DEPARTMENT OF THE INTERIOR
U. S. GEOGRAPHICAL AND GEOLOGICAL SURVEY OF THE ROCKY MOUNTAIN REGION
J. W. POWELL IN CHARGE

REPORT

ON THE

GEOLOGY OF THE HENRY MOUNTAINS

BY G. K. GILBERT

SECOND EDITION

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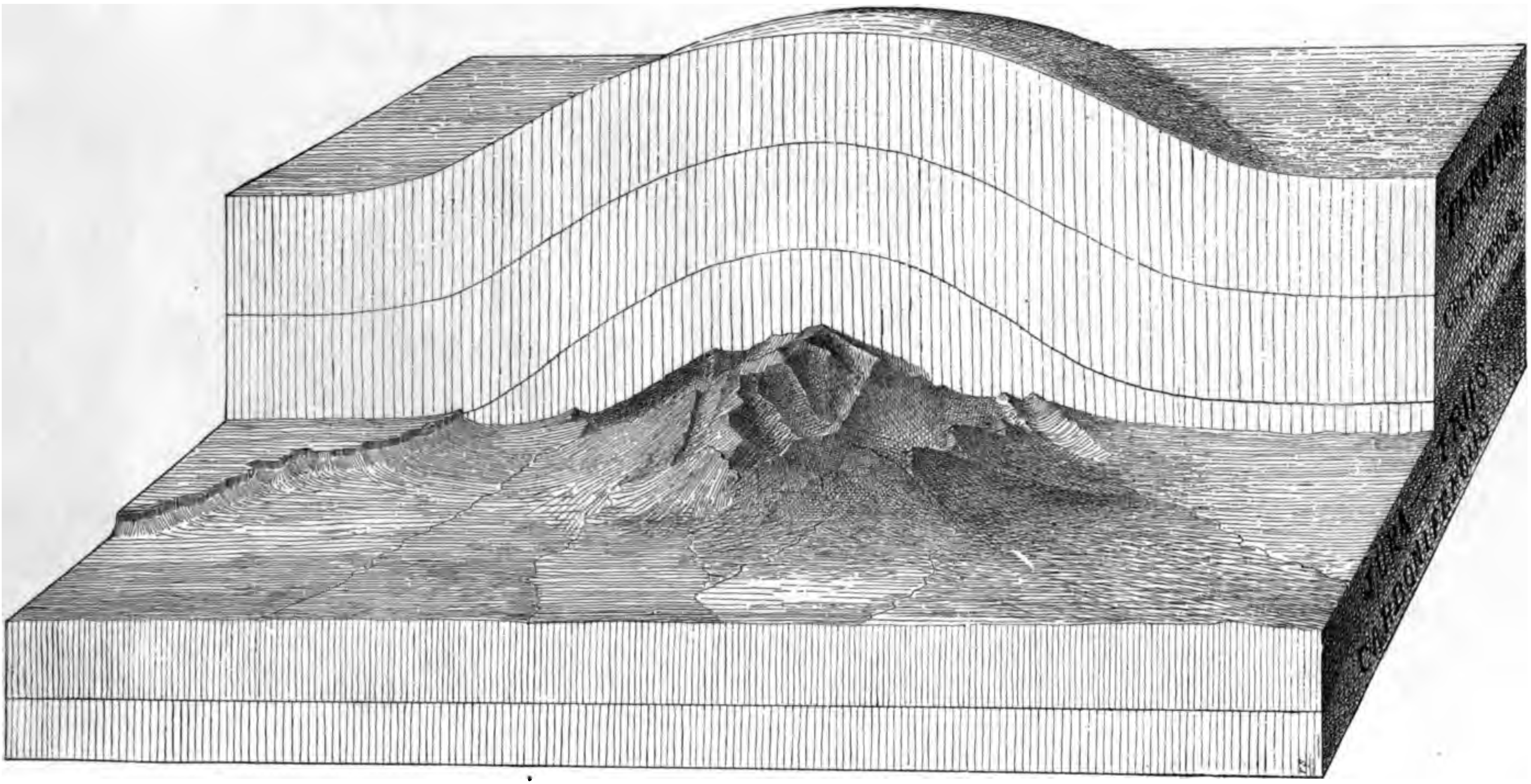

FRONTISPIECE.—**Half-stereogram of Mount Ellsworth, drawn to illustrate the form of the displacement and the progress of the erosion.**

The base of the figure represents the sea-level. The remote half shows the result of uplift alone; the near half, the result of uplift and erosion or the actual condition. (See page 95.)

