, and Rio de las Animas, and Rio de las Palomas, in New Mexico. The Rio Francisco, in Arizona, is flanked here and there by small strips of arable lands, comprising a few acres. The river, however, is chiefly inclosed in a cañon. The Rio Gila, Rio San Pedro, Colorado Chiquito, Chevelon's Fork, in Arizona and the Rio del Cuchilla Negra, Rio Mimbres, and Rio Alamosa, in New Mexico, are bordered by larger belts of good bottom lands. A number of Mexicans have settled on the Rio Mimbres and Rio Alamosa. Several rivers and creeks, on reaching the lowlands, sink or run dry during the summer season, among which are the Rio Puerco of the West, Rio Puerco of the East, Rio Galisteo, and the Pojoaque. The Rio de Santa Fé and Rio Tesuque are small bodies of water capable of supporting but very limited areas by irrigation.

I have not seen the San Juan or Zuni streams, nor Lithodendron Creek, nor the head of the Gila, in New Mexico. The region about these streams is said to be suitable for agricultural and pastoral pursuits.

The White Mountain district, in Arizona, was not visited by our division, (No. 2.)

Since a report on agricultural lands is not at the present day complete, if unaccompanied by the results of investigations of the respective soils, good average specimens were collected from all the agricultural sections visited, being taken from a depth of one foot, and preserved in sealed bottles or well closed tin boxes.

THE VALLEY OF THE RIO GRANDE DEL NORTE.

The bottom lands of this river, which has not unjustly been compared by some writers to the Nile of Egypt, undoubtedly form the best portion of New Mexico in an agricultural point of view. Four-fifths of the population of New Mexico live upon the banks of the Rio Grande. These settlements are traversed by acequias, large irrigating ditches, averaging two feet in depth and three in width. The water of the river carries with it large quantities of a reddish-gray matter, which settles when the water is left in repose for several hours, and supplies the only fertilizer used, the soil yielding fruits, grain, and farm-produce of every description in abundance, notwithstanding it has been under cultivation for over two hundred and fifty years. Here onions weighing over two pounds, cabbages of sixty pounds, turnips of enormous size, peas, watermelons, squashes, beans, Indian corn, and figs, are grown in great profusion. These bottom lands appear well adapted to grape-growing, and already the El Paso wine has gained a great reputation. It was currently reported that, although every effort had been made to raise potatoes in this region, none had been grown; the cause, however, was ascertained to be carelessness on the part of the Mexicans, who neither hoe the ground sufficiently nor remove the numerous caterpillars from the herbage. Careful Americans have succeeded in raising potatoes of fine quality. Notwithstanding the excellent properties of these lands, one would be disappointed who here expected to find a paradise; since this bottom, in average two miles wide, shows upon the mesas embracing it hardly a sign of vegetation, save sage-brush. Wherever water does not border the soil, or is not carried there by ditches, there even grass is absent; vegetation being defeated by scarcity of rains and the sandy, porous nature of the soil. Well-watered ground and a perpetually dry atmosphere form a union of circumstances exceedingly favorable for splendid development of crops of all kinds. This fact can be observed not only in New Mexico along the valleys of the water-courses, but also in Colorado, where by means of irrigation the most abundant crops are developed. Here, in 1872, three times as much corn was raised to the acre than in neighboring Kansas, where a moist atmosphere and occasional rains do not necessitate irrigation. The splendid growth of firs and pines, above an altitude of 7,000 feet, in New Mexico, may be attributed to the above-mentioned fact; the soil contains sufficient moisture for the trees, while the air is mostly dry and the sky seldom covered with clouds. Thus the reduction of carbonic acid is rarely retarded by absence of direct sunlight, the circulation of the sap is greatly increased by the more rapid evaporation from the leaves, and all moisture necessary for the body of the tree is supplied by the roots.

With reference to the water of the Rio Grande, a chemical investigation appeared of great importance, since, if it could be proved that the virtues ascribed to it existed, many hundreds of thousands of acres now lying barren near the banks of the river could be profitably converted into the best farming lands. For instance, just west of Fort Craig there is a wide level plain, which would afford 5,000 acres of good farming land could the water of the Rio Grande be carried to its level by being lifted about 100 feet.

The analysis of the water naturally divides itself into two parts, viz:

(1.) Of the matters in *solution*.

(2.) Of the matters in *suspension*.

During our stay at Fort Craig, six gallons of this water were evaporated and half a pound of the sediment from the river-shore was brought away for analysis. In order to a more concise idea of the composition of the dissolved matters, the analysis of the Rio Grande water is here placed alongside that of the water of the Isar—a stream of Southern Bavaria, possessing no fertilizing properties. In 1,000 parts of water are contained:

Constituent.	Rio Grande del Norte.	River Isar.
Chloride of sodium	0.05938	0.00163
Sulphate of soda	0.02736	0.00569
Sulphate of potassa	0.00140	0.00982
Sulphate of lime	0.03928	0.01788
Carbonate of lime	0.01195	0.07830
Carbonate of magnesia	0.00431	0.01574
Carbonate of soda	Trace	
Phosphoric acid	Very faint trace	
Silicic acid	Trace	Traces.
Nitric acid	Trace	
Ammonia	Trace	Trace.
Alumina	Trace	Trace.
Oxide of iron	Trace	
Organic matter	0.01392	Traces.
Total	0.15760	0.12906

The amount of organic matter was too small to admit close investigation; with *aqua regia* it developed the penetrating odor of trichlormethyl nitride. It is evident at a glance that the fertilizing properties of the Rio Grande water cannot be derived from particles *in solution;* in fact, the amount of potassa is minute, while there is but an exceedingly faint trace of phosphoric acid.

The fertilizing properties must be sought in the *suspended* matters, or in the mud of the river. Although this mud is often styled in New Mexico "rich loam with decayed vegetable matter," neither is present, except in traces. The amount of suspended much exceeds that of the dissolved materials. The quantity varies considerably with the seasons, and with high and low water, and differs even at different points of the river. Where the current is swift there is more in suspension than where the water is slow and shallow, near the margins; in the latter case much will settle at the bottom. The color of the sediment is a dirty reddish-gray; its consistency is that of a fine silt, or dust white; far from having any of the properties of clay, it forms, when dry, simply a loose mass easily crumbling to powder on pressure between the fingers. The mud of the Rio Grande had not heretofore been chemically investigated; that of the Nile, however, has been analyzed repeatedly by English, German, and French chemists, viz: by Horner, Phil. Mag. [4], IX, 465; Lajonchère, Phil. Mag. [3], XXXVI, 325; Payen, Phil. Mag. [3], XXXVI, 325; Moser, Wien, Acad. Ber., XIX, 362; Peters, Jahresber, Agr. Chem., 1860–'61; Knop, Landwirthsch. Versuchst, 1874. These analyses differ somewhat, the samples having been taken from places far distant from each other; some of them do not even mention the presence of phosphoric acid. The amount of organic matter in the Nile mud is very small, and, according to Knop, is an excellent example to prove that mainly upon inorganic matters depends fertility. He pays particular attention to the absorptive power for moisture, which is chiefly due to the presence of the hydrated oxide of iron. The following shows the composition of the Rio Grande mud as compared with that of the Nile:

Constituents.		Rio Grande mud.	Nile mud. (Analysis of Peters.)
Soluble in hydrochloric acid	Hygroscopic moisture	1.890	......
	Chemically-bound water	3.122	......
	Potassa	0.284	0.166
	Soda with trace of lithia	0.064	0.022
	Lime	1.479	1.725
	Carbonate of lime	5.190	......
	Magnesia	0.080	0.046
	Oxide of iron	3.640	8.804
	Alumina	1.308	
	Phosphoric acid	0.092	0.143
Soluble in hydrofluoric acid	Potassa	1.500	......
	Soda with trace of lithia	0.731	......
	Magnesia	0.101	......
	Lime	0.272	......
	Oxide of iron, Alumina	9.942	......
	Silicic acid	70.010	......
		99.705	......

Peters has not analyzed the portion insoluble in hydrochloric acid. To render comparison easy Horner's analysis is selected, which, however, does not give a separate analysis of the portions soluble and insoluble in hydrochloric acid; the above analysis has, therefore, been reduced in an analogous manner:

Constituents.	Rio Grande mud.	Nile mud. (Analysis of Horner.)
Potassa	1.784	0.473
Soda	0.795	0.553
Lime	1.751	1.901
Carbonate of lime	5.190	3.717
Magnesia	0.181	0.762
Oxide of iron, Alumina	14.890	31.870
Silicic acid	70.010	54.585
Sulphate of lime	Trace	0.245
Phosphoric acid	0.092	Not determined.
Water and trace of organic matter	5.012	5.701
	99.705	99.818

On comparing the compositions of the Rio Grande and the Nile mud, we find the former richer in potassa, but with a little smaller amount of phosphoric acid, than the latter. The absorptive power of the mud for moisture is probably greater in that of the Nile on account of its containing more hydrated oxide of iron. Irrigation with these mud-carrying waters furnishes the lands with a layer of the best virgin soil in a finely pulverized condition, and the belief of the farmer that the Rio Grande water is an efficacious fertilizing agent is fully warranted by the facts revealed by chemical analysis. Indeed, the inhabitant of the Rio Grande Valley will never require any other fertilizer than the waters of the Rio Grande del Norte.

SOUTHWESTERN NEW MEXICO.

Proceeding up the Gila from the mouth of the San Francisco River we are soon in New Mexico, near the great western bend of the Gila. Leaving the river at this point we enter to the eastward a wide, level country, bordered on the east by the Burro Mountains and Pyramid range; on this plain there is neither spring nor creek, yet is tolerably well grassed over. No experiments have thus far been made with regard to wells, but it is highly probable that water exists at a moderate depth. The plain lies much higher than the Gila, and irrigation from that source would seem impossible. The soil toward the eastern portion is rather coarse, and is made up partially of granitic and partially of rhyolitic material. Here the maximum vegetation consists of an occasional bush of stunted growth. Ascending the Burro Mountains we here and there encountered a grassy valley of limited extent, but toward the eastern portions the soil becomes poor, the formation being chiefly quartzite. From the Burro Mountains, toward Silver City, stretches a hilly country, inclosing several valleys provided with good grass. There is no running water at Silver City, the inhabitants depending entirely upon wells. Several of the more enterprising citizens, however, entertain the belief that in time a canal will be built to bring the waters of the Gila to the town, something quite impossible, according to my belief, on account of the great difference in altitude. There is no farming done at Silver City. Stock-raising is carried on to some little extent. The chief occupation is mining.

About three miles north of Silver City, on the road to Fort Bayard, a narrow strip of land (Colman's ranch) produced, last year, over sixty bushels of corn to the acre, notwithstanding the unusual dryness of the weather; the seed was planted about one foot deep, a hole being made with a crowbar. Water in abundance was struck at a depth of 16 feet, which accounts for the presence of moisture in the subsoil, and for the ripening of crops without irrigation. The soil is black, of fine grain, and not heavy. The subsoil was found to contain 5.91 per cent of hygroscopic moisture, while the surface-soil only 2.02 per cent. There are several prolific springs near Fort Bayard, seven miles from Silver City; also good grass.

Proceeding from Fort Bayard via Central City, a small mining village, to Mimbres, we crossed a well grassed over undulating country of twenty miles in extent, with occasional springs and farms.

Mimbres, a town on the Mimbres River, formerly had a population of about six hundred, now reduced to less than one hundred. The cause of the emigration was fever and ague, endemic to this region. A large swamp on the south side of the village doubtless caused the disease. This swamp could have been easily drained by a ditch about a mile in length, whereby, moreover, water would have been gained during the summer months when the river runs dry. The river, where it passes the town, is about 12 feet wide and 1 foot deep. Indian corn has been raised in the bottom-lands without irrigation; on some farms irrigation is resorted to once a month. Wheat, barley, oats, and rye ripen before the river runs dry. The average yield was, last year, 1,600 pounds of wheat and 1,800 pounds of corn per acre. There is here a large stock range with 600 head of cattle, and thousands of sheep. Some eighteen miles from the town, toward the mountain range, a good supply of timber is found, chiefly scrub-oak; farther up the mountains pine is abundant. An intelligent farmer of that town informed me that continual cutting and close grazing does not impede the full redevelopment of the grass. He made the distinction between black and yellow grama grasses, and considers them the most nutritious kinds.

This settlement and the town of Upper Mimbres, eight miles above the former, may become of great importance with the development of the mining industry in the neighboring mountains, viz, Burro Mountains, Pinos Altos, Silver City, Santa Rita, &c. The unoccupied bottom-lands of the Mimbres River are of considerable extent. At present there is much corn imported to New Mexico, where the yield is not equal to the demand. Many teams are engaged in freighting from Grenada, the present terminus of the Atchison, Topeka and Santa Fé Railroad, down to Las Cruces, on the Rio Grande, and thence to various military posts and mining settlements. New Mexico is capable of raising more agricultural products than are required for home wants, under a better system of farming. Already signs of improvement are visible about Santa Fé, which, on completion of the proposed railroads, will become an important center.

From Mimbres to Fort Craig is a mountainous country with here and there fine valleys; the hills and bottoms are tolerably well covered with the grama grasses; as a whole, this region is well adapted to stock-raising. At present scarcely any one lives between Mimbres and Cañada Alamosa, thirty miles southwest of Fort Craig, a region traversed by five tributaries of the Rio Grande, some of which carry a large body of water, as the Rio Apache and Rio de las Animas. From Mimbres to Fort Craig the distance is more than one hundred miles.

With regard to the soil of Mimbres, it was thought proper to make another determination of the relative amount of moisture of the sub and surface soils, on account of crops being raised without irrigation.

	Subsoil.	Surface-soil
Gravel and sand	32.14	44.29
Silt, with little clay	58.09	49.66
Hygroscopic moisture	5.21	2.44
Chemically-bound water and trace organic matter	4.56	3.61
Potassa	0.184	
Soda	0.012	
Lime	3.169	
Magnesia, (chiefly present as carbonate)	0.214	
Phosphoric acid	0.101	
Sulphuric acid	0.002	
Alumina, Oxide of iron	4.700	
Insoluble in hydrochloric acid	79.90 per cent.	

This result shows the soil to be of good average quality. The subsoil has not only more water than the surface-soil, but also considerably more silt, while the amount of the coarse sand is decreased.

NORTHWESTERN NEW MEXICO.

With the exception of the region of the San Juan River, which was not visited, there is in this part of New Mexico but little extent of land suitable for settlements, and this small section is principally restricted to the banks of the Rio Grande from Albuquerque up to the boundary of Colorado, and to the well timbered Plateau region of Valle Grande. Over the rest of the country springs are occasionally found, as well as little mountain streams; the water, however, soon sinks into the ground, as, for instance, the Rio Puerco. Wherever the slightest opportunity for irrigation or raising stock is met with, a few Mexicans or Indians have settled, as at Tesuque, on the Rio Tesuque, Ojos Calientes, and Jemez, on the Rio Jemez, San Mateo, at the foot of Mount Taylor, Santo Espiritu, San Pablo, San Miguel, Nacimiento, Laguna, Acoma, the Zuni villages, and a number of localities on the Navajo reservation.

Forts Wingate and Defiance are unusually well provided with water. All these places form minute oases in a sandy desolated land, either barren or covered with sage-brush, or, on the more elevated portions, with juniper and occasonally piñon. The prevailing rock is sandstone, (Cretaceous and Carboniferous,) with here and there interruptions by volcanic formation. It cannot be denied that this is the poorest portion of New Mexico.

The Plateau region, with an elevation of over 7,000 feet above sea-level, is encountered but twice, viz, fifty miles west from Santa Fé (Valle Grande) and fifteen miles west from Fort Defiance, on the boundary-line of Arizona. But the extent of this well timbered plateau is comparatively small, not over forty miles in width. Here the fir and pine are most magnificently developed; oak, also, is plentiful, but only here and there is an old specimen seen, while groves of young trees are numerous. The Valle Grande proper occupies a high altitude, averaging 9,000 feet; it embraces about 100,000 acres and forms fine prairies with a luxuriant growth of grass. Thomas C. de Baca is the owner of this land. He grazes over 12,000 head of cattle, sheep, and goats in the valley, but thus far has done no farming, probably in consequence of the late frosts in spring and early frosts in fall. We had only 26°F. on the morning of the 24th of June. Dew falls almost every night in the year. The springs are of fine clear water, while the creeks abound in trout. The temperature of the springs ranges to that time from 54° to 55°F. The formation being volcanic, (rhyolite,) the soil must be derived from this material. A specimen of it was analyzed, with the following results:

Physical condition:	Per cent.
Fine and coarse sand	87.95
Fine silt and clay	12.05
Hygroscopic moisture	1.351
Chemical-bound water and organic matter	3 633

Chemical constituents:	Per cent.
Potassa	0.074
Soda	0.011
Lime	0.152
Magnesia	trace
Lithia	trace

	Per cent.
Sulphuric acid	trace
Phosphoric acid	0.029
Oxide of iron. } Alumina }	2.600
Insoluble particles of rhyolite	92.15

This soil possesses an unusually small amount of lime, certainly too small; for, although covered with fine grass, its quality for corn or grain is only medium.

With reference to the Rio Tesuque, some twenty miles east of the Rio Grande, it may be remarked that, although but a very small rill, it supplies water to quite a number of farms. The village Tesuque, inhabited by a branch of the Tehua tribe, is situated on its banks, while farther above, about seven miles west of Santa Fé, a number of Mexicans, an Englishman, and a German have settled. Irrigation is applied once a fortnight; grapes, corn, wheat, rhubarb, and cabbage being successfully cultivated. The potato foliage was vigorously developed, but the bulbs were small. Apricot trees of enormous size are raised, some of them 13 feet in circumference at the base, with branches 30 feet in length. Dew rarely falls, notwithstanding the low temperature at night; there is dew, however, on the pine-covered mountain range, six to eight miles to the northward, where the cattle find good pasturage.

THE COUNTRY OF THE MOQUIS.

These Indians dwell in Eastern Arizona, their habitations being built on the summit of several lofty sandstone mesas, surrounded by a wide, barren, sandy region, where grass is found but sparingly and in small patches. When at rare times this region is favored with more rain than usual, grass is plentiful. Thus Lieutenant Ives, who traversed the region in 1857, mentions a luxuriant growth of grass around the base of the mesas. The fully-developed corn-field, with its vivid green, strikingly contrasts with the barren sand, and the question naturally arises, "Why is soil, that will support Indian corn, unable to support grass?" There is no water for irrigation, and only a few small springs for household purposes. The sand is of light reddish color, loose, and does not require plowing. The use of manure is unknown to these Indians, and on it being suggested that their excreta would augment the crops, they answered us with a hearty laugh, doubtless thinking such a proceeding not only unclean, but ridiculous.

It is no longer a secret how the Indian corn is raised, when it is known that the sub-soil contains a sufficient amount of moisture to develop the seed, and that there is a slow and steady replacing of the loss of water by evaporation. That this is really the case is shown by chemical investigation. There must then be a stratum of water at a moderate depth, which ascends by capillary attraction; but, the soil being very loose and the air very dry, the water is rapidly evaporated as soon as it reaches the surface; hence no seed can germinate that falls on the surface. If the subsoil contained more than 5 per cent. of water, the young germ of the seed, which latter is generally planted from 1 foot to 18 inches deep, would rot before seeing the light.

Specimens of surface and subsoil were brought away in well-sealed bottles. Their moisture determinations are as follows:

	Subsoil.	Surface-soil.
Water, lost at 212° F	2.221	1.004
Water, lost at 212°–300° F	0.263	0.277
Water, lost at red heat	1.266	0.325

From this it is evident that the subsoil contains not only more than double the amount of hygroscopic moisture possessed by the surface-soil, but also more water in chemical combination. A great difference was also noticed in regard to the physical conditions, as will be seen by the following comparison:

	Subsoil.	Surface-soil.
Sand	72.04	89.37
Silt	27.96	10.63

From which it will be seen that the subsoil is the richer in silt, and since the nutritive qualities and chemically-bound water are greater in the silt, the value of the subsoil is enhanced in this direction, while from the surface-soil the wind carries away the finer particles. But there are, however, some nutritive qualities connected with the very surface, as will be seen by the analysis of the substances extracted by hydrochloric acid:

Potassa	0.072
Carbonate of lime	2.970 (lime=1.665)
Phosphoric acid	0.031
Soda / Lithia	traces
Alumina / Oxide of iron / Magnesia	2.327

Total extract by hydrochloric acid = 5.40 per cent.
Insoluble = 94.60 per cent.

THE BOTTOM LANDS OF THE COLORADO CHIQUITO AND CHEVELON'S FORK.

The bottom lands of the Colorado Chiquito are barren in the extreme, with but little grass, some grease-wood and sage-brush to relieve the monotony of the dreary landscape. The condition of the valley of Chevelon's Fork is somewhat better, cedar and grass being abundant, yet these bottom lands present nothing attractive or inviting. There is no doubt, however, as to the fertility of these areas, since a most vigorous vegetation may be seen along the margin of the river. The shores of both rivers are fringed with trees of various kinds, and also tall grasses in a flourishing state. Chevelon's Fork has never run dry within the memory of the whites. It is 2 to 4 feet deep, about 18 feet wide, and abounds in otter, beaver, turtle, and fish. The Colorado Chiquito, however, is dry every summer thirty miles below Sunset Crossing—the intersection of the road from Fort Wingate to Prescott. The altitude of this locality is 3,700 feet above sea level. These bottom lands are not inclosed by high mountain ranges, as are those on the Gila. Here the country is mostly a wide plain with occasional low hills, hence the temperature does not fall during the night as low as on the Gila. During our stay from August 8 to August 13, the temperature ranged as follows: At sunrise, 62° to 64° F.; at 2 p. m., 82° to 85°.5 F.; at sunset, 71° to 75° F. During three days it rained twice. Before the rainy season sets in the temperature will probably reach 95° or 100° during the afternoon. Cedar grows within eighteen and pine within seventy-five miles in a westerly direction. There is, however, an abundance of cottonwood along the margins of the river for local wants. The water of the Colorado Chiquito contains a little gypsum, the taste of which could be easily removed by filtering through sand.

With regard to Chevelon's Fork it may be mentioned that the river was visited at three points; at its mouth, thirty miles above, and at its head. Near its mouth the altitude of the country is about 4,000 feet, the land somewhat broken and irregular, but on its upper course where it traverses a region of from 4,600 to 5,200 feet in altitude are many flats suitable for farms. The head of this tributary of the Colorado Chiquito is situated on the southern extension of the forest-clad Mogollon Mesa. From the crossing of the Camp Apache road up to the pine region, some thirty miles, the country is excellently adapted for grazing purposes. Although this soil is sometimes rocky, sometimes coarse, and but a few inches deep, it is covered with a fine growth of grama grass. In this region the sandstone is superseded by basalt. A specimen of the soil of the bottom lands of Chevelon's Fork at the crossing of the Apache road was taken for analysis. It had a reddish color and was devoid of humus, and was derived from sandstone, (Triassic.) The locality was covered with juniper and some grass. Reaction neutral. It consisted of:

	Per cent.
Sand	53.10
Silt with clay	43.55
Hygroscopic moisture	1.89
Chemically-bound water and trace organic matter	1.46

On treatment with hydrochloric acid was obtained:

	Per cent.
Potassa	0.092
Soda	0.010
Lime	0.319
Phosphoric acid	0.070
Sulphuric acid, Magnesia, Alumina, Oxide of iron } by diff.	2.559
Insoluble in hydrochloric acid, (chiefly quartz sand)	93.55

With proper irrigation this soil would suit for crops of every variety. In view of the wide extension of the plateau of the Mogollon Mesa, south and west, it is highly probable that on sinking wells water would be found at a moderate depth in the valley.

THE MOGOLLON MESA.

This timber-covered plateau extends from the vicinity of Camp Apache in a northwesterly direction to the vicinity of the southern extension of the San Francisco Mountains, and is of an average width of ten to fifteen miles and an altitude of 7,000 feet. It was the source of former grand rivers as testified by cañons of gigantic dimensions. The cañon of the Big Dry Fork, for instance, is over seventy miles in length, and from 200 to 400 feet in depth; the walls are principally sandstone, with here and there limestone, and descend in terraces, sometimes, however, quite vertically. Around the small ponds or little rills on the bottom of this remarkable cañon an extraordinary vegetable life has been developed. Nothing of the cañon is noticed until one stands on the very margin where a pathway to the other side is looked for in vain. It was a tributary of the Colorado Chiquito. Its head at the present time is formed by a small creek that sinks when it reaches the juniper region. Numerous creeks head in this plateau, among them Chevelon's Fork, Cedar Creek, and Carrizo Creek. The Tonto Basin, a deep depression, borders this plateau on its south side. The carboniferous strata predominate, but the southern extension is covered by basaltic eruptions. Here are many forest meadows and fine valleys suitable for farming and stock-raising. From August 16th to the 20th the average temperature at sunrise was 54° F.; at 2 p. m., 76°; at sunset, 63°. Although this climate may be unfavorable for raising Indian corn, the hardier vegetables would grow with ease. A specimen of the soil was obtained from a grassy meadow covered with luxuriant vegetation and bordered by gigantic pines in the vicinity of Big Dry Fork. Its analysis resulted as follows:

Physical condition: Color, dark; consistency, loose.

	Per cent.
Sand	42.20
Silt and clay	37.98
Hygroscopic moisture	10.97
Humus and chemically-bound water	8.84

Chemical constituents:

Potassa	0.115
Soda, Lithia	traces
Magnesia	0.029

	Per cent.
Lime	0.153
Phosphoric acid	0.058
Oxide of iron, Alumina, Sulphuric acid } by diff	2.013
Total, soluble in hydrochloric acid, water included	22.188
Insoluble quartz and clay	77.812
	100.000

Not considering the rather small amount of lime, this composition corresponds to a fair average soil.

The rock from which this soil is derived is a red sandstone. The particles of quartz are cemented by ferruginous clay. On analysis, the rock gave 0.007 per cent. of phosphoric acid probably present in the cementing clay as phosphate of iron. As shown by the above results, the soil made up from this sandstone contains over eight times more phosphoric acid than the original rock; the clay and silt are also considerably increased. The latter fact is due to the action of the water in floating the lighter particles of the crumbling rock farther than the coarser ones. The increase of phosphoric acid and potassa is, however, proportionately greater than the increase of silt and clay, which is due to the extraction from the depths of these nutritive materials by the penetrating roots of the trees, providing the leaves, by capillary attraction, with these substances; upon the decay of the leaves these mineral substances remain to enrich the surface-soil for subsequent vegetation.

THE REGION OF THE SAN FRANCISCO MOUNTAINS.

This is a well timbered region, in the heart of Arizona, of an average altitude of 7,000 feet, some peaks being over 10,000 feet high. The predominating rock is basalt; here and there the strata of underlying limestone (Carboniferous) are exposed for some distance. On the way from the Dog Buttes, via the Cosnino Caves, Flat Top Mountain, to Rancheria Springs, we crossed a number of little valleys and open glades, splendidly suited for farming homes, here and there encountering springs and fine grass. The climate is very moderate and is similar to that of the Mogollon mesa.

The specimen of soil collected was from a small valley in the vicinity of Point Lookout and Rancheria Springs, about six miles north from the road to Prescott. Like many other valleys we had passed in this region, it was covered with a luxuriant growth. It being the rainy season at the time of our visit, much importance cannot be given to the amount of hygroscopic moisture found in the specimens.

Physical condition: Color, black; texture, loose; reaction, neutral.	
Gravel and sand	15.95
Fine silt	62.97
Hygroscopic moisture	12.83
Chemically-bound water and humus	8.25
Chemical constituents:	
Potassa	0.130
Soda with trace of lithia	0.017
Lime	0.684
Magnesia, Sulphuric acid	traces
Phosphoric acid	0.284
Alumina, Oxide of iron, by diff.	9.720
Insoluble in hydrochloric acid, basaltic particles and some humus	71.09

This soil is comparatively very rich in phosphoric acid, and therefore most excellent for grain and corn; for beans, peas, and lentils an addition of gypsum would be an improvement, these requiring more sulphur. Gypsum is found some thirty miles east, at the Sunset Gap mesas.

THE BOTTOM-LANDS OF THE SAN PEDRO RIVER.

The Rio San Pedro, in Southern Arizona, tributary of the Gila, which rises in the mountains of Sonora some thirty miles south of the boundary-line of Mexico, is flanked by broad belts of bottom-lands capable of irrigation. The river is on an average 12 feet wide and 2 feet deep. Several small settlements are found along its margins, among them San Pedro and Santa Catalina, two stations of the Southern Overland Mail Route. Below Santa Catalina, the river traverses a wide valley flanked on the west by the Sierra de Santa Catalina, and on the east by the Caliuro Mountains. A good deal of timber exists in this valley, principally mesquite and juniper; it is well grassed over. According to Leopold de Beau, a settler of Santa Catarina since 1857, the river never fails at that place; but during the last fifteen years ran dry twice twelve miles below. We are indebted to this gentleman for valuable information with regard to farming in this region. He informed us that the soil here yielded, per acre, 2,000 pounds of corn, valued at 3 cents per pound; 2,200 pounds of barley, valued at 3 cents per pound; 3,000 pounds of wheat, valued at 3½ cents per pound; 8,000 pounds of potatoes, valued at 10 cents per pound, the last mentioned being 7 cents near the close of the season. From this it will be seen that unusually high prices for farm produce rule in Southern Arizona. But if we take into consideration the occasional Indian depredations, the annual damage by large flocks of blackbirds in spoiling one-third of the crops, and the absence of competition, this condition of things may be easily accounted for. But little damage has been experienced from grasshoppers; bugs and worms, however, do great harm to beans and potatoes. Watermelons and beans are often killed by "rust." The planting of corn is done in the middle of April, and by the beginning of October the crops are ripe. Manure has never been used by Mr. Leopold de Beau. The chief market is Tucson, forty miles to the westward.

With regard to the climate, the gentleman in question remarked that there had been no snow during the last six years; late frosts, however, have been experienced on several occasions, and as late as May 29 the past year, necessitating replanting of the corn. It has heretofore been impossible to raise cattle on account of Indian depredations; the Indians, however, are now nearly all on reservations. Irrigation is carried on once in twelve days. There are over 5,000 acres of land in the immediate vicinity of the settlement that could be brought under cultivation. Similar information was obtained at San Pedro, ten miles above. The soil of these settlements is derived from the detritus of the Catalina and Caliuro mountains. On the former are encountered granite and Carboniferous limestones; on the latter rhyolite, basalt, and volcanic tufa. The soil is a reddish-gray color, of fine grain, neither heavy nor clayey, and of a weak alkaline reaction.

Physical condition:

Sand	14.00
Silt, with little clay	75.40
Hygroscopic moisture	6.09
Chemically-bound water and organic matter	4.51

Chemical constituents:

Potassa	0.401
Soda, with trace of lithia	0.051
Lime	4.356
Magnesia	1.019
Oxide of iron and alumina	6.850
Sulphuric acid	traces
Phosphoric acid	0.213
Insoluble in hydrochloric acid	71.100

As it is well provided with lime, potassa, and phosphoric acid, heavy crops are assured for many years to come without application of manure, except, perhaps, some gypsum. This useful mineral is found in the neighboring Wheatstone Mountains.

There can be no doubt that this portion of the country will prove exceedingly remunerative to the stock-raiser as well as to the enterprising farmer, and that it will be well populated at no distant day.

THE PLAIN OF CAMP GRANT.

The Caliuro Mountains to the west, the Graham Mountain range with Camp Grant to the north, the Chiricahui Mountains to the east, and the Mexican boundary south, inclose an extensive plain of at least eight hundred square miles. Standing near Camp Grant on the base of Mount Graham, one can overlook the whole region. A splendid mirage makes its appearance on the southern horizon every clear morning in the form of a transmuting mountain-chain.

Adjoining this plain to the northwest is Arivaypa Valley, and to the northeast a level stretch of country, bordered by the Peloncillo Mountains in the north. This vast area is without either running streams or timber; it is, however, covered to a great extent with fine grass. The soap-weed, the cactus, the sage-bush, and the grease-wood are but little found here. There are several springs of good water on this plain—Eureka Springs in the northwest and Croton and Sulphur Springs in its southern portion. Experiments have shown that water is reached almost everywhere on this plain at a depth of 10 feet, and it is therefore probable that certain crops could be raised without any irrigation were the seed planted at a depth of about 1 foot.

The surrounding mountain-ranges are well timbered, except the Caliuro

Mountains. The little mountain-streams sink soon after reaching the plain. To the west of the Dos Cabezas Mountain a few square miles are covered with white salt efflorescences, consisting chiefly of sulphate and carbonate of soda. Since the establishment of Camp Grant, about eighteen months ago, two stock-ranges have commenced business, with over 10,000 head of cattle. An abundant supply of water is procured at one ranch (Hooker's) from a well 15 feet deep. Crops will be raised this year for the first time. The soil is of the proper physical qualities, with the exception of a narrow strip of land below Croton Springs, where it is heavy and clayey—a fault easily remedied by an admixture of sand. The soil otherwise contains all the requisite chemical constituents. At some places below *Sulphur Springs** it is perfectly saturated with humidity. Two specimens of soil from this plain have been subjected to analysis; one from the northern, (A,) and one from the southern portion, (B.)

Physical conditions:	A	B
Sand	61.20	8.00
Silt and clay	34.07	58.24
Hygroscopic moisture	2.80	28.72
Chemically-bound water and organic matter	1.93	5.04
Reaction, (A), neutral; (B), alkaline.		
Chemical constituents:	Per cent.	Per cent.
Potassa	0.131	0.172
Soda	0.014	0.508
Magnesia	0.203	1.001
Lime	1.998	14.270
Phosphoric acid	0.095	0.033
Sulphuric acid	0.010	0.012
Oxide of iron / Alumina	2.304	2.199
Insoluble in hydrochloric acid	81.52	67.3

As shown by the results there is a very great difference between these two soils. "A" was taken from the vicinity of Camp Grant, where the ground was well grassed over, and undoubtedly represents a very good soil, but "B" is decidedly inferior. The latter was taken from the vicinity of the salt efflorescences above mentioned; hence the alkaline reaction and

* This spring, although called "Sulphur Springs," contains plain, good, potable water. Wherever this water stagnates a small trace of sulphuretted hydrogen is developed from the action of decaying vegetable matters upon the trace of gypsum present in the water.

excess of soda. This is a rather heavy, clayey soil, and when collected was saturated with humidity. There are, however, not over twenty square miles of this inferior land. The climate is very mild. During five days at Camp Grant, the end of last September, the temperature ranged, at sunrise, from 53° to 59° F.; at 2 p. m., from 85° to 88° F.; at sunset, from 63° to 72° F.

THE BOTTOM-LANDS OF THE GILA RIVER.

This river, next to the Rio Colorado the largest flowing through Arizona, rises in New Mexico, and courses in a southerly direction, bending to the west shortly before entering Arizona; thence to the San Carlos reservation, a distance of nearly one hundred and thirty miles, the valley of the river is bordered by mountain-chains; on the south by the Peloncillo, Graham, and Turnbull ranges, and on the north by the Cordillera del Gila and Triplet Mountains. From time to time the river enters rocky cañons, emerging again in small parks covered with fine grass. The margins are fringed with ash, cottonwood, and willow.

The water is clear, and above the mouth of the Rio Francisco, on an average 1 foot deep, and 15 feet wide; it reaches an average depth, however, of over 3 feet below the junctions of the Rio Francisco, the Prieto, and the Bonito. There are fine, large fishes, principally of the genus *Gila*, in all these rivers.

The Gila traverses many valleys, of one-half to five square miles in extent, that are well suited for small settlements. A great deal of land could be brought under cultivation from San Carlos up to the vicinity of Old Fort Goodwin. A small tributary of the Gila, that would suffice for irrigation in the vicinity of this locality, passes this abandoned military post. The few swamps in this region could be easily drained; being the source of fever and ague, the post was abandoned.

The Pueblo Viejo Valley, which adjoins the Gila bottom-lands, contains numerous and interesting ruins of habitations of extinct tribes. One farmer has recently settled in this valley. Granite, rhyolite, and basalt compose the neighboring mountain-chains, limestone being here and there encountered. The climate is subject to great extremes, owing to the shape of the region, as explained in another paragraph.

The manner in which soil and water are affected by great oscillations of temperature may be seen from the following table:

October 17.	At sunrise.	At 2 p. m.
Air	28° F.	77° F.
Surface-soil	30° F.	96° F.
Subsoil, (1 foot deep)	65°.5 F.	68° F.
Gila River water	56°.5 F.	67°.5 F.

As the summer months are exceedingly warm, the farm produce would thoroughly ripen before the frosts of October.

The soil is generally of fine grain, being coarse only near the base of the slopes. A specimen gave:

Fine sand and silt	92.26
Hygroscopic moisture	4.98
Chemically-bound water and organic matter	2.76
Chemical constituents:	
Potassa	0.242
Soda, with trace lithia	0.039
Lime	1.798
Magnesia	0.570
Sulphuric acid	traces
Phosphoric acid	0.214
Alumina and oxide of iron	2.311
Insoluble in hydrochloric acid	84.85

The soil is well suited for grain, corn, grapes, turnips, and clover; for beans and peas an addition of gypsum is recommended.

GENERAL REMARKS ON SOIL INVESTIGATIONS AND THE SOILS OF NEW MEXICO AND ARIZONA.

Since Justus von Liebig demonstrated the need and importance of mineral matters for vegetation, investigations of soils were inaugurated, which annually increased in interest. As to every other improvement, so opposition was made to this. "Intelligent old farmers" considered their own opinion regarding soils and their properties of more value than the results of scientific investigation, particularly when an inexperienced chemist interpreted an analysis in a wrong way, the farmer opponent pointed triumphantly to the false results of science. These opponents, however, are being rapidly converted; on finding their fields do not bear clover, or are unfit for turnips, they seek an explanation through chemical analysis. The study of the *chemical composition* must naturally go hand in hand with that of the *physical condition* of the soil; the latter may, in some instances, be such as to render agricultural pursuits impossible, notwithstanding the presence of all-important chemical combinations. This is the case, for example, when a soil is composed chiefly of clay. Lack of drainage during a rainy time and hard baking in dry weather here form great obstacles to successful cultivation. On the other hand, the fact of a soil being well covered with ordinary vegetation, as grass, is not positive proof that the soil contains all the conditions necessary for abundant crops. A good illustration is afforded by the contrast of the well-grassed soil of the Valle Grande with the barren soil of the valley of Chevelon's Fork. (See table.) The latter is richer than the former; that wanted water to develop its slumbering powers.

Physical conditions of the soil are porosity, color, conductive power of heat, power of appropriating atmospheric nitrogen, &c. Soil must neither hold too much water nor be coarse enough to retain none. A certain proportion of oxide of iron, clay, and humus is beneficial for the purpose of retaining humidity; humus and sand tend to bring about a certain porosity. A light-colored soil will not reach as high temperature on exposure to the sun as a dark-colored one; a bare soil reaches a higher temperature than a soil covered with vegetation, but cools off more during the night; the presence of moisture and resistance to frost depend in a certain degree upon these circumstances.

During our trip many observations were made as to the temperature soils reach on exposure to the sun's rays; the temperature of the surface, as well as the subsoil, was noted. Time of observation, 2 p. m.

	A	B	C	D	E	F	G	H
	°	°	°	°	°	°	°	°
Temperature of air	86	82	92	87	91	90	77	64
Temperature of surface-soil	129	141	133.5	143	126	106	96	91
Temperature of soil one foot deep	84	92	75	81	79	71	68	59

A.—Soil of vicinity of the Moquis villages; of very sandy nature, porous, dry, of light-reddish-gray color, (August 1.)

B.—Black sand, of volcanic material, from the vicinity of the Dog Buttes, San Francisco Mountain region, (August 3.)

C.—Dark soil, somewhat humid, from Eureka Springs, twenty miles west of Camp Grant, (September 23.)

D.—Dark soil of Camp Grant, foot of Mount Graham, plane inclined to south, (September 26.)

E.—Soil from San Pedro, mail-station of the Southern Overland Mail, from near the river; color light, (October 4.)

F.—Light-colored soil, of clayey character, very humid, from vicinity of Croton Springs, (October 5.)

G.—Soil of the Gila Valley, light-colored, fine-grained, (October 16.)

H.—Soil of Coleman's ranch, three miles west of Silver City, New Mexico, dark color, (October 25.)

The differences of soil-temperature will be found very great, even in instances where the temperature of the atmosphere showed no great differences. The cause of the exceedingly low temperature of "F" compared with "D" lies in the presence of a greater amount of humidity in the former.

Experience has shown that soils of a too much one-sided character are little adapted for farming; such, for instance, are:

Soils with excess of lime and quartz; 75 per cent. carbonate of lime; 20 per cent. quartz.

Soils with 50 per cent. clay and over.

Soils with 50 per cent. humus and 40 per cent. clay.

Soils with over 10 per cent. of chloride of sodium or sulphate of soda.

Soils with over 0.5 per cent. protosulphate of iron.

Soils with deficiency of lime; a soil with only 0.1 per cent. of lime is too poor for clover.

Soils with deficiency of potassa; a soil with only 0.01 per cent. of it would not suit for turnips.

Soils with deficiency of phosphoric acid; a soil containing less than 0.01 of it is a poor one.

Soils with deficiency of sulphuric acid. These occur more frequently than is generally supposed.

Deficiency in oxide of iron and silicic acid is hardly ever met with. The best soils are generally the limestone soils, which average 0.5 per cent. of potassa and 0.2 per cent. of phosphoric acid. Of this character is the soil for a great distance on the eastern slopes of the Mogollon Mesa, rarely met with elsewhere in New Mexico and Arizona.

The sandstone soils when deprived of humidity offer greater barrenness than other soils under this condition; hence the contrast of the northern portions of New Mexico and Arizona with the southern regions, in which granite and volcanic rocks prevail.

The annexed table, containing the soil analyses of the agricultural bottom-lands, is given for greater convenience of comparison. From this it will be observed that the bottom-lands of the San Pedro and Gila Rivers are the richest in potassa, and also that, next to the basalt soil from the San Francisco Mountains, they are the richest in phosphoric acid.