DEPARTMENT OF THE INTERIOR,
U. S. GEOGRAPHICAL AND GEOLOGICAL SURVEY
OF THE ROCKY MOUNTAIN REGION,
Washington, D. C., March 5, 1877.

SIR: I have the honor to transmit herewith a report on the Geology of the Henry Mountains, by Mr. G. K. Gilbert.

I am, with great respect, your obedient servant,

J. W. POWELL,
In charge.

The Hon. SECRETARY OF THE INTERIOR,
Washington, D. C.

DEPARTMENT OF THE INTERIOR,
U. S. GEOGRAPHICAL AND GEOLOGICAL SURVEY
OF THE ROCKY MOUNTAIN REGION,
Washington, D. C., March 1, 1877.

DEAR SIR: I submit herewith my report on the Geology of the Henry Mountains, prepared from material gathered under your direction in the years 1875 and 1876.

I am, with great respect, your obedient servant,

G. K. GILBERT.

Prof. J. W. POWELL,
In charge.

PREFACE.

If these pages fail to give a correct account of the structure of the Henry Mountains the fault is mine and I have no excuse. In all the earlier exploration of the Rocky Mountain Region, as well as in much of the more recent survey, the geologist has merely accompanied the geographer and has had no voice in the determination of either the route or the rate of travel. When the structure of a mountain was in doubt he was rarely able to visit the points which should resolve the doubt, but was compelled to turn regretfully away. Not so in the survey of the Henry Mountains. Geological exploration had shown that they were well disposed for examination, and that they promised to give the key to a type of structure which was at best obscurely known; and I was sent by Professor Powell to make a study of them, without restriction as to my order or method. I was limited only in time, the snow stopping my work two months after it was begun. Two months would be far too short a period in which to survey a thousand square miles in Pennsylvania or Illinois, but among the Colorado Plateaus it proved sufficient. A few comprehensive views from mountain tops gave the general distribution of the formations, and the remainder of the time was spent in the examination of the localities which best displayed the peculiar features of the structure. So thorough was the display and so satisfactory the examination, that in preparing my report I have felt less than ever before the desire to revisit the field and prove my conclusions by more extended observation.

In the description of the details of the structure a demand arose for a greater number of geographic titles than were readily suggested by natural forms or other accidents, and recourse was had to the names of geologists. Except that the present members of my own corps are not included, the names chosen are of those whose cognate studies have given me most aid. Mr. Steward and Mr. Howell saw the Henry Mountains before I did,

PREFACE TO THE SECOND EDITION.

The manuscript of the first edition was finished in the year 1877. It was at once put in type, and in anticipation of a speedy issue the current year was marked on the imprint. There were, however, serious delays in the preparation of the illustrations, and it was not until 1879 that the volume was bound and distributed. Since the preparation of the manuscript the literature of the subject has been enriched by the publication of numerous descriptions of igneous mountains of the Plateau Province and of the Great Plains, and especially by important contributions to the physics of volcanism, in the light of which the author would be glad to give his work a full revision. The necessary time is not, however, at his disposal, and he has contented himself with a few verbal amendments and the addition of an appendix.

The river called Dirty Devil in the first edition is here called Fremont, but it was found impracticable to carry the reform to Plate I, where the old name survives. The change of name was inaugurated by the settlers of the country and is gladly followed. The only mythology that has appropriate place in our geographic nomenclature is that of the aborigines.

CONTENTS.

GEOLOGY OF THE HENRY MOUNTAINS.

BY G. K. GILBERT.

CHAPTER I.

INTRODUCTORY.

The Henry Mountains have been visited only by the explorer. Previous to 1869 they were not placed upon any map, nor was mention made of them in any of the published accounts of exploration or survey in the Rocky Mountain region. In that year Professor Powell while descending the Colorado River in boats passed near their foot, and gave to them the name which they bear in honor of the late Prof. Joseph Henry, the distinguished physicist. In 1872 Prof. A. H. Thompson, engaged in the continuance of the survey of the river, led a party across the mountains by the Penellen Pass, and climbed some of the highest peaks. Frontiersmen in search of farming and grazing lands or of the precious metals have since that time paid several visits to the mountains; but no survey was made of them until the years 1875 and 1876, when Mr. Walter H. Graves and the writer visited them for that purpose.