Lithia was found in traces in almost all these soils. It was also encountered in mica and feldspar, and in ashes of yucca and agave from Southern Arizona.

Some of the soils contained exceedingly faint traces of sulphuric acid. Happily this want is easily supplied, since sulphate of lime, or gypsum, occurs in many localities in New Mexico and Arizona; for example, at Wheatstone Mountains, Chevelon's Fork, Sunset Mesas, in Arizona; and at Rio Jemez, Rio Puerco, Diamond Creek, and Silver City, in New Mexico. It is also found in the adjoining northwestern part of Texas, spread over an area of many hundred square miles in unlimited quantities.

Composition of soils.

	Mimbres.	Valle Grande.	Moquis Villages.	Chevelon's Fork.	Mogollon Mesa.	San Francisco Mountains.	Rio San Pedro.	Camp Grant.	Rio Gila.
Predominating rock	Granite.	Rhyolite.	Sandstone.	Sandstone.	Sandstone.	Basalt.	Granite and rhyolite.	Granite.	Basalt and rhyolite.
Sand	32.14	87.97	72.04	53.10	42.20	15.95	14.00	61.20	....
Silt, with some clay	58.09	12.05	27.96	43.55	37.98	62.97	75.40	34.07	92.26
Potassa	0.184	0.074	0.072	0.092	0.115	0.130	0.401	0.131	0.242
Soda	0.012	0.011	Traces	0.010	Trace.	0.017	0.051	0.014	0.039
Lime	3.169	0.152	1.665	0.319	0.153	0.684	4.356	1.998	1.798
Magnesia	0.214	Trace...	} 2.327		0.029	Trace.	1.019	0.203	0.570
Alumina, Oxide of iron	} 4.700	2.600		2.559	} 2.013	9.729	6.850	2.304	2.311
Phosphoric acid	0.101	0.029	0.031	0.070	0.058	0.284	0.213	0.095	0.214
Sulphuric acid	0.002	Trace...	Trace.	Trace.	Trace.	Trace.	Trace.......	0.010	Traces..
Hygroscopic water	5.21	1.351	2.221	1.89	10.97	12.83	6.09	2.80	4.98
Chemically-bound water and organic matter.	4.56	3.633	1.529	1.46	8.84	8.25	4.51	1.93	2.76
Insoluble in hydrochloric acid	79.90	92.15	94.60	93.55	77.81	71.09	71.10	87.52	84.85

SECTION II.

CLIMATE OF THE GILA VALLEY; OZONE TESTS IN NEW MEXICO AND ARIZONA; GEOGRAPHICAL DISTRIBUTIONS OF PLANTS; LIST OF PLANTS OF MEDICAL AND TECHNICAL USE.

THE CLIMATE OF THE GILA VALLEY.

In this valley several noteworthy peculiarities of climate may be observed which are equally true as regards other regions of a similar character and of dry climate.

Our party was twice in the Gila Valley, crossing the Gila River the first time at the San Carlos reservation, leaving the valley in the vicinity of old Fort Goodwin. The second visit was on our return, when we crossed the Gila near the mouth of the Rio Francisco, (a tributary.) We remained in the valley three days. The differences of temperature per diem were very great, on several occasions amounting to 60°; while in August and the beginning of September the daily temperature ranges from 50° at sunrise to 105° F. at 2 p. m. In the beginning of October it ranges from 30° to 90°, and at the close of this month from 15° to 60° F.

The hygrometer generally, the rainy season—July and August—excepted, indicates a great degree of dryness of the atmosphere, and the wind, if any, blows generally from the southeast. Thus, with only rare exceptions, the temperature of a number of consecutive days is found to be the same at the same hours. But little inconvenience is experienced by this great change of 60° in temperature, since dry air is a poorer conductor of heat than humid air. Such extremes in an atmosphere charged with humidity would doubtless be very sensibly felt and prove injurious to health.

Humboldt tells us that in Cumana, where the air is always charged to its utmost capacity with aqueous vapor, the sinking of the temperature for but 5° Celsius (9° F.) causes a feeling akin to that produced by frosty weather. The great differences observed in a dry climate compared with a humid one are partially due to the differences of the calorific capacity of air and aqueous vapor, and partially to the barrenness of these mountain-ranges which do not reach the altitude of timber-growth. A barren spot when exposed to the sun naturally becomes hotter than a spot covered with vegetation. A humid atmosphere, on the contrary, will rise comparatively slowly in temperature during the morning hours; the dew on the ground will absorb the calorific rays of the sun until it has assumed the gaseous state, while during the night the rapid falling of the temperature is to a certain degree retarded upon reaching the dew-point. Thus water prevents the extremes that would otherwise occur.

But all these considerations, true as they are, are still insufficient to explain peculiarities observed in the Gila Valley. The Gila River, for instance, at sunrise has a lower temperature (57°.5 F., on the 16th of October) than the Rio Francisco, a tributary, (63° F.) The Gila River for the most part flows through a depression from five to ten miles in width, bordered by continuous mountains-chains, while the Rio Francisco courses through the rocky slopes of the Gila Range.

In the Gila Valley, at sunrise on the 17th October, the temperature was 28° F., while at the base of the mountain-range, about ten miles off, it was 40° F.

On the 18th October, when again encamped in the Gila Valley, about fifteen miles above the former camp, the temperature at sunrise was as low as 14° F., yet no change of wind or of any other atmospheric condition had occurred; there was only a change of locality, the contour of the valley being triflingly different, while the barren mountain-chains inclosing it appeared somewhat higher.

On the 19th of October we were encamped on a wide plain adjoining the Gila Valley where it leaves New Mexico and, bending to the westward, enters Arizona. The atmospheric conditions with regard to wind and moisture were the same as before, but the temperature was as high as 40° at sunrise—a great contrast with the previous day.

On the 20th October we camped on the foot of the western slopes of the Burro Mountains, where the temperature was even 2° higher than that of the day previous. Still the altitudes had been steadily increasing during the march, as will be seen by the following table:

Date.	Altitude.	Temperature.	
		At sunrise.	At sunset.
	Feet.	°	°
October 18	4,500	14	53
October 19	5,200	40	56
October 20	6,100	42	57

From this it will be seen that although not differing essentially at sunset, the temperatures present a marked contrast during the night. This fact is characteristic of a dry climate. *In a valley inclosed by mountain ranges or chains, the night temperature will sink lowest where the depression is greatest.* This may be easily understood when it is recollected that the surface of the barren mountains heated by the sun's rays must in cooling off during the night necessarily produce a motion of the atmosphere from the strata of the upper regions down to the greatest depression, as here illustrated:

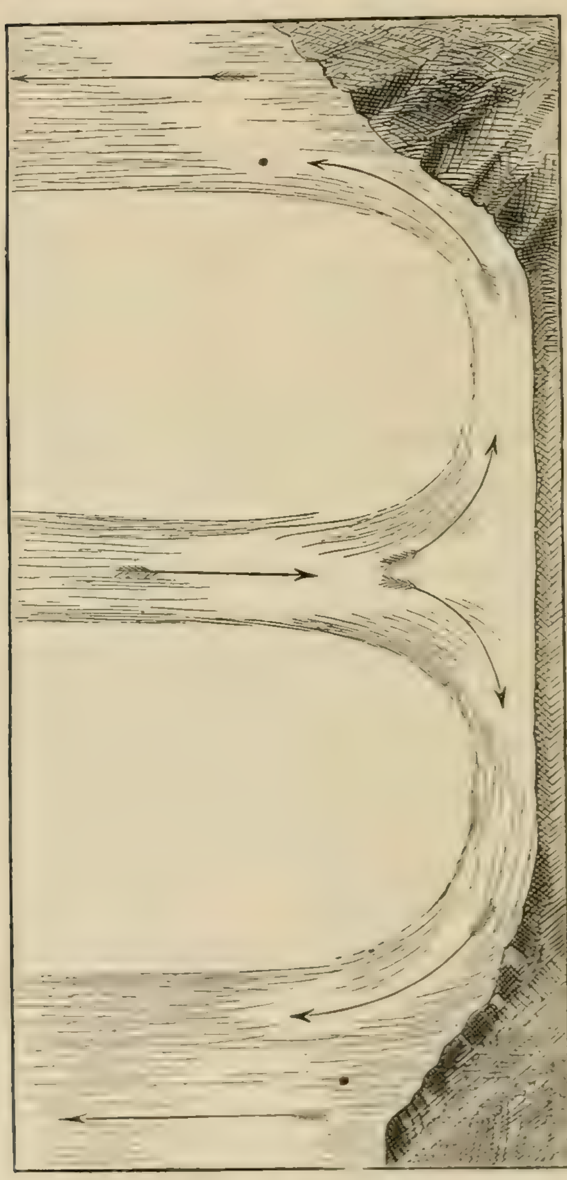


Fig. 170.—Ideal sketch of air-currents in interior mountain valleys.

Thus the point *a* will be the coolest place, and *b* the warmest; the descending current having arrived at *a*, in proceeding to *b*, takes up the heat of the ground. Immediately after sundown a current sets in from the mountains toward the valley, caused by the sudden contraction of the air of the latter region, which is naturally hotter during the day than the air of the mountain; but about two hours after sunset a reverse current takes place as above illustrated. The cooling-off of a wide plain during the night evidently takes place under different circumstances. The air ascending from the warm ground meets resistance in the descending cool air, and while a slow mingling thus takes place the falling of the temperature will be retarded. The loss by radiation is insignificant compared with the loss by atmospheric circulation. Another instance of the considerable falling of temperature in valleys was observed at Eureka Springs, the greatest depression of the valley adjoining the western slopes of Mount Graham in Arizona. Here the temperature, at sunrise on the 22d of September, was 44° F., while at Camp Grant, twelve miles east, and immediately at the foot of Mount Graham, it was 53° F. The altitude of Camp Grant is 5,400 feet, while that of Eureka Springs is but 4,900. We have therefore *a lower night temperature notwithstanding the lesser altitude.*

Recognition of the above elucidated law may prove of value in establishing farms in the dry regions of the West. Many plants growing along the slopes of a mountain-chain will not thrive in the adjoining valley, a marked example being the Giant Cactus, (*Cereus giganteus.*) This plant cannot bear a very low temperature.

It can easily be understood why in other climates the temperature, *cæteris paribus*, does not, in basins surrounded by mountain-chains, sink as low during the night as in the dry regions; the falling dew would counteract the upward movement of the air along the mountain sides; moreover, a country well covered with trees and grass does not admit as free circulation of the air as do the bare, rocky slopes of mountains.

OZONE TESTS IN NEW MEXICO AND ARIZONA.

Few substances have for the past twenty years awakened such interest in the chemical world as ozone, particularly that of the atmosphere, to which many noted investigators have devoted special attention; indeed, the subject has developed a voluminous literature.

The air of forests and deserts, of mountains and valleys, of cities, mines, and factories, of healthy and sickly regions, of hot and cold, and of wet and dry seasons, have been subjected to careful tests; but the general conclusions arrived at by different observers thus far do not perfectly agree. Among the latest contributions on this subject are communications from M. Ebermayer, "On Atmospheric Ozone and Spread of Diseases," (*Moniteur Scientifique*, October, 1873,) and one by Houzeau, (*Chemical News*, November, 1873.) The latter concludes, as the results of his inquiries, that the chief cause of the production of ozone in the atmosphere is electricity. There is no doubt, however, that a certain portion is produced by the oxydation of vegetable matter. Ozone was found to act as a strong disinfectant by its energetic power of oxydation; hence it was inferred by some authors that the atmospheric ozone could arrest infection by destroying the germs of malarious disease. But it must not be forgotten that the ozone operated within the laboratory was at least a thousand times more concentrated than that found in the atmosphere. Dr. Mitchell says: "No sound conclusions can be deduced from the comparison of the fluctuations of disease with ozone observations as at present made."

Dr. George Baird says: "Summing up in a few words, we may say that atmospheric ozone is more abundant during the winter and spring, because in those seasons there is much rain, snow, hail, and wind, a low temperature, and a maximum of electricity. In the summer and autumn, ozone is least abundant, because during these seasons there is no snow or hail, less wind and rain, high temperature, and a minimum of electricity." Further, in relation to disease, he says: "A deficiency of ozone in the air probably bears a certain relation to epidemic and chronic diseases. Deficiency of ozone invites disease, debilitating the system, and thus making it less capable of contending with morbid influences."

During our trip, numerous tests were made for ozone, from June to November, in various altitudes, of from 4,000 to 10,000 feet above sea-level, in well-timbered regions and in deserts, in healthy and unhealthy, or malarious places. The tests were made with papers impregnated with iodide of potassium-starch, which were freshly prepared for each test. The papers were generally exposed during the night; for tests during the day, they were well protected against the direct rays of the sun. The following conclusions were arrived at:

(1.) There is no difference in the amount of ozone between healthy and malarious places. At old Fort Goodwin, a place noted for fever and ague, and abandoned on this account by the military authorities, ozone reactions of the same intensity were obtained September 15 as at Camp Apache September 5, a place not affected by malaria.

(2.) The dryness and uniformity of the climate of New Mexico and Arizona are the cause of the insignificant changes in the quantity of ozone. Even in the barren region of the Painted Desert the usual intensity was observed. A moderately strong wind was blowing during the night of observation.

(3.) No marked differences could be observed between the intensities of the reactions of September, October, and November.

(4.) A very marked increase of ozone was observed in the well-timbered plateau region of Valle Grande, June 30; in a small side-valley filled with the perfumes of flowering plants, Menthene and Terebene were particularly prominent.

THE GEOGRAPHICAL DISTRIBUTION OF PLANTS.

In a country where the altitudes are subject to repeated and great variations—where low bottom-lands continually alternate with plateau regions—a favorable occasion is presented for close study of the geographical distribution of plants. A botanical specialist, with the material derived from such a region, could produce a most interesting volume.

The facts here presented as the results of observations during our trip, though mere outlines, may serve as a basis for further study of this interesting subject, which is undoubtedly of considerable value in an agricultural point of view.

The regions of the Southwest may be divided into four distinct zones, (according to altitude:)

(1.) Zone of Cactus, Yucca, and Agave; altitude, 3,000 to 3,500 feet; grass is scanty. Where there is water, a most luxuriant vegetation springs up.

(2.) Zone of Obione and Artemisia, (Greasewood and Sage-brush;) altitude, 3,500 to 4,900 feet. Grass is poor, with few exceptions, on granitic and volcanic soil. The Cactus species are diminished in number.

(3.) Zone of *Juniperus occidentalis*, (Cedar;) altitude, 4,900 to 6,800 feet; Cactus species few.

(4.) Zone of Pine and Fir, 6,800 to 10,800 feet, (highest points.)

These limitations are subject, of course, to some variation through various local causes; they descend more on eastern and northern than on southern and western slopes. Above 8,000 feet nightly dews fall. Thus a flora may exist in many respects resembling that of our eastern forests as well as of the forests of Central Europe. Below the pine regions the flora becomes more scanty, and assumes quite a distinct character, corresponding to the dry climate. Glancing at the flora of the pine region in Arizona and New Mexico, we find in the more elevated portions the Quaking Aspen, (*Populus tremuloides*,) a tree seldom occurring below 7,500 feet; the same may be said of the Fern, (*Pteris aquilina.*) *Quercus alba* (White Oak) accompanies the pine from 7,000 feet upward; it is not found, however, to any great extent, and is principally in small patches, or groves.


FIG. 171.—Specimen of secondary tree-growth, Colorado Plateau.

A peculiar species of juniper, of tree-growth, is here and there met with at an altitude of 7,000 feet. *Rubus ideaus* and *Ribes cynosbati* (Raspberry and Goose berry) occur at the same height. We observed them, however, only at Point Lookout, in the San Francisco Mountains. *Cerasus* (Wild Cherry) was not met with. Quite a number of species of pine and fir was encountered; the former predominating, and occasionally so vigorously developed that branches ramify in a descending direction to such extent as to resemble a widely diverging root. Sometimes a branch was seen converted into a secondary tree, with roots, trunks, and branches.

Splendid forests of gigantic pines were traversed, wherein no young trees were noticed. At an altitude of 10,000 feet, in the Valle Grande, fifty to sixty miles west of Santa Fé, the following-named plants and trees were observed: *Viola canina; Tormentilla erecta; Gnaphalium sylvaticum; Cerastium arvense; Taraxacum dens-leonis; Achillea millefolium; Sambucus nigra; Vicia; Geranium; Lithospermum.*

At an altitude of 7,500 feet, in the San Francisco Mountains, we encountered, in August, *Solidago virga-aurea; Linum perenne.*

On the Mogollon Mesa, in an altitude of 6,800 feet, were found, in August, *Epilobium angustifolium; Rosa; Myosotis palustris; Acer; Ranunculus acris; Humulus lupulus; Brunella vulgaris; Chærophyllum; Allium; Valeriana.*

Of the cryptogams were noticed the genera *Equisetum, Dicranum, Barbula, Usnea, Polytrichum, Mnium, Parmelia, Hypnum, Fontinalis,* but never *Sphagnum;* all efforts to find it proved futile. This moss is unable to live in absence of abundant water.

The zone of *Juniperus* embraces that of the Piñon, (*Pinus edulis,*) which is found at an altitude of 5,700 to 6,800 feet. Scrub Oak and Live Oak, (*Quercus acrifolia* and *Q. emoryi,*) especially in Southern Arizona, are associated with the Juniper.

Yucca baccata (Amole, or Soapweed) forms an essential part of the flora, and is the only Yucca of this zone. Here and there *Opuntia arborescens* occurs. Other plants, found occasionally here, are *Achillea millefolium, Ephedra antisyphylitica, Solanum, Mentzelia albicaulis, Pectis angustifolia, Aplopappus.*

We find along creeks *Epilobium montanum; Juglans nigra,* (Black Walnut;) *Humulus lupulus,* (Hops;) *Platanus occidentalis,* (Sycamore;) *Populus monilifera,* (Cottonwood;) *Schrankia uncinata,* &c.

The latter plant was found but once, namely, at the head of Cañon Diablo.

Campanula rotundifolia was encountered only once in this zone, and then near a spring in the Navajo reservation, (July 26.) In the Pine region, however, it occurs at an altitude of 10,000 feet, near the summit of Mount Graham, (September 28.) Thus this plant appears to range through wide altitudes. A peculiar Mistletoe vigorously vegetates upon the Juniper-bushes, often entirely covering them.

The species of Cactus increase in number as we descend and become more numerous at an altitude of 3,000 to 4,000 feet.

Opuntia bulbispina, O. grahami, O. emoryi, Cereus giganteus, Cereus stramineus, Echinocactus septispinus, and many others are limited to the southern part of Arizona. The species of Yucca also there increase to six.

Cereus giganteus can hardly be found above an altitude of 3,500 feet. This plant appears to depend also considerably upon the nature of the ground, inasmuch as it favors calcareous soil. The Mesquite-tree (*Algarobia*) is found in three species, in altitudes of 3,000 to 4,500 feet, but rarely occurs north of the Gila, except in a low bush-like species. The Mesquite-tree, Cactus, and Yucca are the representatives of a dry and hot climate. It is clearly shown by the structure of these plants that it is necessary they should by every means prevent the loss of water by evaporation from their surface. The leaves are either very small, (as in Mesquite, Stinkweed, Greasewood,) or they are covered with a thick, dense layer, (as in Yucca, Agave,) or they have no leaves proper, the function of these being performed either by the trunk, as in Cactus, or by the branches, as in Ephedra. A further peculiarity is the large amount of mineral matter they have accumulated, which yields protection during long drought.

Of the grasses, the grama-grasses *Chondrosium* and *Bouteloua* are the most important. They exist in altitudes of from 4,000 to 7,000 feet, and are partial to granitic, rhyolitic, and basaltic soil, avoiding that derived from limestone, clay, or sandstone. They are frequently accompanied by the mesquite-grass, (*Sesleria dactyloides.*)

Beyond 7,000 feet, various other grasses occur. The peculiar growth of the grasses in "bunches" is characteristic. The cause is evidently this: the seeds of the grasses can rarely germinate on account of the dryness of the surface, coarseness of the soil, and absence of aqueous precipitates. Sweeping winds carry the finer particles away from the dry surface, leaving only the coarse ones. The grasses therefore mainly spread by their roots, thus causing the "bunch" growth. Hence a New Mexico prairie is in striking contrast to our eastern meadow, where the grass forms a net-work so dense as to render the surface of the ground invisible to the eye. Among other grasses may be mentioned *Arundinaria*, growing in swampy places, and the so-called *Sacaton* grass. Around salt-marshes, the peculiar *Bryzopyrum spicatum* is frequently found.

LIST OF PLANTS OF MEDICAL AND TECHNICAL USE.

Numerous valuable plants are indigenous to Arizona and New Mexico, but more time would be required for a detailed study than a hasty trip through these Territories affords. We mention the following:

Yucca baccata, (Amole, Soapweed, Spanish Bayonet.) This and related species form a conspicuous part in the flora of those Territories. Their peculiar leaves are provided with strong fibers well suited for rope, cloths, strong paper, &c. The roots, especially that of *Yucca baccata*, are used by the Mexicans and Indians as a substitute for soap, which is said to be excellent for cleansing woolen goods and hair, to which it imparts a peculiar glossy appearance. The pounded root is reduced to a pulp by adding water, when it is ready for use. The fruit of *Yucca baccata* is of excellent taste, resembling that of the Banana, but unfortunately the plant seldom flowers.

Agave, next related to *Agave decipiens—Maguey* of the Mexicans, and *Mescal* of the Indians.—The undeveloped leaves (or the "heart") of this plant are used as an article of food, and also in the manufacture of an alcoholic beverage. For further particulars see page 610.

Arundinaria is a grass of 10 to 14 feet in height, of strong fiber, well suited for paper making. A specimen of paper-pulp was prepared from this fiber. It could easily be bleached by the application of a diluted solution of permanganate of potassa and sulphurous acid.

Algarobia, the Mesquite-tree, occurs in three species in Southern Arizona. It furnishes a valuable gum, undistinguishable from genuine gum Arabic.

Algarobia glandulosa occurs in dense forests here and in Western Texas, the gum of which has constituted an article of commerce for some years past. The beans of the tree are rich in grape-sugar, containing as much as 30 per cent., and furnish a valuable food for cattle. The taste, though sweet, is disagreeable, which renders them undesirable as food for man. Indians of the Comanche tribe prepare an alcoholic beverage from the beans. The wood of the tree, which is dense and hard, is an excellent material for cabinet-work. The charcoal prepared from it is unsurpassed for metallurgical and smelting purposes.

Opuntia.—The fruit of this Cactus contains pectin, grape-sugar, and tartaric acid; it is an article of food for Indians as well as for bears.

Pectis angustifolia.—A small yellow Composite, growing in Cedar-woods, possesses an intense odor of essence of lemon. It may be worth while to experiment upon its cultivation, since the essence of lemon is a valuable article. Another and larger species of *Pectis* has a peculiar action on the salivary glands.

Juniperus occurs in several species. In the vicinity of Santa Fé, a balsam is gathered from it by boring a hole into the lower part of the trunk, and is used in various urinary diseases. Mr. A. Krummeck, apothecary in Santa Fé, recommends the following formula: Balsam. junip., 1 dr.; alcohol, 1 oz.; manna, 2 drs.: dose, two drops three times a day. This gentleman asserts that this substance is far superior to Canada balsam. It is of strong aromatic odor, of light-yellow color, perfectly transparent, and imperfectly soluble in alcohol. It has also been found to be valuable in the preparation of varnish.

Populus tremuloides.—The bark of this tree is used by Indians as a remedy against fever and ague. On analysis, populin and salicin, known constituents of the Poplar family, were found. No trace of quinine could be detected; and the febrifugal properties are probably due to the salicin and populin.

Ephedra antisyphilitica is used in form of a decoction against venereal diseases, which are said to be peculiarly wide-spread in these regions.

Angelica, a peculiar species of the umbelliferous family, grows upon the Sierra Gorda, and furnishes a strongly aromatic root, used for weakness of the system. Mr. Krummeck considers this root more effectual than that of our eastern Angelica species.

Among plants used for bathing purposes in rheumatic affections, the so-called Creosote-bush, *Larrea Mexicana*, (Stinkweed or Etiontio,) may be mentioned. The branches of this plant are often found covered with a red-brown exudate,* caused by an insect; the leaves are rich in a peculiar resin. The alcoholic extract of the leaves on evaporation yields a greenish-brown residue of a specific and somewhat disagreeable odor, more strongly perceptible on boiling the extract with water. This residue is only to a small extent soluble in water, and the solution has an acid reaction. It yields a

*A red coloring-matter can be extracted showing all the reactions of cochineal.

light-yellow precipitate with acetate of lead. The part of the alcoholic extract that is insoluble in water is easily soluble in alkalies. It also dissolves in nitric acid at a moderate heat, whereby oxydation takes place. On addition of water, a yellow, brittle mass is precipitated. For bathing purposes, an infusion of the leaves is made, which is said to be of excellent service.

THE CHEMICAL CONSTITUENTS OF THE SOAPWEED.

The root of *Yucca baccata* is used, as before mentioned, as a substitute for soap. The froth produced on shaking the pounded root with water resembles the foam of soap. The root is cylindrical, 2 to 3 inches thick, branching, and covered with a brown, brittle bark. The taste is at first sweet, afterward bitter and scratching. Ether extracts but little, consisting of resinous and fatty matter. The alcoholic extract of the root on cooling deposits a flocculent precipitate; on evaporation, the filtrate leaves a residuum, containing, among other substances, sugar and resin.

The aqueous extract of the root has an acid reaction and behaves as follows:

Ammonia or potassa—no precipitate.

Baryta water—flocculent precipitate.

Acetate of lead—precipitate insoluble in excess.

Fehling's copper solution—red precipitate on boiling. The reaction is much stronger after boiling with dilute acids.

Chloride of iron—greenish coloration. About a pound of the root was cut into small pieces and extracted with warm water; the extract was evaporated to a sirupy liquid, and this treated with alcohol. One part remained insoluble—chiefly gum—while another was dissolved, consisting partially of grape and cane sugar. The alcohol was distilled off, the residue dissolved in water, and precipitated with neutral acetate of lead; the precipitate filtered off, washed, and decomposed by a current of sulphureted hydrogen filtered and evaporated; thus a body was obtained easily soluble in water, less in strong alcohol, of burning, scratching, bitter taste. On shaking, the aqueous solution produces a voluminous foam; it has an acid reaction, and gives a precipitate with baryta water, insoluble in excess of it.

All this agrees with the qualities of *saponin*, a substance contained in many other plants, as *Agrostemma githago, Silene inflata, and Polygala senega.*

The property of the Yucca root, to produce froth on agitation with water, is therefore due to the presence of saponin, and the cleansing of goods may mainly be attributed to the froth.

THE MESCAL.

In Southern Arizona, some parts of Utah and New Mexico, a peculiar species of *Agave* occurs, (most related to *Agave decipiens,*) called Maguey or Mescal, which is used by Indians as an article of food. The undeveloped leaves, folded one into another like a bud, are perfectly white and soft as long as they remain protected against the sunlight by the exterior leaves. They are of a slightly sweet taste at first; afterward, somewhat biting. These leaves, the so-called "heart" of the plant, assume a very sweet taste, which is, at the same time, somewhat sour when exposed to heat for several hours, when it becomes sufficiently soft to enable the fibrous parts to be easily removed. No peculiar smell is perceptible. In such localities where the plant grows abundantly, stone-hearths have been erected, upon which the Mescal is subjected to roasting; the charcoal fire is kept up about six hours. A large hearth of about five feet in diameter was seen by us on the south side of Mount Turnbull, in Southern Arizona. On trying the experiment of roasting the Mescal myself, I was somewhat surprised by the thorough change that took place, and endeavored in vain to trace such a behavior to a known substance. We are aware that starch will yield sugar on being boiled with diluted sulphuric or muriatic acid; or, also, on being digested at 60° with diastase. We know, also, that there are many glucosids that are split up, on treatment with mineral acids, into sugar and various other compounds. But with the Mescal the case is different, the sugar being formed without aid from mineral acids. There is no starch present in the plant; iodine does not reveal even a trace of it; neither is there present any known isomer of starch, as inulin or lichenin. I was therefore led to the conclusion that we have either a new isomer of starch, or a new glucosid before us, and took a sufficient amount of the raw, dried material for investigation. If the finely-pulverized Mescal be treated with alcohol to remove the trace of adhering sugar, the substance, upon boiling with water for a few minutes, yields grape-sugar in abundance; this also takes place on treatment with a large quantity of cold water, and it appears to be an impossibility to separate the new substance from the cellular tissue without simultaneous formation of grape-sugar; all attempts to this end were in vain. If the substance was a glucosid, another product besides grape-sugar would be formed in the decomposition; and if this product could be isolated, the nature of the original compound in the Mescal would be revealed, inasmuch as it represents a glucosid of this secondary product. Such a substance was, indeed, found; it is contained in solution, together with sugar, when Mescal is boiled with water; it yields a precipitate with neutral acetate of lead. This precipitate, after being well washed, was decomposed by sulphureted hydrogen, and the filtrate from the sulphide of lead evaporated. Thus an acid was obtained of an agreeable taste, easily soluble in alcohol and water. A close examination proved it to be *Citric acid*, easily recognized by the peculiar behavior of the lime-salt, which is more soluble in cold than in hot water. Oxalic, succinic, malic, aconitic, and fumaric acids were absent; tartaric acid was present in small quantities. The nature of the original substance is thus revealed, and proves to be a glucosid of citric acid—a compound heretofore neither found in nature nor prepared artificially in the laboratory. This glucosid forms an exception to the usual behavior of this class of bodies, as water alone can bring about its decomposition into grape-sugar and citric acid. The rational name for this combination is Citro-glucosid.

INVESTIGATION OF EPHEDRA ANTISYPHILITICA.

This plant, as above mentioned, is largely used by Mexicans as a remedy for venereal diseases, and it is claimed that it possesses all the virtues ascribed to it. Were this confirmed by our medical men of experience, another step toward the knowledge of our medical herbs and shrubs would be made. With this view, chemical examination was made. The mineral constituents of the air-dried leaves amount to 5.58 per cent. The aqueous extract of the leaves has an acid reaction, and an astringent taste, resembling that of tannin.

Lime-water produces a greenish-black precipitate.

Chloride of iron produces a black precipitate.

Acetate of lead produces a light-yellow precipitate.

Basic acetate of lead produces an increased light-yellow precipitate.

Fehling's solution undergoes reduction.

Preliminary experiments had convinced me that there was no body resembling an organic base or alkaloid present, and that the active principle, if any was present, was of either a neutral or an acid character.

A large quantity of aqueous infusion was precipitated with basic acetate of lead, and the precipitate, after being well washed, decomposed by sulphureted hydrogen. The filtrate had an astringent and strongly sour taste: the former due to tannin; the latter to tartaric acid present in the plant. Besides these combinations, there is *Pectin* in the filtrate, as is indicated by the jelly-like precipitate produced by the addition of alcohol.

The whole filtrate from the sulphide of lead was concentrated in the water-bath. In this operation an interesting phenomenon was observed, consisting in the separation of a dark-red, insoluble powder, the development of the characteristic odor of crude pyroligneous acid, and the formation of glucose. This decomposition was no doubt due to the action of the tartaric acid upon the tannin. It is known, from recent investigations, that there are quite a number of bodies showing more or less the properties of "tannin" formerly supposed to be one identical substance in many different plants, and that there are two distinct groups of tannins; the one yields *green*, the other blue and black precipitates with salts of oxide of iron. The latter are glucosids, furnishing sugar on treatment with acids and various other compounds, and, upon dry distillation, pyrogallic and carbonic acids, while the former yields, on dry distillation, pyrocatechin.

The "tannin" of *Ephedra antisyphilitica* is evidently a glucosid: on treatment with acids, it splits up into sugar and the red amorphous powder above mentioned. I took this red powder at first to be "rufigallic acid," but subsequent tests proved this opinion erroneous. It is not soluble in water and alcohol, easily in alkalies, yielding brown-black solutions. It is quite a distinct body, and I name it *Ephedrin*. The principle which in *Ephedra antisyphilitica* may prove of medical action would be due to the peculiar kind of tannin it contains.

CHAPTER XXII.

ANALYSES OF MINERAL SPRINGS AND MINERALS.

The mineral springs of Ojos Calientes and San Isidro, N. Mex.; The hot springs of the Rio San Francisco, Ariz.; The mineral springs of Cañon City and Manitou, Colo.; Parnassus Springs; Warm sulphur springs on the Navajo River; Carlisle Spring; Springs of Wagonwheel Gap; Las Vegas Springs and Hot Springs of Abiquiu, N. Mex.; Spring near Rio Pajarito; Pagosa Hot Sulphur Spring, Colo.; Salt from a salt lake east of the Sandia Mountain, N. Mex.; Salt efflorescences from Ojo de Tao, N. Mex.; Sunset Crossing, Santa Catarina, and Croton Springs, Ariz.; Incrustation from the Alum Cave on Cook's Peak, N. Mex., and from Cosonino Caves, Ariz.; "Wheelerite," a new fossil resin; The coals of New Mexico and Colorado; Composition of various ores from New Mexico and Colorado; Composition of kaolin from Arizona and Utah.

THE MINERAL SPRINGS OF OJOS CALIENTES, NEW MEXICO.

These far-famed springs of New Mexico are situated twelve miles above the town of Jemez, on the Jemez Creek, and are inclosed in a deep spacious cañon. (See Plate XIII.) The slopes of the cañon are formed by strata of limestone and sandstone of Carboniferous age, often changed from their original positions by protruding volcanic material. There are two distinct groups of warm springs in the valley, two miles apart. The springs of the lower group consist of:

(1.) A geyser with a surface of 60 square feet, and an aperture of 1 square foot; the temperature is 168° F.; large quantities of escaping carbonic acid keep the water in violent agitation; thick deposits of snow-white crusts are formed, consisting chiefly of carbonate of lime. This spring yields about fifty gallons of water per minute.

(2.) One spring with a surface of 6 square feet and a temperature of 130° F.; it contains free carbonic acid and forms a red-brown deposit.

(3.) Three springs, with a temperature of 119° F., covered with a vigorous growth of a peculiar alga. Dr. Schaeffer, of the Army Medical Museum, who kindly examined a specimen of this vegetable scum of intense green color, pronounces it as filaments of *Oscillatoria*, 0.005 of an inch in thickness. Globular *Gonidia* were also found.*

When this vegetable scum is left to stagnate in the small pools near the springs, a black deposit of sulphide of iron is formed. This is the result of the action of the sulphureted hydrogen upon the carbonate of iron in the water and the oxide of iron in the alga-plant. The sulphureted hydrogen is a product of the reduction of the gypsum contained in the water.

(4.) One spring of 110° F.

(5.) Two springs of 108° F.

(6.) Several small springs of 94° to 102° F.

The water of the geyser contained in 100 parts—

Chloride of sodium	0.1622
Sulphate of soda	0.0035
Carbonate of lime	0.0641
Carbonate of magnesia	0.0103
Potassa	Traces.
Lithia	Traces.
Silicic acid	Traces.
Sulphate of lime	Traces.
Total amount of salts	0.2401

Tests were made for iodine in the evaporation residue of several gallons of the water, but none was detected.

One of the springs of 119° F. gave the following composition:

Specific gravity = 1.0016.

In 100 parts of water are—

Chloride of sodium	0.1508
Sulphate of lime	0.0262
Carbonate of lime	0.0300
Carbonate of magnesia	0.0240
Carbonate of iron	0.0002
Silicic acid	0.0010
Lithia	Traces.
Potassa	Traces.
Carbonate of iron	Traces.
	0.2322

* Prof. H. C. Wood determined the alga as *Nostoc Calidarium*.

The upper group consists of forty-two springs; the taste of the water is somewhat like Vichy; the temperature ranges between 70° F. and 105° F., with but few exceptions; the surface of each is less than 1 square foot. The most of these springs originate in cones and mounds, consisting of spring-deposit, chiefly carbonate of lime. One of these mounds is 20 feet high, 10 feet wide, and 130 feet long, with twenty-two springs on it. A few yards above, and at right angles to it, is another mound, 30 feet high, about 200 feet long, and 15 feet wide. On the eastern end of this mound is a cave 10 feet high, 25 feet long, and 7 feet wide, with snow-white walls and two columns. The water of the first spring, or the most southerly of this group, was subjected to analysis. After the loss of the free carbonic acid, it has an alkaline reaction.

Specific gravity = 1.0023.

In 100 parts are contained—

Chloride of sodium	0.2642
Sulphate of soda	0 0059
Carbonate of soda	0.0219
Carbonate of lime	0.0548
Carbonate of magnesia	0.0057
Silicic acid	0.0201
Phosphoric acid Potassa Lithia	Traces.
	0.3726

This composition resembles that of several springs of Marienbad in Bohemia. Besides these warm mineral springs, there are other springs of ordinary cold water in the valley. People from different parts of New Mexico, especially those syphilitically afflicted, resort hither during the summer months on account of the curative properties of these waters.

As there are no hotel accommodations, tents are pitched usually in the immediate vicinity of the springs. There are some half a dozen Mexican families residing in the vicinity. Half-way between the two groups are seen the ruins of a grand edifice, formerly perhaps a fortified Jesuit church; the walls are fully seven feet thick. The climate is mild, while the scenery, grand in the extreme, surpasses description. The plateau to the eastward, covered by dense forests of pine, is replete with attractive features, among which is Monument Cañon. This deep gorge is full of columns of conglomerate, whose rocky peaks, towering a hundred feet, present a weird scenery surpassing in grandeur that of the "Garden of the Gods" at Colorado Springs. Not far off is Valle Grande, a splendid park on the plateau, penetrated by streams whose silvery waters are the home of numerous trout. The town of Jemez, twelve miles below Ojos Calientes, also offers many points of interest. The natural wonders of this region, added to its varied and enchanting scenery, and the dry, healthy atmosphere, tend to constitute it a favorable watering-place at no distant period. Here is the place especially recommended to those afflicted with lung-diseases, science as well as experience having demonstrated beyond a doubt that for consumptives the climate of New Mexico far surpasses that of Minnesota, California, or Florida.

MINERAL SPRING OF SAN ISIDRO, NEW MEXICO.

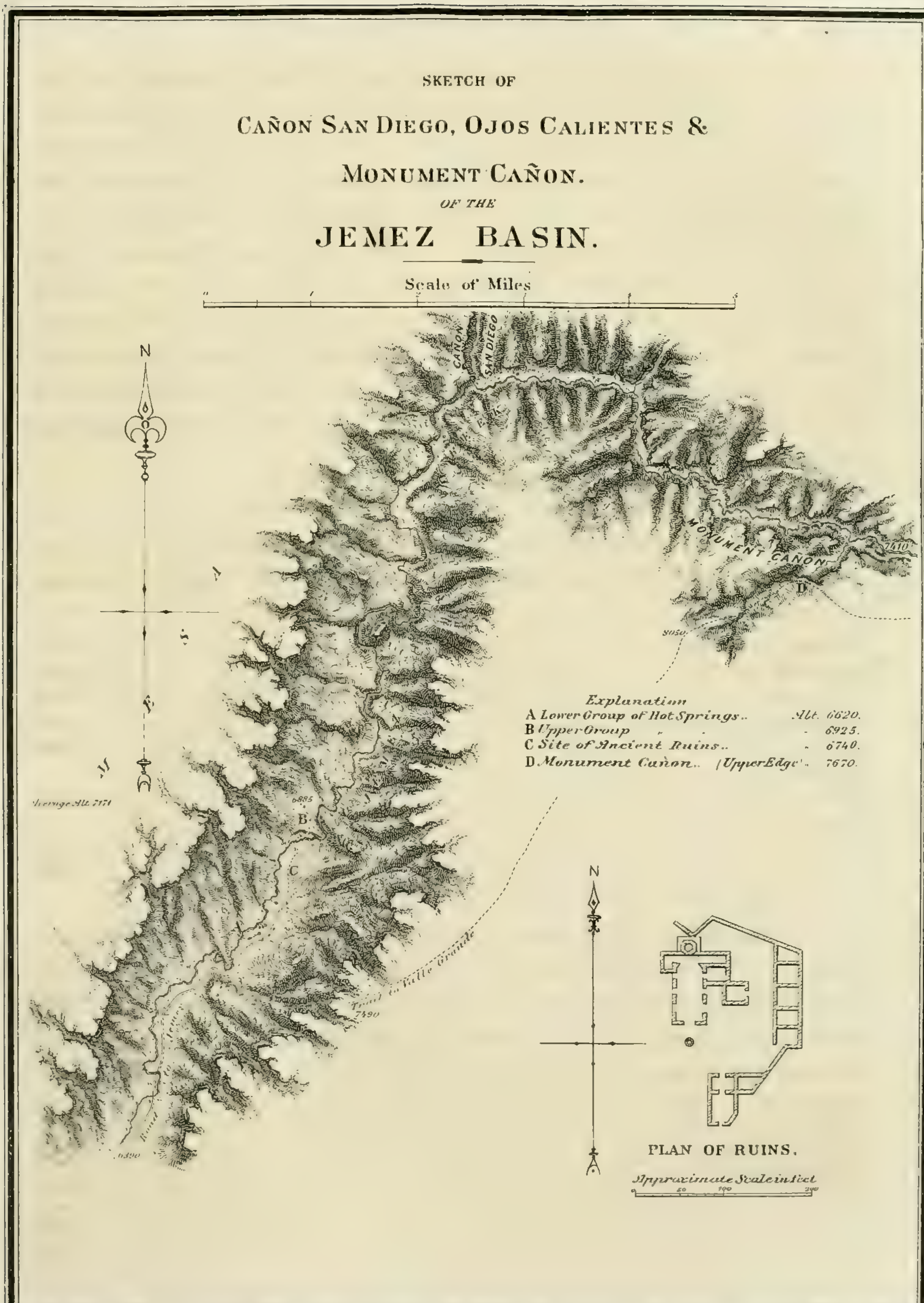
This spring is situated three miles south of the Indian town of Jemez. Its water is rich in carbonic acid and of very agreeable taste. It contains in 100 parts—

Chloride of sodium	0.3072
Sulphate of soda	0.1639
Carbonate of lime	0.0670
Carbonate of magnesia	0.0243
Carbonate of iron	0.0008
Potassa	Traces.
Lithia	Traces.
Siicic acid	Traces.
	0.5632

HOT SPRINGS OF THE RIO SAN FRANCISCO, ARIZONA.