They are situated in Southern Utah, and are crossed by the meridian of 110° 45′ and the thirty-eighth parallel. They stand upon the right bank of the Colorado River of the West, and between its tributaries, the Fremont and the Escalante.

At the time of their discovery by Professor Powell the mountains were in the center of the largest unexplored district in the territory of the United States—a district which by its peculiar ruggedness had turned aside all previous travelers. Up to that time the greater part of the knowledge that had been gained of the interior of the continent had been acquired in the search for routes for transcontinental railways; and the cañons of the Colorado Basin, opposing more serious obstacles to travel than the mountain ranges which were met in other latitudes, were by common consent avoided by the engineers.

The same general causes which have rendered the region so difficult of access and passage have made it a desert, almost without economic value. The physical conditions of elevation and aridity which have caused it to be so deeply carved in cañons, have prevented the streams with which it is scantily watered from being bordered by tracts of land which can be irrigated; and agriculture without irrigation being in that climate an impossibility, there is nothing to attract the farmer. As will be explained in the sequel, the mountains offer no inducements to the miner of the precious metals. There is timber upon their flanks and there is coal near at hand, but both are too far removed from other economic interests to find the market which would give them value. It is only for purposes of grazing that they can be said to have a money value, and so distant are they at present from any market that even that value is small.

But while the Henry Mountains contribute almost nothing to our direct material interests, they offer in common with the plateaus which surround them a field of surpassing interest to the student of structural geology. The deep carving of the land which renders it so inhospitable to the traveler and the settler, is to the geologist a dissection which lays bare the very anatomy of the rocks, and the dry climate which makes the region a naked desert, soilless and almost plantless, perfects the preparation for his examination.

The study of the mountains is further facilitated by their isolation. They mark a limited system of disturbances, which interrupt a region of geological calm, and structurally, as well as topographically, stand by themselves.

The Henry Mountains are not a range, and have no trend; they are simply a group of five individual mountains, separated by low passes and arranged without discernible system. The highest rise about 5,000 feet above the plateau at their base and 11,000 feet above the level of the ocean. Projecting so far above the surface of the desert, they act as local condensers of moisture, and receive a comparatively generous supply of rain. Springs abound upon their flanks, and their upper slopes are clothed with a luxuriant herbage and with groves of timber. The smaller mountains and the foot-hills of the larger are less generously watered and but scantily clothed with vegetation. Their extent is small. From Ellen Peak to Mount Ellsworth, the two summits which are the most widely separated, the distance is but twenty-eight miles, and a circle of eighteen miles radius will include the whole group.

Mount Ellen which is the most northerly of the group, has an extreme altitude of 11,250 feet, and surpasses all its companions in horizontal extent as well as altitude. Its crest-line is continuous for two miles, with an elevation varying little from 11,000 feet. From it there radiate spurs in all directions, descending to a series of foot-hills as conspicuous in their topography as they are interesting in their structure. In some places the base of the mountain is guarded by a continuous, steep ridge, through which a passage must be sought by the approaching traveler, but within which movement in any direction is comparatively unimpeded.

Mount Pennell is a single peak rising to an altitude of 11,150 feet. On one side its slopes join those of Mount Ellen in Pennellen Pass (7,550 feet), and on the other those of Mount Hillers in the Dinah Creek Pass (7,300 feet). Its profiles are simple, and it lacks the salient spurs that characterize Mount Ellen. From the west it is difficult of approach, being guarded by a barrier ridge continuous with that of Mount Ellen.

Mount Hillers is more rugged in its character, and although compact in its general form, is carved in deep gorges and massive spurs. Its rugosity is contrasted by the smoothness of its pedestal, which to the south and west and north is a sloping plain merging with the surrounding plateau.

Mount Ellsworth (8,000 feet) and Mount Holmes (7,750 feet) stand close together, but at a little distance from the others. The pass which separates them from Mount Hillers has an altitude of 5,250 feet. They are single peaks, peculiarly rugged in their forms, and unwatered by springs. They stand almost upon the brink of the Colorado, which here flows through a cañon 1,500 feet in depth.

THE ROCK SERIES.

The sedimentary rocks which occur in the Henry Mountains and their immediate vicinity, range from the summit of the Cretaceous to the summit of the Carboniferous. It is probable that they were covered at one time by some thousands of feet of Tertiary strata, but from the immediate banks of the Colorado these have been entirely eroded, and their nearest vestiges lie thirty miles to the westward, where they have been protected by the lava-beds of the Aquarius Plateau.

Cretaceous.—The Cretaceous strata do not reach to the Colorado River, but they extend to the Henry Mountains, and are well displayed upon the flanks. They include four principal sandstones, with intervening shales, in the following (descending) order:

1. The Ma-sūk' Sandstone, yellow, heavy-bedded	500 feet.
2. The Ma-sūk' Shale, gray, argillaceous, and toward the top slightly arenaceous	500 feet.
3. The Blue Gate Sandstone, yellow and heavy-bedded	500 feet.
4. The Blue Gate Shale, blue-black and argillaceous, weathering to a fine gray clay (*Inoceramus deformis* and *I. problematicus*)	1, 000 feet.
5. The Tu-nunk' Sandstone, yellow and heavy-bedded	100 feet.
6. The Tu-nunk' Shale, blue-black and argillaceous, weathering to a fine gray clay (*Inoceramus problematicus* and *Baculites anceps*)	400 feet.
7. The Henry's Fork Group, consisting of—	
a. Friable yellow sandstone with numerous fossils (*Ostrea prudentia, Gryphea Pitcheri, Exogyra læviuscula, Exogyra ponderosa, Plicatula hydrotheca, Camptonectes platessa,* and *Callista Deweyi*)	10 feet.
b. Arenaceous shales, purple, green, and white, with local beds of conglomerate	190 feet
c. Coarse sandstone and conglomerate, with many white grains and pebbles, interleaved with local beds of purple and red shale, and containing immense silicified tree-trunks	300 feet.
Total Cretaceous	3, 500 feet

The three upper sandstones, the Masuk, the Blue Gate, and the Tununk, are so nearly identical in their lithologic characters that I was unable to discriminate them in localities where their sequence was unknown. This was especially the case upon the summits of Mounts Ellen and Pennell where they occur in a somewhat metamorphosed condition. All of them contain thin beds of coal, none of which are continuous over large areas, and only one of which was observed of workable thickness. At the western foot of Mount Ellen, a bed four feet thick lies at the base of the Blue Gate Sandstone.

There is almost equal difficulty in discriminating the Masuk, the Blue Gate, and the Tununk shales. The first is usually of a paler color and is more apt to include arenaceous bands. It has not been found to contain fossils, while the lower shales rarely fail to afford them when search is made. The Blue Gate and Tununk shales are typical examples of fine argillaceous sediments. They are beautifully laminated and are remarkably homogeneous. It is only in fresh escarpments that the lamination is seen, the weathered surface presenting a structureless clay. The fossils of these shales are so numerous that, when they have been sought out and studied, they will probably serve not merely to discriminate the two, but also to correlate them with some of the beds which have been examined elsewhere in the Colorado Basin. For the present I am unable to refer any of the Cretaceous rocks above the Henry's Fork Group to the divisions which have been recognized elsewhere, and it is for this reason that I have given local, and perhaps temporary names to such beds as I have need to mention in the discussion of the structure of the mountains.

The fossils of the Henry's Fork Group have been more fully collected, and they have been referred without question by Dr. White to the group of that name, as recognized in the Green River Basin (Geology of the Uinta Mountains, pp. 82 and 94). The white grit which lies at the base of the group is a conspicuous bed of unusual persistence, and is recognized wherever Cretaceous rocks are found in the upper basin of the Colorado.

Jura-Trias.—The rocks which intervene between the base of the Cretaceous and the summit of the Carboniferous are of doubtful age, having been referred to the Trias by one geologist and to the Jura and Trias by others, while the fossils recently discovered by Mr. Howell (Geology of Uinta Mountains, page 80) lead to the suspicion at least that they are all

Jurassic. It is probable that the uncertainty will soon be dispelled by the more thorough working of Mr. Howell's new localities; but while it remains, it seems best to recognize its existence in our nomenclature, and I shall include the whole of the doubtful series under the title of *Jura-Trias.* At the Henry Mountains it is easily divided into four groups, as follows:

1. Flaming Gorge Group; arenaceous shales or bad-land sandstones, purple and white at top and red below	1, 200 feet.
2. Gray Cliff Group; massive cross-laminated sandstone, buff to red in color	500 feet.
3. Vermilion Cliff Group; massive cross-laminated sandstone, red, with a purple band at the top	500 feet.
4. Shin-ar′-ump Group; consisting of—	
a. Variegated clay shale; purple and white above and chocolate below, with silicified wood	300 feet.
b. Gray conglomerate, with silicified wood; the "Shinarump Conglomerate"	30 feet.
c. Chocolate-colored shale, in part sandy	400 feet.
Total Jura-Trias	2, 930 feet.