On the margin of the river of this name, seven miles above its junction with the Gila, in Southern Arizona, are situated four springs of strong salty taste. Three show a temperature of 127° F. and one of 130° F. The surrounding ground is covered with salt efflorescences. The water of one of these springs contained in 100—

Chloride of calcium	0.1981
Chloride of sodium	0.3252
Chloride of magnesium	0.1025
Sulphate of lime	0.0410
	0.6668


SKETCH OF
CAÑON SAN DIEGO, OJOS CALIENTES &
MONUMENT CAÑON.
OF THE
JEMEZ BASIN.
Scale of Miles
CAÑON SAN DIEGO
MONUMENT CAÑON
N
MESA
7410
D
8050
Explanation
A Lower Group of Hot Springs.. Alt. 6620.
B Upper Group - 6925.
C Site of Ancient Ruins.. - 6740.
D Monument Cañon.. (Upper Edge). 7670.
6885
B
C
Trail to Valle Grande
7490
N
PLAN OF RUINS.
Approximate Scale in Feet
50
100
200

THE MINERAL SPRINGS OF CAÑON CITY, COLORADO.

A number of mineral springs exist in the vicinity of Cañon City, Colo., which hitherto have not been chemically analyzed. As I had no opportunity to visit the locality, Lieutenant Marshall, who explored this region, provided me with specimens of the waters through the kindness of Drs. O. B. Bryan and T. L. Prentiss, of Cañon City. The springs are named Iron Duke, Big Ute, Little Ute, Aqua Vida, Congress, and Hot Spring. There is still another, called "Mills Sulphur Spring;" the amount of its mineral salts, however, is exceedingly small. The analyses of the six springs above mentioned is given in the following table, from which it will be seen that the Congress and Hot Springs are inferior to the rest. All the springs contain the same constituents, varying, however, in the proportion. Slight traces of iron, potassa, and lithia were detected. These waters, no doubt, possess valuable medicinal properties; the most effective constituent is evidently carbonate of soda. The waters are saturated with free carbonic acid; the taste is very agreeable.*

The mineral waters of Cañon City, Colo.

In 100 parts water.	Mineral springs.					
Constituents.	Iron Duke.	Little Ute.	Big Ute.	Aqua Vida.	Congress.	Hot Spring.
Chloride of sodium	0.137236	0.195648	0.225810	0.207060	0.065221	0.030162
Sulphate of soda	0.020110	0.020719	0.028032	0.024985	0.028642	0.013407
Carbonate of soda	0 126700	0.126690	0.059421	0.125822	0.033200	0.011940
Carbonate of lime	0.053580	0.037499	0.073214	0.067856	0.048214	0.055357
Carbonate of magnesia	0.024971	0.023458	0.025728	0.030268	0.031025	0.021188
Total in 100 parts water	0.362597	0.404014	0.412205	0.455991	0.206302	0.132054

There are in Southwestern New Mexico, between Fort Bayard and Fort Cummings, and between the latter post and Fort Craig, at Cañada Alamosa, a number of hot springs; but the amount of their mineral constituents was too small to warrant a quantitative analysis. They contained mere traces of chloride of sodium and sulphate and carbonate of lime. Formerly they probably held considerable quantities, as the mounds around them would indicate.

* In connection with these springs, it may be mentioned that there are several at Idaho Springs, in Clear Creek County, which, however, on inspection, I found to be of but little value, their mineral constituents being mere traces.

MINERAL SPRINGS OF MANITOU, COLORADO.

These springs are situated between the foot-hills on the eastern slopes of Pike's Peak and neighboring mountains in the valley of the Ruxton and Fontaine qui Bouille Creeks. The locality has an elevation of 6,350 feet above sea-level, and is situated five and a half miles west of Colorado Springs, a railroad station and a rapidly-increasing town seventy-five miles south of Denver. In an air-line direction it is eight miles from the famous Pike's Peak, whose summit forms an attractive point for tourists. It is nine miles from Cheyenne Cañon, whose walls are precipitous bluffs 2,000 feet high, nine miles from Monument Park, four miles from Glen Eyre, and three miles from the Garden of the Gods—all points of unusual interest. The surrounding scenery is charming and romantic, while the towering peaks in the distance are awe inspiring. The sky is rarely obscured by clouds. The climate is delightful; the dry air having a most favorable effect upon the human system.

It is only a few years since Manitou Springs and the attractive scenery which surrounds them became so well known, yet in so brief a period a town of eighty-six buildings has sprung up, while improvements are constantly going on; roads and small parks have been laid out; and already this hidden mountain-place is connected by telegraph with the business centers of the world.

A little below the junction of the two creeks referred to above are situated the principal soda springs, four of which have been improved, while numerous others, unimproved, exist along the creek-bed. A number of springs originate even in the creek-bed itself, if we may judge from the gas-bubbles that rise in the water of the stream. Formerly, these springs must have been many more in number, as indicated by the holes in the deposit in the valley. The iron springs are about one mile above the soda springs, in Engelman's Cañon, where the predominating rocks are gneiss and granite. The principal springs are—

Little Chief.—Basin 6 square feet; red deposit; temperature, 43° F.*

Iron Ute.—This spring is surrounded by a neat summer-house, and has a temperature of 44°.3 F.; red deposit.

* The temperatures were taken on a winter's day, (November 28,) with an atmospheric temperature of 23° F.

Manitou.—Situated on the left bank of the "Fontaine qui Bouille," and next to a neat summer-house. Its origin is in a mound formed by former spring deposits; it is of 1 square foot surface, and has a temperature of 56° F.

Navajo is just opposite Manitou, on the right-hand side of the creek; surface about 6 square feet; it forms a white deposit, and is violently agitated by the escaping carbonic-acid gas; temperature, 58°.2 F.

Ute Soda Spring is a few yards above the one just mentioned.

Shoshone is some 50 feet below Ute Soda; has a summer-house; temperature, 48°.5 F.

In one hundred thousand parts of spring-water are contained parts as follows:

Constituents.	Iron Ute.	Little Chief.	Manitou.	Navajo.	Ute Soda.	Shoshone.
Sodium carbonate	59.34	15.16	52.26	124.69	23.82	88.80
Lithium carbonate	Trace	Trace	0.21	0.24	Trace	Trace.
Calcium carbonate	59.04	75.20	111.00	129.40	40.00	108.50
Magnesium carbonate	14.56	13.01	20.51	31.66	6.10	
Iron carbonate	5.78	1.80	Trace	......	1.40	......
Potassium sulphate	7.01	6.24	13.35	16.21	Trace	5.12
Sodium sulphate	30.86	51.88	19.71	18.42	12.24	37.08
Sodium chloride	31.59	47.97	40.95	39.78	13.93	42.12
Silicic acid	2.69	2.22	2.01	1.47	Trace	Trace.
Total solid constituents	210.87	213.48	260.00	361.87	97.49	281.62

Gases: Free carbonic acid in excess.

A comparison with other mineral springs shows that these springs resemble those of Ems and Teplitz, while they excel those of Spa.

PARNASSUS SPRINGS, COLORADO.

These springs are situated twelve miles southwest from Pueblo, near the head of Red Creek, a tributary of the Arkansas, in the northern foot-hills of the Wet Mountains, or Sierra Mojada, Greenhorn Mountains, or Sierra del Cuerno Verde. The altitude of the springs is 6,100 feet. Red Creek, where it leaves the foot-hills, cuts its way through a cañon the walls of which are formed by Cretaceous limestone and shales. The foot-hills of the mountain, however, consist of gneiss, and a coarse conglomerate, composed chiefly of the constituents of granite. The quartz of this conglomerate forms rounded pebbles, and the muscovite and feldspar are cemented together with those by a reddish clay. The strata have an easterly dip of about 22°. Near the springs are some block-houses. The surrounding hills are well timbered. There is one spring of plain water with a temperature of 52°F., and five springs of mineral water, all within a few yards of each other.

No. 1. A small bubbling spring of 66°F.

No. 2. A large spring of about 6 square feet, and of 72°.5 F. Its owner, Mr. C. Thatcher, informed me that it had grown decidedly colder the past year.

Nos. 3 and 4 closely resemble No. 2; temperature, 71°F.

No. 5 contains, besides saline constituents, sulphureted hydrogen; temperature, 59°F.

All these springs are of very pleasant taste, and contain free carbonic acid.

In one hundred thousand parts of spring-water are contained parts as follows:

Constituents.	No. 1.	No. 2.	No. 5.
Sodium carbonate	126.04	118.45	73.32
Lithium carbonate	Trace	1.78	0.15
Calcium carbonate	71.00	54.54	46.91
Magnesium carbonate		22.43	17.03
Iron carbonate	1.54	2.23	2.75
Potassium sulphate	19.22	18.44	14.54
Sodium sulphate	8.78	3.98	3.28
Sodium chloride	102.96	104.13	53.23
Silicic acid	4.21	7.94	6.00
Organic matter	Trace	Trace	
Total solid constituents	333.75	333.92	217.21
Sulphureted hydrogen			Trace.

Carbonic acid in excess.

WARM SULPHUR SPRING, SOUTH FORK OF NAVAJO RIVER, COLORADO.

This spring was visited by Lieut. C. W. Whipple's party while traversing Southwestern Colorado; the officer in charge very kindly provided me with the following notes:

"I had no thermometer with me, but judge the temperature of the spring to be about 80° F. The spring itself is situated on the south side of the South or main Fork of the Navajo, and rises in a basin some fifty yards from there. The basin is perhaps four yards long by three yards wide. The water bubbles up quietly, and flows out at the rate of nearly a gallon a minute. It appears to be quite strongly impregnated with sulphur, but not nearly as much so as the hotter springs of Pagosa, nor is the water as clear. It flows into a flat on the river-bottom, where it collects in three large connected pools, the whole forming a kind of marsh, quite a fourth of a mile long and a hundred yards wide, through which, at intervals, I detected a slight bubbling."

Another hot sulphur spring exists on the South Fork of the San Juan River, and still another twelve miles north of Del Norte.

The water of the Warm Sulphur Spring contains in one hundred thousand parts the following constituents:

Calcium sulphate	61.5 parts.
Calcium carbonate	10.2 parts.
Magnesium carbonate	17.1 parts.
Solid constituents	88.8 parts.

Gases: Carbonic acid; hydrogen sulphide.

CARLISLE SPRING, COLORADO.

This spring is situated on the banks of the Arkansas twenty miles above Pueblo, having its origin in beds of Cretaceous age. A deposit from this spring, formed in a thickness of 6 or 7 feet, overhangs the rocky banks of the river. The overhanging walls growing too heavy from time to time, large blocks of the deposit have been precipitated into the river. The chief components of these deposits are carbonate of lime and magnesia, with a small proportion of iron.

Carlisle Spring yields about eight gallons of water per minute; has a surface of about 5 square feet; and is of 65° F. temperature, (July 15,) the temperature of the air at the time being 76°. The water is clear, of agreeable taste, and deposits a red sediment. After concentration, an alkaline reaction can be observed. A similar spring is found six miles south from Cañon City, on the Rosita road.

In one hundred thousand parts of Carlisle Spring are contained parts as follows:

Sodium carbonate	15.42
Calcium carbonate	38.40
Magnesium carbonate	19.52
Iron carbonate	0.51
Potassium sulphate	1.20
Sodium sulphate	34.28
Sodium chloride	19.30
Silicic acid / Organic matter	Traces.
Total solid constituents	128.63

Gases: Carbonic acid.

SPRINGS OF WAGONWHEEL GAP, COLORADO.

The waters of these springs were collected by Mr. Cowles, topographer of the main party, who furnished me with the following memoranda:

"The name 'Wagonwheel Gap' has been given to a pass in the range northeast of the Sierra la Plata, about thirty-four miles west of Del Norte. The springs are situated near this pass, in the valley of the Hot Spring Creek, one and one-fourth miles from the Rio Grande, of which this creek is a tributary. The springs are owned by Mr. Goodwin and Mr. Meade, of neighboring cattle-ranch, who have erected log-cabins capable of accommodating a limited number of persons desirous of using these waters."

No. 1* has a temperature of about 150° F., is bubbling continually, and is about 8 feet wide and 12 long.

No. 2 is a small bubbling spring, cold, of about 1 foot in diameter, and gives out a strong odor of sulphureted hydrogen.

No. 3 is situated some distance from Nos. 1 and 2, on the foot of a hill; it bubbles constantly, and is of a temperature of 140° F. This spring is about 3 feet wide and nearly the same in length. It is called "Hot Soda Spring."

* On opening the bottle, the odor was found to be exceedingly weak.

In one hundred thousand parts of the water of the springs of Wagon-wheel Gap are contained parts as follows:

Constituents.	No. 1.	No. 2.	No. 3.
Sodium carbonate	69.42	Trace	144.50
Lithium carbonate*	Trace	Trace	Trace.
Calcium carbonate	13.08	31.00	22.42
Magnesium carbonate	10.91	5.10	
Potassium sulphate	Trace	Trace	Trace.
Sodium sulphate	23.73	10.50	13.76
Sodium chloride	29.25	11.72	33.34
Silicic acid	5.73	1.07	4.75
Organic matter	Trace	Trace	....
Sulphureted hydrogen	Trace	12.00	....
Total	152.12	71.39	218.77

* The lithia was present in such quantity that I could easily have determined it had a gallon of the spring-water been collected.

THE LAS VEGAS MINERAL AND HOT SPRINGS, NEW MEXICO.

Las Vegas, a thriving town, is situated on the eastern slope of the continuation of the Rocky Mountain system, some seventy-five miles east of Santa Fé. While the wide plains bordering the mountain-ranges on the east side are principally composed of strata of *Cretaceous* deposits, the foot-hills of the mountains are generally of *Carboniferous* age. The vicinity of Las Vegas presents a most striking example of this kind at the hot springs, four miles north of the town. In the latter case, however, the strata are much displaced, and for a half mile occupy an entirely vertical position. Beneath these inclined strata, a red granulite, probably of an eruptive nature, makes its appearance. The most eastern portions of this rock are covered by efflorescences of alum, while from the fissures a little above issue the hot springs to the number of about a dozen, only four of which, however, have been improved—that is, have been widened and provided with bath-houses. Near by is a small hotel with accommodations for quite a number of visitors.

The temperature of these springs ranges from 90° F. to 130° F.

No. 1. Temperature, 130°; basin, 6 feet deep, 5 feet long, 4 feet wide; taste, weak saline; no odor observable; bubbles of carbonic acid constantly rising; yield, about fifteen gallons per minute.

No. 2. Temperature, 123° F.; basin, 3 by 3.5 feet.

No. 3. Temperature, 100°.5 F.; basin, 2 by 3 feet.

No. 4. Temperature, 123° F.; basin, 2.5 by 1.5 feet.

In one hundred thousand parts of water are contained parts as follows:

Constituents.	No. 1.	No. 2.	No. 3.
Sodium carbonate	1.72	1.17	5.00
Calcium carbonate } Magnesium carbonate }	9.08	10.63	11.41
Sodium sulphate	14.12	15.93	16.27
Sodium chloride	27.26	24.37	27.34
Potassium	Traces	Traces	Traces.
Lithium	Strong traces.	Strong traces.	Strong traces.
Silicic acid	1.04	Traces	2.51
Total solid constituents	53.22	52.10	62.53

These springs are doubtless weaker than many other hot springs of New Mexico and Colorado.

There is another, but a cool mineral spring, three miles northeast of Las Vegas and two miles east of Green's ranch. It issues from the strata of Cretaceous limestone, and possesses a strong odor of sulphureted hydrogen. It showed the following composition:

In one hundred thousand parts of water are parts as follows:

Sodium carbonate	120.00
Calcium carbonate } Magnesium carbonate }	13.75
Sodium sulphate	5.26
Sodium chloride	6.41
Silicic acid	Trace.
	145.42

Gases: Carbonic acid and hydrogen sulphide.

HOT SPRINGS OF ABIQUIU, NEW MEXICO.

Fifteen miles northwest of Abiquiu is the Mexican village Ojo Caliente, in the valley of the creek of the same name. One mile above the village four warm springs issue from the foot of a hill. While the surrounding region consists of sand-hills, and volcanic dykes, and mesas, the hill in question is composed of gneiss, through which run veins of a very coarse-grained granite, the feldspar and quartz forming masses of several cubic feet, and the muscovite large plates several inches thick. An American, who here built a few bath-houses for visitors, stated that last summer from forty to fifty invalids were there using the waters for medicinal purposes; the majority of these suffered from rheumatism and syphilis. The waters are of good quality. Where they evaporate on the rocks, a white residue is formed, erroneously called there "borax." Three of the springs have been widened and otherwise improved.

No. 1 has a basin 20 feet long, 9 feet wide, and a temperature of 114°.5; a reddish deposit is formed, containing a trace of iron.

No. 2, basin 10 feet square; temperature, 108° F.

No. 3, basin 5 feet long, 2 feet wide; temperature same as No. 2.

No. 4, basin 6 feet square; unimproved; temperature same as No. 2. The taste of all these springs is saline and alkaline.

In one hundred thousand parts of water are contained parts as follows:

Constituents.	No. 1.	No. 2.
Sodium carbonate	196.95	184.29
Lithium carbonate	0.21	0.16
Calcium carbonate Magnesium carbonate	} 6.25	5.40
Iron carbonate	Trace	Trace.
Potassium sulphate	5.17	5.34
Sodium sulphate	13.60	19.33
Sodium chloride	38.03	39.78
Silicic acid	Trace	Trace.
Total solid constituents	260.21	254.30

Gases: Carbonic acid.

SPRING NEAR RIO PAJARITO, NEW MEXICO.

This warm spring was visited by Lieutenant Birnie, who has kindly furnished me with information regarding it. It is situated not far from Rio Pajarito, a small, and for the most part dry, creek, in the extreme west of New Mexico. Its temperature was found to be 68° F.; smell and taste strongly of sulphur. The water is in constant agitation, here and there breaking through the sand, all the openings occurring within a circle of 5 feet in diameter. The rock of the region is basalt.

In one hundred thousand parts of the water are contained parts as follows:

Sodium carbonate	17.01
Calcium carbonate } Magnesium carbonate }	7.19
Sodium sulphate	14.60
Sodium chloride	9.11
Silicic acid	Trace.
Potassium	Trace.
Lithium	Trace.
Total solid constituents	47.91

Gases: Carbonic acid; hydrogen sulphide.

WARM SPRINGS OF CONEJOS, COLORADO.

There are several warm springs near Conejos in Southern Colorado. On analysis, however, the amount of mineral matter they contained was found to be so limited that a trustworthy result could not be obtained with the small quantity of the water at my disposal.

THE PAGOSA HOT SPRINGS, COLORADO.

I did not visit these springs, but the samples of the waters taken by Dr. H. C. Yarrow and Lieutenant Whipple were turned over to me. The latter gentleman also kindly supplied me with some notes in regard to these springs.

* The Pagosa Hot Springs are found on the south side of the San Juan River, about twenty-five miles from its headwaters, on the road from Tierra Amarilla to the Animas Park, and distant from the former about fifty miles. The river cuts its channel through old spring deposits, consisting chiefly of carbonate of lime. The main spring is at the highest point of the basin, and 200 feet from the nearest point of the river, while around, at distances varying from 200 to 500 feet, are ranged four other hot springs. The main spring is within an inclosure of about 70 feet in length, 50 in width, and 40 in depth; temperature about 141° F. The principal outlet is by an underground channel to the northward, traceable, however, at intervals by the steam rising through the holes and crevices of the deposit.

* See report of Prof. J. J. Stevenson, Part IV, Chap. XVI.

The waters of four of these springs were subjected to analysis, and proved to be very similar in their composition. The chief constituent of these springs is sulphate of soda. The analysis resulted as follows:

In one hundred thousand parts are contained parts as follows, (No. 1, main spring:)

Constituents.	No. 1.	No. 2.	No. 3.	No. 4.
Sodium carbonate	4.70	3.33		
Lithium carbonate	0.71	Trace	Trace	Trace.
Calcium carbonate	59.00	59.50	54.51	58.73
Magnesium carbonate	4.85	3.92	3.68	3.59
Potassium sulphate	7.13	6.98	6.63	7.10
Sodium sulphate	221.66	220.20	223.92	224.59
Sodium chloride	29.25	29.36	31.21	29.81
Silicic acid	5.70	5.21	5.53	3.82
Organic matter	Trace	Trace	Trace	Trace.
Total solid constituents	333.00	328.50	325.48	327.64

Gases: Carbonic acid; hydrogen sulphide.

SALT FROM A SALT LAKE SEVEN MILES EAST OF THE ZANDIA MOUNTAINS, NEW MEXICO.