The rock of the Flaming Gorge Group is of a peculiar character. It is ordinarily so soft that in its manner of weathering it appears to be a shale. It is eroded so much more rapidly than the Henry's Fork conglomerate above it, that the latter is undermined, and always appears in the topography as the cap of a cliff. Nevertheless, it is not strictly speaking a shale. The chief product of its weathering is sand, and wherever it can be examined in an unweathered condition it is found to be a fine-grained sandstone, massive and cross-laminated like those of the Gray and Vermilion Cliffs, but devoid of a firm cement. In a number of localities it has acquired, locally and accidentally, a cement, and it is there hardly distinguishable from the firmer sandstones which underlie it. In the immediate vicinity of the Henry Mountains it varies little except in color from summit to base, but in other localities not far distant it is interrupted near the base by thick beds of gypsum and gypsiferous clays, and by a sectile, fossiliferous limestone.

The Gray Cliff and Vermilion Cliff sandstones are often difficult to distinguish, but the latter is usually the firmer, standing in bold relief in the topography, with level top, and at its edge a precipitous face. The former is apt to weather into a wilderness of dome-like pinnacles, so steep-sided that they cannot often be scaled by the experienced mountaineer, and separated by narrow clefts which are equally impassable.

The colors of the two sandstones are not invariable. The lower, which although not reddened throughout its mass is usually stained upon its surface with a uniform deep color, appears in Mount Ellsworth and at other points of elevation with as pale a tint as that of the Gray Cliff. The latter sandstone, on the other hand, where it lies low, is often as deep in color as the Vermilion. Standing upon one of the summits of the Henry Mountains and looking eastward, I found myself unable to distinguish the Gray Cliff Sandstone by color either from the lower part of the Flaming Gorge Group or from the Vermilion Sandstone. The bleaching of the redder sandstone in Mount Ellsworth is probably a result of metamorphism; the reddening of the gray sandstone may depend on the hydration of the iron which it contains.

The thickness of individual strata in these great sandstones is remarkable, and is one of the elements which must be taken into account in the discussion of the problem—which to my mind is yet unsolved—of the manner in which such immense quantities of homogeneous sand were accumulated. Ordinarily the depth of strata is indefinable, on account of the impossibility of distinguishing stratification from lamination; but where, as in this case, the lamination is oblique to the stratification, the upper and lower limits of each stratum are definitely marked. I have at several points measured single strata with thicknesses of about fifty feet, and near Water-pocket Cañon a stratum of Vermilion Cliff sandstone was found to be 105 feet thick.

One other measurement is worthy of record; the inclination which oblique lamination bears to the plane of the stratum in which it occurs appears to have a definite limit. The maximum of a series of measurements made at points where to the eye the dip seemed to be unusually great, is 24°.

The sandy layers at the base of the Shinarump Group are characterized by profuse ripple-marks.

Carboniferous.—Beneath the Jura-Trias is the Carboniferous. A few hundred feet of its upper member, the Aubrey Sandstone, are exposed near the summit of Mount Ellsworth. At that point the sandstone is altered to the condition of a quartzite, but where it is cut by the upper and lower cañons of the Dirty Devil River it is massive and cross-laminated, differing from the Gray Cliff sandstone chiefly in the abundance of its calcareous cement.

UNCONFORMITIES.

From the Masuk Sandstone to the Aubrey Sandstone, inclusive, there is perfect conformity of dip. The fold system of the region, of which a description will be found in succeeding pages, was established after the deposition of all these strata, and the whole series were flexed together. Nevertheless, the strata do not represent continuous deposition. There were intervals in which the sea receded and exposed to erosion the sediments which it had accumulated. Shallow valleys and water-ways were excavated, and when the sea returned it deposited new sediments upon the somewhat uneven surface of the old.