This salt is used in Albuquerque and Santa Fé as table-salt. Some people are of the opinion that it contains saltpeter, because of its peculiar sharp taste. Although convinced to the contrary, I subjected it to a chemical investigation, and found it to contain in one hundred parts—

Chloride of sodium	82.57
Sulphate of soda	6.89
Chloride of magnesium	5.88
Water	4.66
Sulphate of lime	Traces.
	100.00

As the medium table-salt of commerce rarely contains above 1 per cent. of chloride of magnesium and sulphates, this salt must be considered very impure; still there is no serious objection to its use.

SALT EFFLORESCENCE OF OJO DE TAO, NEW MEXICO.

There are three springs in the Valle de San Miguel, about four miles north of the Cerro de Alesna, New Mexico. Their temperature (in July) was 59°.5 F. The taste was weak salty. The surrounding ground was covered with a white saline mass of the following composition:

Sesquicarbonate of soda	88.01
Sulphate of soda	10.60
Chloride of sodium	0.91
Traces of lime, magnesia, and loss	0.48
	100.00

SALT DEPOSIT AT SUNSET CROSSING, ARIZONA.

At the time of our visit to the Colorado Chiquito, this deposit was a salt pond, caused by heavy rains.

Chemical analysis of the evaporation residue gave—

Chloride of sodium	78.79
Chloride of calcium	5.48
Chloride of magnesium	12.16
Sulphate of lime	3.07
Traces of alumina, oxide of iron, and loss	0.50
	100.00

The quantity of this salt is not large, and in taste it is disagreeable.

SALT EFFLORESCENCE OF SANTA CATALINA, ARIZONA.

Santa Catalina is forty miles east of Tucson, and a station of the Southern Overland Mail Company. Several small areas in the vicinity are covered by salt efflorescences, apparently remnants of former salt springs.

The efflorescence was composed of—

Sulphate of soda	94.04
Chloride of sodium	5.93
Traces of lime, magnesia, and loss	0.03
	100.00

SALT EFFLORESCENCE OF CROTON SPRINGS, ARIZONA.

A wide plain extends between the Dos Cabezas Mountain range and the Dragoon Mountains in Southern Arizona, several square miles of which are covered with a thick salt deposit. There also exist two small ponds, whose waters are completely saturated with the salts, and on whose shores are deposits of white crusts. Although this water has a decided taste of carbonate of soda, ducks were seen in great numbers on these ponds. On analysis, neither borates, nitrates, nor iodides were found, but decided traces of lithia, potassa, and phosphoric acid. Specimens of this salt deposit, as well as of the crust, were analyzed, with the following results:

Salt deposit.

Sesquicarbonate of soda	15.51
Sulphate of soda	74.66
Chloride of sodium	8.85
Traces of silicic acid, phosphoric acid, potassa, lithia, lime, magnesia, and loss.	0.98
	100.00

Salt crust.

Sesquicarbonate of soda	26.25
Sulphate of soda	60.03
Chloride of sodium	13.14
Traces of silicic acid, phosphoric acid, potassa, lithia, lime, magnesia, and loss.	0.58
	100.00

INCRUSTATION FROM THE "ALUM CAVE" ON COOK'S PEAK, NEW MEXICO.

This cave is 5 feet high, 10 feet wide, and about 8 feet deep, and is situated on the mouth of a cañon not far below the summit. Until quite recently, it was inhabited by savages. The walls are covered by a white fibrous incrustation, of alum taste. On adding potassa, these crusts evolve an ammoniacal odor, with a decided by-smell of tobacco-smoke, undoubtedly due to the absorption of the alkaline products of combustion of tobacco by the acid wall crusts. The composition of these crusts corresponds nearly to that of alunogen:

Alumina	18.11
Sulphuric acid	30.90
Water	48.38
Traces of ammonia, oxide of iron, protoxide of manganese, lime, lithia, potassa, and loss	2.61
	100.00

INCRUSTATION FROM THE COSNINO CAVES, ARIZONA.

These caves, fourteen in number, are situated about twenty miles east of Humphrey's Peak, the highest point in the San Francisco Mountains, on a steep slope; their walls formed by flows of basaltic lava. They are partly side by side and partly above each other, and were formerly dwelling-places of Cosnino Indians. From their rear, narrow and low tunnels lead some distance into the hill. Some of the caves had evidently served as sheep-corrals. The dung is many inches thick, and gives out an intense odor of ammonia. Here and there the walls showed white incrustations, which consist principally of nitrate of potassa, (81.4 per cent.) The remaining constituents are nitrate of ammonia, nitrate of lime, nitrate of magnesia, nitrate of soda. The nitric acid is undoubtedly derived from the oxydation of the ammonia evolved by the sheep-dung, while the fixed bases were furnished by the wall rock.

INCRUSTATIONS OVER PYRITIFEROUS ROCKS IN COPPER GULCH, BURRO MOUNTAINS, NEW MEXICO.

The well-dried substance contained—

Protosulphate of iron	95.31
Sulphate of copper	4.69
	100.00

INCRUSTATIONS OVER BASALTIC ROCKS.

In a great many instances in New Mexico and Arizona, white crusts were observed covering basaltic rocks. These crusts proved to be carbonate of lime. It is still an open question how these crusts were formed. The hypothesis that they are the result of the action of calcareous springs is untenable, since they may be seen even on the very summits of hills, where the spring could not possibly pour its waters.

A NEW FOSSIL RESIN—"WHEELERITE."*

In the Cretaceous beds of Northern New Mexico, a yellow resin is frequently found, filling the fissures of the coal, and interstratified with it in thin layers.

On the way from Nacimiento to Willow Springs and Fort Wingate, more of this substance was encountered than in any other section of our journey. Fibrous gypsum not unfrequently accompanies this coal. The behavior of the resin toward reagents, as well as a chemical analysis, proved

* This article was published in the "American Journal of Science and Arts," June, 1874.

it to be a compound heretofore undescribed. The principal part is easily soluble in alcohol, while a small portion, another distinct combination from the hot alcoholic solution, separates in flocculi in cooling off. If, after the separation of this compound, the alcoholic solution of the resin is evaporated, a yellowish-brown body is obtained, very brittle and strongly electric on friction. It melts at 154° C., and at about 200° C. begins to decompose, emitting an aromatic odor. It burns with a smoky flame; the residuum being a voluminous coal. The resin is also somewhat soluble in ether; less so in bisulphide of carbon. Concentrated sulphuric acid dissolves it in the cold with a dark red-brown color. It may be again precipitated by water. It is easily soluble in potash, and acids precipitate it from these solutions in an unchanged condition. It is readily oxidized by strong nitric acid evolving nitrous fumes. The final analysis gave the following results:

(1) 0.106 grain yielded 0.284 carbonic acid and 0.076 water.
(2) 0.101 grain yielded 0.270 carbonic acid and 0.071 water.

These data give us the formula $C_5 H_6 O$.

	Theory.	Experiment.	
Carbon	73.11	73.07	72.87
Hydrogen	7.31	7.95	7.88
Oxygen	19.58		
	100.00		

The molecular formula of this resin is probably more than six times as high as the empyrical formula indicates. No one of the investigated fossil resins is identical with this. The retinic acid of Johnston, which he obtained by extracting the retin asphalt from Bovey with alcohol, is the only combination bearing any relation to it, and this only in a few particulars. This retinic acid has the formula $C_{40} H_{45} O_6$, and is little soluble in alcohol, freely in ether; its melting-point lies at 120° C. In honor of the officer in charge of the survey, this new fossil resin has been named "*Wheelerite.*"

THE COALS OF NEW MEXICO AND COLORADO.

While numerous deposits of coal are found in these two Territories, there are but few in Eastern Arizona. They belong principally to the Cretaceous age; in some exceptional cases, however, to the Carboniferous. These coals differ widely in composition and appearance in different localities;

they often bear impressions of leaves, particularly the brown-coal stratas in Northwestern New Mexico.

COAL FROM THE PLACER MOUNTAINS, NEW MEXICO.

This bed is between slate and limestone on the northern slope of the Placer Mountains, thirty miles south of Santa Fé. The coal is compact, massive, not friable, nor intumescing. Color, jet black; luster, brilliant; fracture, conchoidal, uneven; specific gravity, 1.45. The coal is probably of Carboniferous age, and ranges among the semi-anthracites. Its composition is as follows:

Water	2.10
Volatile combustible matter	6.63
Fixed carbon	86.22
Ash	5.05
	100.00

COAL FROM THE RIO PUERCO OF THE EAST, NEAR NACIMIENTO, N. MEX.

The strata of brown coal are freely exposed in the perpendicular walls of the *mesas*, and are accompanied by shales, slate, clay, and sandstone. Their thickness varies from 6 inches to 8 feet. In some instances, the strata have been partially destroyed, and undoubtedly by fire, as evidenced not only by the accompanying clay being turned into brick, but also by heaps of slag composed of silicates of iron and alumina. This brown coal frequently contains a yellow resin, which has been subjected to analysis, (see article on "Wheelerite.") It is bituminous and of Cretaceous age, not coking, very brittle, somewhat laminated; luster, dull.

Water	6.00
Volatile matter	37.49
Fixed carbon	52.28
Ash	4.23
	100.00

COAL FROM SILVER CITY, NEW MEXICO.

This bed is said to be of moderate extent. I did not visit the locality in person, but obtained a specimen of the coal at Silver City. It is compact, massive, very hard, not intumescing; luster, metallic; fracture, conchoidal, splintery. It belongs to the semi-anthracites. Its composition is as follows:

Water	2.13
Volatile matter	4.86
Fixed carbon	86.56
Ash	6.45
	100.00

COALS FROM GOLDEN, BOULDER, AND CAÑON CITY, COLORADO.

These coal-beds are of Cretaceous age, as indicated by the fossils contained in the accompanying clay-strata. The composition of the coals of the three localities does not differ essentially; they are of a bituminous nature, friable, of brilliant luster, and not coking.

Constituents.	Coal of—		
	Golden.	Boulder.	Cañon City.
Water	8.32	11.81	5.37
Volatile matter	29.92	31.40	35.08
Fixed carbon	58.25	53.38	56.66
Ash	3.51	3.41	2.89
	100.00	100.00	100.00

ANALYSIS OF COAL-SPECIMENS FROM COLORADO.

(1.) *Coal from Colorado Springs, Colorado.*

Within the last year there have been two coal-deposits discovered in the vicinity of Colorado Springs—one nine miles to the east, the other nine miles to the northwest of the town. These are bituminous, friable, free-burning, non-coking coals. The latter is the better gas coal. Ashes white or light-gray. Composition as follows:

	No. 1, 9 miles east.	No. 2, 4 miles northwest
Water	7.14	8.12
Gas	24.56	37.09
Fixed carbon	52.27	47.29
Ash	16.03	7.50
	100.00	100.00

(2.) *Coal from Trinidad, Colorado.*

Near the thriving town of Trinidad are extensive beds of iron ore and coal. The latter is of excellent quality, and yields about half its weight in gas, is of coking character, brilliant luster, and contains an exceedingly small amount of moisture. The Denver Gas Works pay $12 per ton for the freighting only of this coal by ox-teams from Trinidad to the railroad at Pueblo; although there is a large supply within easy reach of the railroads in the vicinity of Denver. The Trinidad coal, however, is of the very best quality for gas purposes. It contains—

Water	0.80
Gas	50.32
Fixed carbon	40.18
Ash	8.70
	100.00

(3.) *Coal from Red Creek.*

Near Elizabethtown, on the Red Creek, some twenty miles below Costilla, in Southern Colorado, is a bed of bituminous coal 10 feet in thickness, non-coking, dull luster, ashes yellow. The following is its composition:

Water	2.70
Gas	24.44
Fixed carbon	59.36
Ash	13.50
	100.00

COAL FROM THE LOS CERILLOS AND PLACER MOUNTAINS, NEW MEXICO.

From the Rio Santa Fé and Rio Galisteo to the Placer Mountains, the country is broken into hills and cañons; in some portions, however, it is nearly level.

The principal rocks in the northwestern portion are basalt and sandstone, with hills of gypsum, called, in New Mexico, "Hasped" or "Yeso." The Los Cerillos Mountains are made up of granite, trachyte, and quartzites, and partly, also, of quartzite schist, while the southeastern portion of the region consists of strata of clay, coal, shales, and sandstone, which are well exposed in their succession in the cañons and in the narrow channels, or arroyos. The thickness of the coal strata varies from ½ foot to 5 feet, and, as traced, is one continuous bed through Cañon de los Ojitos, Cañon Chupadera, and Cañon de la Chapina; the croppings extending over an area of fully 20,000 acres. Island-like hills of primitive and volcanic rocks jut out through the sedimentary beds. The original horizontal position of the strata has been changed in several instances to an incline. In the southeastern portion of this region a trachyte dike of considerable dimensions has penetrated the strata of coal and sandstone, and changed the horizontal position to such an extent that they now dip at an angle of 25° west. The stratum of coal at this place is fully 5 feet thick, and is overlaid by sandstone about 28 feet in height. The coal is hard, dense, of brilliant luster, and resembles anthracite in every respect. Its specific gravity is 1.43. Indeed, chemical analysis of this coal shows the same composition as that of anthracite. Its best application would be for blast-furnaces and smelting purposes generally; and since there has thus far been no anthracite coal found west of the Mississippi River, the bed in question is of particular interest and highly valuable. Although the statement may be superfluous, it may be said that this coal contains no injurious pyrites.

Three specimens were examined—one from a short tunnel in the southwestern portion of the tract, where the coal was dug, or mined, forty years ago; another from Cañon de la Chapina; and the third from the Cañon de los Ojitos.

Constituents.	No. 1.	No. 2.	No. 3.	No. 4.
Water	2.10	2.12	1.91	....
Gas	6.63	7.20	11.74	3.84
Fixed carbon	86.22	84.33	70.52	87.45
Ash	5.05	6.35	16.46	7.37

No. 4 is Prof. W. R. Johnson's analysis of a specimen of Pennsylvania anthracite, for which see Dana's Mineralogy, p. 758.

The specific gravity of *true* anthracite coal varies from 1.32 to 1.7. The amount of carbon varies in Pennsylvania anthracite from 85 to 93, and in the anthracite of France, from 80 to 83 per cent.; further, the amount of volatile combustible matter (gas) varies in different anthracites from 2 to 8 per cent.

In consideration of these facts, we must pronounce the coal in question a *true anthracite* coal.*

This coal-bed belongs to the Mesita Juana Lopez grant, which is the more valuable on account of fine pastures, good pine-timber, and presence of water in springs, and the Galisteo Creek.

ANALYSES OF ORES.

The ores analyzed were fair average specimens of a mine, or a number of mines; generally a large piece, weighing several hundred grammes, was reduced to powder, and from 2 to 5 grammes taken for investigation.

Copper-ore from Springhill district, New Mexico.

Copper-glance	46.56
Silicate of copper	3.52
Silver	0.28
Gangue, (quartz)	49.05
	99.41

A ton of this ore would contain $90 in silver.

Copper-ore from the Rio Francisco, Arizona.

No silver was found in this ore. Its composition was—

Ferruginous sulphide of copper	53.41
Green carbonate of copper	8.55
Quartz, (by difference)	38.04
	100.00

Zincblende from Gilpin County, Colorado.

This contained copper, lead, and iron, as accessory metals. Neither cadmium nor iridium could be detected.

Bismuthite from Ward district, Colorado.

Copper and iron were found in this ore, but none of the rarer metals.

Uraninite from Leavenworth Gulch, Gilpin County, Colorado.

This mineral is accompanied by iron and copper pyrites. Careful

* Dr. J. L. LeConte, who examined specimens of this coal before, came to exactly the same conclusion. (See his report on the survey for the extension of the Union Pacific Railway, Eastern Division—now the Kansas Pacific Railroad—pages 38 and 39, and page 58 for the analyses.)

search was made for rarer metals, especially for vanadium and molybdenum, but none were detected. Its composition is as follows:

Uranoso-uranic oxide	11.37
Sulphides of iron and copper	45.81
Gangue, (quartz, by difference)	42.82
	100.00

ANALYSIS OF KAOLINITE.

Analyses of kaolinite are important not only for a rational manufacture of China ware, but, also, in the application of this substance as a fire-proof material in metallurgical furnaces. The presence of iron or lime would render it useless for the latter purpose.

Kaolinite from Gunnison, Utah.

This clay is of a yellowish color and of uniform consistency. In consequence of its containing oxide of iron, it cannot be classified among the fire-proof clays. Its composition is:

Silica	46.79
Alumina	34.00
Oxide of iron	5.04
Water	14.07
	99.90

Kaolinite from the Rio Francisco, Arizona.

This mineral exists in this locality as the hanging of an extensive vein of cuprite; the thickness of the vein is 8 feet. It is snow-white, and retains its whiteness perfectly on ignition. It does not show a trace of iron, and is free from grit. The small amount of lime it contains is of no significance, and therefore it may be considered a first-class fire-proof clay; in fact, its composition is that of the best kaolinites known. Its composition is:

Silica	45.00
Alumina	36.43
Lime	0.23
Magnesia	Slight trace.
Water	18.21
	99.87

CHAPTER XXIII.

THE ERUPTIVE ROCKS OF ARIZONA AND NEW MEXICO.

Among the volcanic regions of the West, Arizona and New Mexico occupy conspicuous positions, not only with regard to the extent of country covered by volcanic material, but also in regard to the great variety of chemical composition, texture, and accessory constituents of these rocks. These volcanic masses present protrusions through the Cretaceous, as well as through the Triassic and Carboniferous beds, and occupy equally extensive tracts in the Azoic formations; a dike of basalt, 26 feet in width, and many hundred feet in length, protrudes from a mesa of Cretaceous age, about twelve miles southeast from the seat of the Moqui Pueblo in Eastern Arizona. Some forty miles south, hills of volcanic ashes cover the banks of the Colorado Chiquito, whence extends the basaltic formation southward over great areas, leaving exposed only little islands of the underlying Carboniferous beds. The Cosnino Caves,* Flat Top Mountain, and Point Lookout constitute the most notable features in the volcanic region, representing parts of the easterly section of the Sierra San Francisco.

The cañon Diablo, heading in the southeast portion of this region, is the dry bed of a former tributary of the Colorado Chiquito, and represents an erosion of 150 feet in depth, and of an average width of 40 to 50 feet, running partially in basalt, partially in sandstone. The Sunset Gap Mesas, twenty miles west of Sunset Crossing, (the crossing of the Prescott road over the Colorado Chiquito,) represent two mesas of 400 to 500 feet in height, and a quarter of a mile in length, running from northwest to southeast; the road to Prescott passes through the gap between them. The mesas are covered with a layer of basalt 12 to 20 feet in thickness; the slopes are more or less covered with this material, but where a land-slide has taken place the true nature of these elevations is well exposed. They con-

* For description, see page 629, in chapter on Mineral Waters, Incrustations, &c.

sist of a remnant of the former Triassic beds, namely: 300 feet red sandstone, with silicified wood; 72 feet alternating layers of gypsum and clay; 65 feet red sandstone; 7 feet of white sandstone. Another instance of this kind occurs at Cañon Butte—a basaltic cone near the junction of Chevelon's Fork with the Colorado Chiquito.

Extensive masses of basalt cover the eastern portion of the Mogollon Mesa and the Cordillera del Gila in Arizona; leaving here and there the underlying Carboniferous beds freely exposed; for example, at Camp Apache and near the Triplet Mountains. Chevelon's Fork heads near the western rim of the extended basaltic formation on the Mogollon Mesa, a mesa composed chiefly of sandstone of Carboniferous age. The road from Camp Verde to Camp Apache strikes this basaltic formation some fifty miles west of north from Camp Apache. Volcanic tuff and conglomerate, lava and scoria, not unfrequently accompany the basalt. Some fifteen miles east of the Triplet Mountains, and two miles to their southward, tuff and conglomerate become quite conspicuous. In the latter locality, the strata of tuff occupy a partially inclined position, and are overlaid by horizontal strata of the same material. In the former locality, the strata of tuff are superposed by a more recent basaltic flow.

That these volcanic outbursts have been frequent is therefore evident. Analogous protrusions through Carboniferous strata may be observed in the cañon of the Jemez Creek in New Mexico, some sixty miles west of Santa Fé. The walls of this cañon are 1,000 to 1,500 feet in height, and consist chiefly of sandstone beds of the Carboniferous period. Only in a few spots, however, is the underlying limestone, with the characteristic shells of *Productus* and *Spirifer*, exposed. These sandstone walls have been burst in many places by the protruding volcanic material, which, exposed in long vertical fissures, presents a most interesting feature in a geological point of view.

Basalt and rhyolite compose the Peloncillo Mountain range in Southeastern Arizona; the lands bordering on the Rio Grande Valley in New Mexico are also in many places extensively covered with basalt. The five tributaries of the Rio Grande that originate in the Sierra Mimbres have worn channels for great distances through basalt, especially the Rio de las Animas, Rio de las Palomas, and Rio del Cuchilla Negra, while rhyolite prevails on the Rio Apache and Rio Alamosa, the most southern and most northern of these five tributaries. The Sierra Mimbres is an extensive elevation, composed of rhyolite and basalt. On the Rio de las Animas and Rio de las Palomas, basalt appears in extended flows, in the form of mesas, through which frequently run steep and tortuous cañons. Rhyolite underlies this formation, and farther toward the mountain-range appears in conspicuous pyramids, surrounded by basalt.

In the cañon of Rio de las Animas were found small bowlders of andesite and aphanite, which would indicate the presence of these rocks in the neighboring mountains. In the cañon of Rio de las Palomas, transitions of basalt into dolerite are distinctly recognized. Here olivine is rarely met with and sometimes not at all—a noticeable feature also of the basalts of Iceland.

On the Rio del Cuchilla Negra, basalt appears in massive cones, the depressions being filled with tuff, which in some instances is from 20 to 25 feet thick, the strata of the latter dipping 5° to 18° south and southwest, and overflown by more recent basaltic masses. The Rio Alamosa is formed by the union of two creeks, which originate in warm springs. This union takes place about 40 yards above the entrance of the stream into the Cañada Alamosa. November 9, the temperature of these creeks was respectively 80° F. and 67°.5 F. just above their junction. The stream formed by the mingling of these waters was 70°.5 F. It follows, therefore, that the latter carries 1.4 more water than the former. The cañon through which this stream flows is of moderate width. The walls are from 50 to 100 feet in height, and are particularly interesting on account of the variety of volcanic material of which they are composed. The juxtaposition of these rocks is such as not to permit a definite conclusion as to their relative ages. The red rhyolites are followed by white, these by propylite, and farther down the river, near the settlement Alamosa, by dark-gray rhyolite, and then trachyte. The propylite of this cañon consists of a fine-grained greenish paste, composed of a mixture of hornblende and feldspar. In the paste are imbedded large crystals of orthoclase and hornblende, with little sanidine; there is no magnetic titaniferous iron present.

Next to basalt, rhyolite occupies a very conspicuous position in the volcanic regions of Arizona and New Mexico. It constitutes the greater part of the Sierra Caliuro in Southern Arizona. The summits of this range are

8,400 feet above the level of the sea; with the exception of a trifling quantity of oak, no timber is met with. Deposits of white tuff, 30 feet in thickness, are exposed on the foot of the northern slopes. This tuff incloses fragments of basalt and rhyolite, and consists here and there of what resembles most nearly metamorphosed zeolites; the crystalline form is partially retained, but the substance is changed, and has assumed a clayey character. While the lower and middle portion of these mountains is rhyolite, the summits of several of them are capped with basalt. On the western slopes of the northern foot-hills dykes of trachyte are quite conspicuous; the matrix is of a brownish-violet color. A great thickness of conglomerate rests upon the rhyolite on the western side of this mountain-range, sloping off to the Rio San Pedro. A system of deep cañons has been formed in these deposits, which dip in various directions, and occupy only exceptionally their original horizontal positions. On the Gila River, above the mouth of Rio Francisco, rhyolite is accompanied by basalt, pumice, obsidian, and pitchstone. The far extending beds of conglomerate are here often covered by opal and quartzites; the opal, chiefly milk-opal, frequently incloses fragments of basalt. Chalcedony appears in basalt as well as in rhyolite in this region.

The western foot-hills of the Burro Mountains, in New Mexico, are also composed of rhyolite. Here the rock exhibits a close relation to the granite which it overlies, inasmuch as it incloses semi-fused fragments of the latter. Moreover, we can trace quite distinctly the effects of various degrees of heat upon masses of feldspar, which have, in some instances, assumed a glassy appearance; extensive veins of quartz also penetrate this rhyolite. From this, it would appear that we here have a granite with partial transformation into a rhyolite. In many instances, the volcanic outbursts may consist of molten or semi-molten gneiss, primitive clay-slate, mica-schist, hornblende-schist, or granite, that came into contact with the forward pushing liquid interior of the earth, and whose great variety in texture and accessory constituents may be traced back to the varieties of these primitive rocks. On the other hand, accessory constituents may be taken up during the act of protrusion. Several examples were observed to confirm this view. On the Rio Francisco, seven miles above its mouth, masses of rhyolite occur that contain through the whole particles of kaolin of the size of a small pea.

It is not reasonable to belive that this is the result of a metamorphosis of feldspathic particles formerly contained in the rock. Further, this is evident, that previous to the outburst this kaolin was not contained in the liquid interior of the earth. The most plausible explanation of this is that the liquid rhyolitic mass, on bursting through the earth's crust, had to penetrate beds of clay, which, being thereby shattered into fragments, mingled with the volcanic material and was ejected with it.

An analogous case is the occurrence of carbonate of lime in basalt. No chemist will admit that the former was contained in the basalt before its ejection, since the lime would have been combined with the silicic acid of the molten mass and carbonic acid liberated. Neither is there any foundation for the hypothesis that this carbonate of lime was deposited by infiltration of calcareous waters; to a close observer this appears quite an impossibility. At places where the occurrence was observed, (Sierra del Gila, Rio San Carlos, Camp Apache,) its presence could be traced without any difficulty to the strata of limestone that had to be burst by the protruding volcanic material. The limestone broken into fragments by the concussion and heat of the molten mass fell in small particles upon and became entangled by it. The heat, however, liberated a part of the carbonic acid of these limestone particles, and formed a bubble that could not escape, the mass assuming a thicker consistency after its ejection. The pressure prevented the total decomposition of the limestone particles, but the heat imparted to them a crystalline structure; hence the *calcite* in the amygdaloid spaces of *basalt*. A piece of such basalt, two hundred grains in weight, was pulverized, and five grammes taken for a determination of the carbonate of lime, of which there was found 21.47 per cent.

Another interesting point is the occasional occurrence of black dendritic ramifications in the amygdaloid spaces of basalt. On the northern slope of the Peloncillo Mountains they were found especially well developed. Analysis proved them to consist of peroxide of manganese; also a substance that would be decomposed by the enormous heat of fused basalt. It was most probably formed during the cooling state of the ejected mass from the protoxide of manganese contained originally in the mass. The amygdaloid spaces in which this formation had taken place must have contained oxygen, otherwise the formation of the peroxide would be unintelligible.

The Carboniferous limestone frequently forms islands in the volcanic formations. Some interesting cases of this kind were observed between the southwestern foot-hills of the Sierra Mimbres, in New Mexico. On the headwaters of the Rio Apache there is one of these, of over a mile in length, surrounded by rhyolite; its most western portion adjoins a dike of pyrolusite. The strata of the limestone dip 45° to 50° east. At a distance of six to seven miles to the southward, in gulches, sandstone is exposed, underlying the rhyolite; the strata dip 35° to 37° east.

The Sierra Madalena and Sierra San Mateo, in New Mexico, are also for the greater part composed of rhyolite, as well as the plateau, fifty miles west of Santa Fé, (Baca's grant.) In this latter locality this rock is accompanied by great thicknesses of pumice; also by obsidian, that in some instances is full of spharulite.

On the southwestern slope of this volcanic plateau, toward the town of Jemez, there is an interesting occurrence of labradorite porphyry; large crystals of labradorite, with a magnificent blue iridescence, are imbedded in a gray, apparently quite uniform, matrix. Pitch stone also occurs in this vicinity.

The volcanic tuffs have but seldom been the subject of close investigation; I therefore subjected a tuff of a peculiar character to analysis. On the plain extending from Fort Bowie to the Peloncillo Mountains, about four miles south of Whitlock's Cienega, are found stratified deposits of a yellowish, soft, porous material, in thickness from 12 to 13 feet, and in extent about one-sixth of a mile. The mass easily crumbled to powder between the fingers, had no similarity at all to clay, and the presence of very fine grit could be distinctly recognized.

On digestion with strong acids, a complete decomposition was effected. Alumina, lime, magnesia, oxide of iron, and alkalies were dissolved, while silicic acid was separated, and remained with the fine grit, which proved to be plain silica.

Quantitative analysis gave the following results at 100° C.:

Silica	64.61
Alumina	14.32
Oxide of iron	2.98

Lime	3.01
Magnesia	1.36
Soda	3.19
Potassa	Traces.
Water	10.12
Loss	0.11
	100.00

It follows, therefore, that this tuff is a mixture of free particles of quartz, with a hydrous silicate, somewhat related to chabazite or stilbite.

The presence of a phonolitic rock upon the Peloncillo Mountains would easily account for this zeolitic deposit. This bed is joined on its south side by another one composed of a mixture of carbonate of lime with apparently the same hydrous silicate. Trachyte everywhere accompanies rhyolite in smaller or larger masses. Trachyte, with sanidine and biotite, occurs on the Caliuro Mountains; also with large crystals of feldspar at Silver City, and with hornblende at Ojo del Macho and Fort Cummings.

According to Baron Richthofen, andesite, propylite, trachyte, rhyolite, and basalt are of Tertiary and post-Tertiary age. Von Cotta, while admitting this as a general rule, considers it doubtful in many cases. Cotta maintains that there are basaltic masses in Azoic formations the age of which cannot be told. Cases of this kind occur in New Mexico and Arizona.

Of the older eruptive rocks, we have to mention:

Eruptive gneiss at Ojos Calientes in the cañon of the Jemez Creek, in New Mexico. It is a red gneiss, so-called protogyne, and makes its appearance as a dyke in sandstone of Carboniferous age.

Eruptive granite on a mountain five miles west from the town of Jemez, in New Mexico. The summit of the mountain is represented by the protruded mass of a red granite, accompanied by massive red orthoclase. The strata of Carboniferous limestone are much tilted and displaced, and the underlying gray fine-grained gneiss is here and there exposed.

Eruptive syenite has been observed by Lieutenant Tillman, of this survey, on Cook's Peak. The limestone strata (Carboniferous) dip 18° to 20° to southwest, and are metamorphosed on the contact surface with the syenitic summits.

Orthoclase-porphyrite composes a number of foot-hills on the southern slopes of the Cordillera del Gila, and besides appears in dikes on Mount Turnbull, where it is impregnated with copper ores.

Melaphyr also forms a dyke on Mount Turnbull. This designation, however, is a very elastic conception, so much so that Girard calls melaphyr the "black ghost upon the theater of mineralogical science."

Brongniart defines melaphyr as porphyry with black felsitic and hornblendic matrix and distinct feldspar crystals. Leopold von Buch deviates widely from this definition, denominating the rocks of the Fassa Valley in Tyrol as melaphyrs. These rocks are composed of a black augitic matrix, containing crystals of augite.

Richthofen defines melaphyr as a rock containing plagioclase and hornblende, with occasional apatite, magnetic iron, and biotite.

Senft describes melaphyrs as rocks with a labradoritic matrix, containing titanic iron and calcspar; Naumann, as a rock free from quartz, with a crypto-crystalline structure, that only exceptionally becomes granular, but usually is of a vesicular or amygdaloid character. The mass is composed of labradorite and pyroxene, with mica and zeolites as less frequent admixtures.

Zirkel denominates the melaphyr as a crypto-crystalline rock, frequently of porphyritic and amygdaloid structure, principally composed of oligoclase, augite, and magnetic iron.

Von Cotta defines melaphyr as an intimate mixture of feldspar, augite, hornblende, and magnetic iron; while Haarmann, who recently made extended microscopical investigations of melaphyrs from various localities, (Inaugural Dissertation, Leipsig, 1872,) pronounces feldspar as one of the usual constituents, adding that it is generally accompanied by magnetic iron and olivine; accessory constituents are augite, apatite, quartz, and nepheline, but never hornblende. He maintains, however, that the subject is still far from being definitely settled, and that rigid investigations of this class of rocks from various other localities have still to be made.

G. Leonhard is of the opinion of Zirkel, but says the dense structure is more frequent than the crypto-crystalline.

CHEMICAL COMPOSITION OF THE VOLCANIC ROCKS.

The volcanic rocks may not only be classified in a mineralogical point of view, but their many interesting chemical relations lead also to a chemical system. While, on the one hand, alumina, oxide of iron, lime, and magnesia are conspicuous constituents of basalts and dolerites; on the other hand, silica and the alkalies are more conspicuous in the trachytes and rhyolites. Under the like circumstances, the former rocks yield to disintegration more readily than the latter, and therefore, in spite of their containing less potassa, are more valuable in an agricultural point of view.

Bunsen, who paid especial attention to the study of the volcanic regions of Iceland and of the Armenian plateau region, proposed a chemical classification, based upon the difference between the normal maximum and normal minimum of silicic acid. The former type embraces trachytes and rhyolites, which are called "acidites;" while the latter type includes the pyroxenic rocks, basalt and dolerite, the so-called "basites." This classification, however, bears no relation to their respective ages; the acidites and basites may have issued from the same fissures in different periods. In New Mexico and Arizona, for instance, basalt often accompanies rhyolite. This forms an analogy to Iceland, where trachytic dikes in basaltic regions have been observed.

Comparatively little attention has been paid to the chemical composition of the volcanic rocks of the Far West, although it is a more important field for investigation than is supposed by many mineralogists, since in many basalts, trachytes, and rhyolites of Arizona and New Mexico, elements are found not previously known to exist in such rocks, namely: cobalt and nickel. The prevalence of these elements in this volcanic region is, indeed, surprising, when it is considered that cobalt has been found very sparingly, and only in a very few ores. We were first led to suspect the presence of cobalt by the pink-red spots of certain rhyolites on the western slopes of the Burro Mountains in New Mexico, while in basalts the cobalt and nickel were found in the attempt to determine the amount of manganese. This discovery gains still more importance on taking in consideration that cobalt and nickel are always associated with iron in meteorites of various kinds. In determining the amount of potassa and soda, hydrofluoric acid was used, while the other constituents were determined in the usual way by previous fusion of the finely-pulverized rock with alkaline carbonates. Some authors have found vanadium in basalts, also traces of rubidium and caesium. Our attempts in this direction, however, proved futile. Ten grammes served for the tests. No facilities were available for operating with larger quantities. The rocks for investigation were: Basalt from the northern slopes of the Peloncillo Mountains in Arizona. This specimen was obtained from a narrow cañon about seventeen miles east of the Rio Francisco. The cañon was about 8 feet wide, with walls 50 feet high, and terminated in the valley of the Gila River. The rock contained, sparingly, little crystals of augite and nepheline. With the magnifying-glass distinct dark-red cubes and light-green spots could be recognized.

The analysis gave the following result:

Silica	51.50
Alumina	18.60
Proto-sesquioxide of iron	14.09
Lime	7.75
Magnesia	4.68
Oxide of cobalt } Oxide of nickel }	0.03
Protoxide of manganese	Traces.
Soda	1.03
Potassa	1·22
Lithia	Traces.
Phosphoric acid	Traces.
	98.90

BASALT FROM CAÑON BUTTE, ARIZONA.

This locality lies about one hundred and fifty miles to the west of north from the Peloncillo Mountains, and a hundred miles north from Camp Apache. It is a conspicuous basaltic cone, and adjoining it is a small island of Triassic beds covered by the basalt. A number of cañons, the walls of which consist of cross-bedded sandstone, head near the base of the butte; hence the name "Cañon Butte." Cobalt, nickel, and titanium were found in the basalt, but in too little amount for a quantitative determination.

The analysis yielded—

Silica	40.91
Alumina	23.03
Oxide of iron	17.36
Oxide of manganese	Traces.
Oxide of cobalt	Traces.

Oxide of nickel	Traces.
Titanic acid	Traces.
Lime	11.66
Magnesia	2.20
Potassa } Soda } (by differences)	4.84
	100.00

RHYOLITE FROM THE PELONCILLO MOUNTAINS, ARIZONA.

This rock was of a light-violet color, with small crystals of sanidine and biotite distributed sparingly through its mass. On the weathered surface were observed minute specks, which proved to be malachite. Traces of cobalt were also found, and at a glance it would appear that the violet color of certain rhyolites was due to the presence of this element. Although no free quartz is visible in the rock, the quantity of silica would classify it among the rhyolites.

Its composition is:

Silica	71.54
Alumina	10.44
Oxide of cobalt	Traces.
Oxide of copper	Traces.
Peroxide of iron	5.25
Lime	0.56
Magnesia	0.53
Potassa	5.01
Soda	4.94
Lithia	Traces.
	98.47

TRACHYTE FROM THE SIERRA CALIURO, SOUTHERN ARIZONA.

This mountain-range is about fifteen miles in length and four miles in width, and is composed of rhyolite, trachyte, and basalt. The paste of the trachyte is of a brownish-violet color, and incloses numerous crystals of biotite and orthoclase, which are, however, of small size.

It has the following composition:

Silica	66.57
Alumina	12.26
Oxide of cobalt	0.02
Oxide of nickel	Traces.
Peroxide of iron	5.99

Lime	1.96
Magnesia	1.02
Potassa	4.80
Soda	4.67
Lithia	Traces.
	98.29

RHYOLITE FROM THE BURRO MOUNTAINS, NEW MEXICO.

On the western slopes of the Burro Mountains, where the trail to the Gila River leaves the foot-hills, there is a cañon in which a whitish rhyolite with pink-red specks is exposed, due to a silicate of cobalt; no distinct crystals of any kind are imbedded in it.

The rock contains—

Silica	76.84
Alumina	10.50
Oxide of iron	1.02
Oxide of cobalt	Traces.
Oxide of nickel	Traces.
Lime	1.41
Magnesia	0.83
Potassa, Soda (by difference)	9.40
	100.00

In order to compare these results with the chemical composition of related rocks from other Territories, some analyses were made of volcanic rocks from Utah, Nevada, and California.

RHYOLITE FROM BELMONT, NEV.

The matrix is of a light-grayish color, and imbedded in it are numerous sanidine crystals of moderate size. Some biotite is also present. Cobalt and nickel were absent.

It gave on analysis—

Silica	76.23
Alumina	7.95
Oxide of iron	3.08
Lime	1.34
Magnesia	Trace.
Potassa, Soda (by difference)	11.40
	100.00

PROPYLITE FROM SEVIER PLATEAU, UTAH.

This is a crypto-crystalline rock of a greenish color, in which small crystals of hornblende and sanidine are recognized. Small particles of magnetic iron are also present. Although this rock differs somewhat from the genuine propylite, it is more related to this volcanic rock than to either trachyte or rhyolite. The chemical analysis also shows less silica and more lime than in both these latter rocks. No traces of manganese, cobalt, or nickel could be discovered.

It consists of—

Silica	62.86
Alumina	14.49
Proto-sesquioxide of iron	7.98
Lime	6.90
Magnesia	0.71
Soda, Potassa (by difference)	7.06
	100.00

ANDESITE FROM GRASS VALLEY, UTAH.

This rock represents a dense mass of a dull-black color, with here and there white amorphous spots. It includes sanidine sparingly; cobalt, nickel, and titanium could not be detected.

The analysis gave—

	I.	II.
Silica	65.95	65.09
Alumina, Oxide of iron	21.23	24.14
Lime	3.13	2.61
Magnesia	0.57	4.10
Soda, Potassa (by difference)	9.12	5.45
	100.00	

In column II is represented the composition of an andesite from the Chimborazo. The amount of silica in both is very nearly the same.

BASALT FROM CALIFORNIA, (EL PASO MOUNTAIN.)

It contained some olivine. Neither cobalt nor nickel were found.

The analysis gave—

Silica	62.90

Alumina / Oxide of iron	26.87
Protoxide of manganese	Trace.
Lime	7.39
Magnesia	1.01
Soda / Potassa (by difference)	1.83
	100.00

A glance at the following table will suffice to show the great difference of composition existing among the basites as well as the acidites. The quantity of silica in the basalt of Cañon Butte is far below that of the normal basitic composition, while the basalt from California is unusually rich in it. With regard to the acidites, we find the rhyolite of Belmont, Nev., and of the Burro Mountains, New Mexico, nearly of the normal composition, especially with regard to the amount of silica; while the rhyolite, from the Peloncillo Mountains, has 5.13 per cent. less silica.

T. Sterry Hunt had already pointed out that no definite system could be based upon the distinction established by Bunsen, although the two great natural groups of volcanic rock are fixed between certain outlines. Between these the composition may vary considerably.

Table for comparing the composition of basites and acidites.

Constituents.	Normal basite.	Basalt from Peloncillo Mountains, Arizona.	Basalt from Cañon Butte, Arizona.	Basalt from El Paso Mountain, California.	Normal acidite.	Trachyte from Sierra Calitro, Arizona.	Rhyolite from Peloncillo Mountains, Arizona.	Rhyolite from Burro Mountains, New Mexico.	Rhyolite from Belmont, Nev.
Silica	48.47	51.50	40.91	62.90	76.67	66.57	71.54	76.84	76.23
Alumina / Oxide of iron	30.16	18.60	23.03	26.87	14.23	12.26	10.44	10.50	7.95
Oxide of iron		*14.09	*17.36			5.99	5.25	1.02	3.08
Oxide of copper	....	....	....	....	....	....	Trace...	....	....
Oxide of manganese	....	Trace...	Trace...	Trace...	....	....	Trace...	....	....
Oxide of cobalt / Oxide of nickel	....	0.03	Traces..	....	....	0.02	Traces..	Traces..	....
Titanic acid	....	....	Trace...	Trace...	....	....	....	....	....
Lime	11.87	7.75	11.66	7.39	1.44	1.96	0.56	1.41	1.34
Magnesia	6.89	4.68	2.20	1.01	0.28	1.02	0.53	0.83	Trace.
Lithia	....	Trace...	Trace...	....	....	Trace...	Trace...	....	....
Soda	1.96	1.03	†4.84 (Soda and Potassa)	†1.83	4.18	4.67	4.94	†9.40 (Soda and Potassa)	†11.40
Potassa	0.65	1.22			3.20	4.80	5.01		
Total	100.00	98.90	100.00	100.00	100.00	98.29	98.47	100.00	100.00

* As proto-sesquioxide of iron. † Including loss and traces of water, being calculated from difference.

CHAPTER XXIV.

MINERALOGICAL TABLES.

ELEMENTS.

Mineral.	Locality.					Remarks.
	Colorado.	New Mexico.	Utah.	Nevada.	Arizona.	
Copper, (native)	....	....	....	Bull Run, Eureka, Battle Mountain, Austin, Reese River.	Rio Francisco	Chiefly accompanying cuprite.
Silver, (native)	Gold Hill, in petzite; Georgetown, in zinc blende; Montezuma.	Sierra de los Ladrones, in quartz; Silver City, in slate.	....	San Antonio, Belmont, Silver Peak, Eureka.		
Gold	Nevada lode, in blue copper; John's lode, in zinc-blende; Red Cloud lode, in petzite; Briggs's lode, in chalcopyrite; Oro City, in rhyolite; Mosquito, San Juan district.	Placer Mountain, in quartz, hematite, and sandstone; Fort Bayard, Madalena range.	....	Gold Mountain, Silver Peak, in quartz and galenite.	Pinal range, Wickenburg, Rio Francisco, Fort Bowie.	Sierra Nevada, California. Gold is especially widely distributed in Boulder, Clear Creek, and Gilpin Counties, Colorado.
Bismuth	French Gulch.					
Antimony	Gold Hill.					
Tellurium	Gold Hill.					
Sulphur	....	....	Cove Creek Fort	Lucifer mine	....	Owen's Lake, California.
Graphite	....	Burro Mountains	Beaver Lake district.			

SULPHIDES.

Pyrite	Gilpin County, Clear Creek County, Cañon City, Oro City, San Juan district, Mount Lincoln, Buckskin.	Placer Mountains, Pinos Altos, Cook's Peak.	Provo, Antelope Spring.	Galena	....	Often auriferous and argentiferous.

Sphalerite, (zinc-blende.)	Central City, Georgetown, Peru, Oro City, Mosquito.	Pinos Altos		Ivanpah		In some cases argentiferous.
Galenite	Clear Creek County, Gilpin County, Cañon City, Mount Lincoln, Elko, Rosita, Montezuma, San Juan district.	La Joya, Madalena range, Silver City, Placer Mountains.	Mount Nebo district	Galena, Railroad district	Wheatstone Mountain	Mostly argentiferous.
Chalcocite, (copper-glance.)	Central City, Idaho Springs, Cañon City, Mosquito.	Ojos Calientes, Santa Rita mines, Burro Mountains, Socorro mines.		Reese River	Rio Bonito, Rio Francisco, Turnbull Peak.	Sometimes argentiferous.
Covellite, (blue copper.)	Mosquito, Central City, Cañon City.	Burro Mountains			Rio Francisco.	
Bismuthinite	Ward district.					
Argentite, (silver glance.)	Black Hawk, Georgetown, Mount Lincoln, Caribou, Buckskin, Montezuma, Peru.	Silver City	Ohio district	Cope district, Mineral Hill, Palmetto, Bull Run.		Partzwick, California.
Molybdenite	Boulder County.					
Stibnite	Boulder County		Tintic district	Battle Mountain, Reveille district.		Blind Spring district, California.
Freieslebenite				Belmont.		
Stembergite, (iron and silver sulphide.)	Georgetown	Spring Hill district		Reese River district.		
Polybasite	Boulder County.					
Chalcopyrite	Argentine district, Mosquito.	Madalena range		Galena district, Railroad district.	Rio Francisco.	
Stephanite	Montezuma			Reese River district.		
Mispickel				Morey.		
Selensulphide				Lucifer mine.		
Stromeyrite				Belmont, Pioche, Mineral Hill, San Antonio, Palmetto, Cope district.		
Pyrargyrite, (ruby silver.)	Montezuma, Peru			Austin, Galena, Reese River district.		

Mineralogical tables—Continued.

METALLIC OXIDES.

Mineral.	Locality.					Remarks.
	Colorado.	New Mexico.	Utah.	Nevada.	Arizona.	
Hematite	Cañon City	Silver City, Burro Mountains, Placer Mountains.	Iron City	Lone Mountain	Colorado River, Rio Francisco.	Worked in Utah.
Limonite		Madalena range, Nacimiento.		Lone Mountain	Rocker Creek, Dos Cabezas.	
Menacanite, (titaniferous oxide of iron.)				Carlin, Eureka, Morey, Belmont.	Dragoon Mountains.	
Magnetite	Cañon City		Iron City, Rocky district.	Iron Spring, Wheeler's Peak, Railroad district.		Extensively worked in Utah.
Pyrolusite, (peroxide of manganese.)		Silver City, Burro Mountains.		Morey		Associated sometimes with pilomelan and manganite.
Uraninite, (uranpitch-blende.)	Leavenworth Gulch, Gilpin City.					Shipped to England.
Bismite, (bismuth-ocher.)	French Gulch, Ward district.					
Massicot		Spring Hill district, Socorro mines.		Galena.		
Minium	Georgetown, Central City.	Madalena range, Socorro mines	Lincoln district	Pioche		Often accompanies galenite.
Melaconite	Pollock, Mosquito	Burro Mountains	Rocky district.			
Cuprite, (red oxide of copper.)	Cañon City	Burro Mountains, Sierra de los Ladrones.	Tintic district	Austin, Battle Mountain.	Rio Francisco	Often accompanied by native copper.
Stetefeldite		Spring Hill district		Mineral Hill, Belmont, Battle Mountain.		All these oxides of antimony are found in Blind Spring district, California.
Cervantite						
Partzite						

TELLURIDES, FLUORIDES, CHLORIDES, IODIDES.

Altaite, (telluride of lead.)	Gold Hill					Associated sometimes with tellurides of iron and bismuth.
Petzite, (telluride of gold and silver.) Nagyagite	Gold Hill					Dr. Schirmer, director of the United States branch mint at Denver, has an extensive and most interesting collection of the tellurides of Colorado.
Fluorite, (fluor-spar.)	Jamestown, Bear River.			White Mountain district.		Extensively used as flux in metallurgical processes.
Iodide of silver				Star lode, Austin.		
Cerargyrite, (chloride of silver.)		Silver City, Socorro mines.		Pioche, White Pine district.	Prescott.	
Embolite, (bromo-chloride of silver.)	Gold Hill	Silver City		Mineral Hill.		
Halite, (chloride of sodium.)	South Park, Snake River, Cañon City.	Placer Mountains, (lake).	Salt Creek	Virgin River, Silver Peak, Hyko, Black Cañon.		In many saline efflorescences it is frequently found; also in springs.
Chlorides of calcium and magnesium.					Rio Francisco	Accompanying the chloride of sodium in salt-ponds or salt-springs.

CARBONATES.

Carbonate of soda, (Trona.)		Ojo de Tao		Hot Springs	Prescott, Dragoon Mountains.	
Calcite		Silver City, Sierra Madalena.	Manti, Sevier Lake, Mount Nebo, Gunnison, Salt Creek Cañon.	Bristol district	Camp Apache, mouth of Paria Creek.	As aragonite, it is found at Ojos Calientes, N. Mex., and Mineral Hill, Nev.
Rhodochrosite, (carbonate of manganese.)	Sweet Home lode			Reese River district, Morey.		
Cerussite, (carbonate of lead.)	Cañon City, Peru	Santa Rita mines, Socorro mines, Silver City.	Tintic district, Big Cottonwood district.	Bull Run		Often argentiferous.

Mineralogical tables—Continued.

CARBONATES—Continued.

Mineral.	Locality.					Remarks.
	Colorado.	New Mexico.	Utah.	Nevada.	Arizona.	
Malachite, (green carbonate of copper.)	Oro City, Pollock, Cañon City, Montezuma.	Burro Mountains, Socorro mines, Ralston; Placer Mountains.	Tintic district	Railroad district, Battle Mountain, Belmont, Austin, Bristol district.	Rio Francisco, Gila Bonito Creek, Rio San Carlos, Turnbull Peak.	
Azurite, (blue carbonate of copper.)	Montezuma, Oro City...	Burro Mountains, Socorro mines.	Tintic district..........	Galena, Ophir Cañon ...	Rio Francisco.	
Bismuthite, (hydrated carbonate of bismuth.)	Ward district, Las Animas mine.					
Siderite, (carbonate of iron.)	....	....	Gunnison	....	....	Blind Spring district, in California.

SULPHATES.

Mineral.	Colorado.	New Mexico.	Utah.	Nevada.	Arizona.	Remarks.
Sulphate of soda ..	....	Savinal	....	Hot Springs	Santa Catalina range, Dos Cabezas, Sunset Crossing.	In many saline efflorescences.
Sulphate of magnesia.	....	Savinal	....	Hot Springs............	Santa Catalina range....	In efflorescences.
Barite, (sulphate of baryta.)	Montezuma.............	Silver City, Fort Bayard.				
Gypsum, (sulphate of lime.)	South Park, Rock Creek, Eagle River, Arkansas River, Turkey Creek, Colorado Springs.	Jemez, Diamond Creek, Silver City, Madalena range.	Salt Creek Cañon, Lost Creek.	Cottonwood Creek, Mineral Hill, Eureka.	Wheatstone Mountains, Sunset Crossing, Cañon Butte.	Including all varieties of it, selenite, &c.
Sulphate of copper and iron.	....	Copper Gulch, Burro Mountains.				
Alunogen, (neutral sulphate of alumina.)	....	Bacon Springs, Cook's Peak, (in Alum Cave.)	....	Thirty-five miles northwest of Silver Peak.		
Glockerite, (basic iron persulphate.)	Central City, Idaho Springs.	....	....	....	....	Forming incrustations over iron pyrites.

Anglesite, (sulphate of lead.)	West Argentine district.			Railroad district.		Partzwick, California.

MOLYBDATES, TUNGSTATES, ARSENATES, NITRATES, PHOSPHATES, BORATES.

Wolfenite, (molybdate of lead.)	Park County, Boulder County, Gold Hill.			Eureka.		
Wolframite, (tungstate of iron and manganese.				White Mountains.		
Hubnerite				White Mountains.		
Scheelite. Mimetite, (arsenate of lead.)						Blind Spring district, California.
Wawellite				Belmont.		
Apatite				Lone Mountain.		
Niter					Cosnino Caves	As wall-incrustation.
Boronatro-calcite				Hot Springs		Coyote, in California.
Turquois		Los Cerillos		Columbus district.		

SILICIC ACID.

Agate	South Park	Nacimiento, San Mateo	East fork of Sevier River, Red Cañon.	Tuscarora, San Antonio, Fish Lake Valley.	Rocker Creek.	
Jasper		Jemez, Willow Springs	Harrisburgh, Washington, Wahsatch range.	Lone Mountain, San Antonio, Silver Peak.	Colorado Chiquito, Navajo reservation, Moquis villages.	Chiefly in Triassic and Cretaceous beds.
Flint	South Park	San Ildefonso, Fort Wingate.	Gunnison	Belmont, Tuscarora	Painted Desert	Death Valley, California.
Opal		Rio Puerco		Agate Mountain, Tuscarora.	Chevelon's Fork.	
Chalcedony		Fort Defiance	Wahsatch range, Pine Valley, Sevier River, Beaver.	San Antonio, Eureka, Virgin river, Tuscarora.	Cordillera del Rio Gila, San Carlos Creek.	
Amethyst			Iron City.			
Silicified wood	Currant Creek, South Park.	Bacon Springs, Rio Puerco.	Toquerville	Agate Mountain, Tuscarora.	Navajo reservation, Painted Desert, Sunset Crossing.	Abundant in the Triassic beds.

Mineralogical tables—Continued.

SILICATES.

Mineral.	Locality.					Remarks.
	Colorado.	New Mexico.	Utah.	Nevada.	Arizona.	
Garnet		Fort Defiance			Black Cañon	Were the cause of the "diamond" excitement some years since in Arizona.
Chrysolite		Fort Defiance				As olivine, often in basalts of New Mexico.
Orthoclase*	Central City, Georgetown, Boulder.	In huge red masses near Jemez.	Common	Fish Lake Valley, Palmetto, Gold Mountain.	In large crystals in the Dragoon Mountains, Pinal range.	Occurring in rhyolite, basalt, and granite.
Albite		Jemez				Frequent constituents of rocks, as granite, basalt, rhyolite.
Labradorite						
Sanidine	Rio Grande	Burro Mountains			Camp Apache, Caliuro range.	
Pumice		Valle Grande		Silver Peak, Owen's River Valley.	Rio Gila, Peloncillo range, Bill Williams' Mountain.	
Obsidian						
Epidote	Prosser Hill.					
Biotite		Sierra Mimbres		Silver Peak, Palmetto	Graham Peak	Common as constituents of granite; sometimes in rhyolite.
Muscovite	Gilpin and Gold Hill Counties.	Placer Mountains			Pinaleño range	
Natrolite		Valle Grande				Analcite at San Antonio, Nev.
Datolite		Head of the Gila		Columbus.		
Tourmaline	Black Hawk	Santa Fé.				
Amphibol	Clear Creek County				Graham Peak, Santa Catalina range.	
Chrysocolla	Cañon City	Burro Mountains	Rocky district		Rio Gila.	
Calamine	Park County	Pinos Altos.				
Talc	Black Hawk	Placer Mountains, Burro Mountains.				
Kaolinite	Gold Hill	Burro Mountains	Gunnison		Rio Gila, Rio Francisco.	

ORGANIC COMPOUNDS.

Wheelerite, (C_5H_6O.)	....	Nacimiento, Willow Springs, Fort Wingate.	....	....	Navajo reservation......	A new fossil resin in the Cretaceous coal-beds, described in American Journal of Science, June, 1874.
Petroleum........	Cañon City.					
Mineral charcoal..	....	Mesa de los Torreones.				
Anthracite........	....	Placer Mountains, Silver City.				
Bituminous coal and lignite.	Golden, Boulder, Cañon City.	La Joya, Nacimiento, San Mateo, Fort Wingate, Albuquerque, Ojo del Pueblo.	Fairview, Kanara, Salina Creek, Mount Pleasant, Cove Creek fort.	Elko............	Camp Apache, Moqui villages.	
Asphaltum........	Cañon City.					

ROCKS.

Granite...........	Boulder County, Gilpin County, Clear Creek County; from Denver to New Mexico, Arkansas range.	Santa Fé range, Placer Mountains, Pinos Altos, Zuñi Mountains.	Wahsatch range, Granite Mountain, Gosiute range, Mineral range, Picacho range.	Wheeler's Peak, Bull Run Mountains, Humboldt range, Lone Mountain, Belmont; Leach's Point, California.	Pinaleño range, Pinal range, Dragoon Mountains, Santa Catalina range, Grand Cañon, San Prieto.	In some varieties the mica is almost disappearing, as at Central City, Gold Hill, Colorado; in some cases replaced by talc.
Syenite...........	Chalk Creek*...........	Fort Bayard...........	Wahsatch range........	Eldorado Mountain, Dead Mountain, Ivanpah.	Chiricahui range........	Inyo range, California; Sierra Nevada, California; eruptive syenite occurs at Cook's Peak, New Mexico.
Gneiss............	Arkansas range, Tenmile Creek.	Upper Mimbres, Burro Mountains.	Wahsatch range, Picacho Mountain, Mineral range.	Lone Mountain, Belmont, Humboldt range, Toyabe range.	Graham range, Grand Colorado Cañon, Black Mountains, Camp Bowie, San Prieto, Santa Catalina range.	Eruptive gneiss occurs at Ojos Calientes, N. Mex.; eruptive granite near Jemez, N. Mex., Cienega; San Simeon, N. Mex., and Palmetto, Nev.
Quartzite, (massive.)	South Park, Sangre de Cristo Mountains, Brown Mountain.	Burro Mountains, Madalena range, La Joya.	Wahsatch range, Beaver Creek range, Dry Pass.	Bull Run Mountains, Toyabe range, Snake range, Schell Creek range, Pioche range.	Turnbull Peak, Sierra Ancha, Cañon Creek, Mogollon Mesa, Camp Bowie.	

* Well developed in crystals 3 to 4 inches long in the Arkansas range.

Mineralogical tables—Continued.

ROCKS—Continued.

Mineral.	Locality.					Remarks.
	Colorado.	New Mexico.	Utah.	Nevada.	Arizona.	
Mica schist	Idaho Springs, Saint John's.	Santa Fé range.........	Wahsatch range	....	Pinaleño range.	
Primitive clay-slate	Clear Creek County	Santa Fé range.........	....	....	Pinaleño range.	
Sandstone	South Park, Sangre de Cristo Mountains, San Juan River, Rio Piedra, Los Pinos River, Las Animas River, Taylor River, Rock Creek.	Rio Puerco Basin, Ojos Calientes de Jemez, Rio Galisteo, San Ildefonso.	Great Cliffs, Vermillion Cliffs, Shinarump Cliffs, southern boundary.	Bull Run range	Moqui villages, Painted Desert, Aubrey Cliffs, Grand Colorado Cañon, House Rock plateau, Tres Hermanos basin, Chevelon's Fork, Big Dry Fork.	
Limestone:						
1. Paleozoic ..	Idaho Springs, azoic; South Park, Blue River, Rock Creek, Roaring Fork, Arkansas River, Taylor River, Las Animas River, East River.	Silver City, Ojos Calientes, Santa Fé, La Joya, Upper Mimbres, Fort Cummings, Fort Wingate, Sierra Mimbres, Sierra Madalena, Zuñi Mountains, Zandia Mountains.	Wahsatch range, Oquirrh range, Onaqui range, Cedar range, Thomas range, House range, Gosiute Mountains, Hawawah range, Picacho range, Mineral range, Pahvant range, Tintic range, Lake range, Virgin City.	Bull Run Mountains, Lone Mountain range, Battle Mountain range, Toyabe range, Reveille range, Worthington range, Pahranagat range, Hyko range, Timpahute range, Amargosa range, Schell Creek range, Highland range, Snake range, Spring Mountain range, Bear Mountain range.	Santa Catalina range, Dragoon Mountains, Big Dry Fork, Chiricahui range, Camp Apache, San Francisco plateau, Grand Cañon, Kaibab plateau, Kanab Cañon, Sheavwitz plateau.	
2. Cretaceous.	Boulder, South Park, Huerfano Park, Blue River, Cañon City, San Juan River, Arkansas River, Colorado Springs.	Rio Puerco basin, Nacimiento, Navajo Creek, Rio Chama.	....	....	Ojo del Oso.	
3. Tertiary....	....	....	Pink Cliff, Pahvant range, Salt Mountains, Snowy range.			

4. As deposit of mineral springs.	Cañon City, Mound Soda Springs.	Ojos Calientes, Cañada Alamosa, Mimbres.				

ERUPTIVE ROCKS.

Rhyolite..........	Rio Grande, Gunnison River.	Sierra Mimbres, Madalena range, Sierra San Mateo, Rio Apache, Fort Cummings, Burro Mountains, Valle Grande.	Beaver range, Champlin range, Thomas range, Pine Valley range.	Hyko, Silver Peak, Tuscarora district, Shoshone range, Toyabe range, Toquima range, Monitor range, Hot Creek range, Kawich, range, Pancake range, Reveille range, Belted range.	Caliuro range, Peloncillo range, Rio Francisco, Postal's Ranch, Truxton Springs.	Hornblende and biotite here and there as accessory constituents; sanidine is a common constituent.
Trachyte	(Dikes occur through all the mountains.) Blue River, McClellan Mountain, Hamilton Pass, Mount Lincoln, Cebolla Creek.	Silver City, Cañada Alamosa, Sierra del Datil, Taylor Peak.	East fork of Sevier River, Fountain Green.	Independence Valley, Timpahute, Reveille range, Pahvan range, Antelope range.	Cordillera del Rio Gila, Rio Bonito, Colorado range, Sierra Blanca, Black Mountains, Mount Floyd, Mount Sitgreaves, Mount Kendrick.	
Basalt	Between South Park and Arkansas Valley, Pleasant Valley.	Rio de las Palomas, Rio del Cuchillo Negro, Sierra Mimbres, Rio Puerco basin, Cerro de Cabezon, San Ildefonso.	Headwaters of Dirty Devil, Upper Kanab, Toquerville, Santa Clara Valley, Grand Wash, Northside Mountains, Deseret.	Owyhee Valley, Copper Cañon, Reveille.	Mogollon Mesa, Camp Apache, Cañon Butte, Sunset tanks, Dog Buttes, Point Lookout, Peloncillo range, Triplets, Black Hills, Truxton Springs, Mount Davis.	Often amygdaloid with calcite in the cavities; also opal, chalcedony, and quartz as incrustations; olivine often wanting.
Volcanic tufa and conglomerate.	Cebolla Creek	Cañon de San Diego, Rio del Cuchillo Negro, Sierra San Mateo.	Pahvant Butte..........	Monitor range, Pancake range, Osino range, Maggie Creek, Logan, Castle Mountain.	Caliuro range, Triplets..	

INDEX.