The first occurrence of this sort was at the close of the Aubrey epoch. Its evidence was not found in the Henry Mountains; but at the confluence of the Paria with the Colorado, eighty miles to the southeast, the surface of the upper member of the Aubrey Group, which is there a cherty limestone, is unevenly worn, and in its depressions are beds of conglomerate, the pebbles of which are derived from the chert of the limestone itself. The shaly, rippled sandstones which succeed this conglomerate indicate that the water remained shallow for a time, and in the middle of the Shinarump epoch the region was once more abandoned by the sea. The chocolate shales and shaly sands were unevenly worn, and the first deposit that the returning sea spread over them was a conglomerate. The evidence of this break is found at many points. The Shinarump conglomerate although remarkably persistent for a conglomerate thins out and disappears at a number of points, and at the margins of its areas it is evident to the eye that it occupies depressions of the surface on which it rests

The next break is at the base of the Vermilion Cliff Group. In the region of the Virgin River and Kanab Creek the change from the variegated shales of the Upper Shinarump to the homogeneous sandstone of the Vermilion Cliff is gradual, the interval being filled by a series of alternating shales and sandstones; but further to the east, in the region of the Henry Mountains and Waterpocket Cañon, the change is abrupt, and the firm sandstone rests directly upon the soft shale. The abruptness of the change would suggest that the currents which brought the sand had swept away all evidence of the intermediate conditions which are likely to have connected the epochs represented by the two sediments; but in one locality, at least, there is direct evidence that the surface of the clay was exposed to the air before it was covered by the sand. On the northern flank of Mount Ellsworth are the vestiges of a system of mud-cracks, such as form

FIG. 1.—Fossil Suncracks in the Shinarump Shale.

where wet clays are dried in the sun. Where the under surface of the Vermilion sandstone is exposed to view, it is seen to be marked by a network of ridges which once occupied the sun-cracks of the Shinarump clay; and where the clay is seen in juxtaposition, tapering fillets of sand can be traced from the ridges downward ten feet into the clay.

From the base of the Vermilion to the summit of the Cretaceous no evidence of land erosion has been found; but the association of coal seams with all of the Cretaceous sandstones except the lowest, shows that the sea-bottom was frequently brought to the surface of the water if it was not carried above.

Thus it is evident that the strata of the Henry Mountain region do not represent continuous sedimentation. At the close of the Aubrey epoch, in the middle of the Shinarump, and again at the close of the Shinarump, not merely was the accumulation of sediments interrupted, but the process was reversed, and a portion of the deposits which had already been formed were excavated by the agency of rains and rivers, and swept away to some other region. Each break is indefinite, alike as regards the interval during which the record of the sea was interrupted and as regards the extent of the record which was at the same time obliterated. And yet the evidence of these breaks is of such nature that it would probably elude observation if a single section only were examined, and in a region masked by the soil and vegetation of a humid climate it would hardly be discovered except by accident. The parallelism of contiguous strata is not alone sufficient evidence that they were consecutive in time.

At the close of the Cretaceous period there came an epoch of disturbance. The system of strata which has been described was bent into great waves, and the crests of the waves were lifted so high above the sea that they lost thousands of feet by erosion.

In the troughs between the waves lakes remained, in which the material removed from the crests was redeposited, and by a later change the lake waters rose so as to cover the truncated crests, and deposit upon the worn edges of the upbent strata a series of unconforming, fresh-water, Tertiary sediments.

Thus was produced the only *unconformity of dip* which involves the Henry Mountain rocks, and even this is not to be observed in the immediate vicinity of the mountains, for a later erosion has thence removed all of the Tertiary strata, and has resumed the degradation of the older beds.

THE GREAT FOLDS.

The disturbances at the close of the Cretaceous period were of the Kaibab type*. It seems as though the crust of the earth had been divided into great blocks, each many miles in extent, which were moved from their original positions in various ways. Some were carried up and others down, and the majority were left higher at one margin than at the other. But although they moved independently, they were not cleft asunder. The strata remained continuous, and were flexed instead of faulted at the margins of the blocks. Subsequent erosion has obliterated in great part the inequality of the surface, and the higher-lying blocks do not stand as mountains, but are outlined by zones of tilted strata which mark the flexures by which the blocks are separated. Along the zones of flexure it frequently happens that a hard stratum outcropping between two that are softer will be preserved from erosion and form a long, continuous ridge. Such ridges, and other forms produced by the erosion of the flexures, are conspicuous features of the topography, and the tracing out of the limits of the blocks is a simple matter. Indeed the flexures are the first elements of the structure to attract attention, and it is easy in studying them to overlook the fact that they merely mark the limits between displaced masses of great extent. If the reader will examine Plate I at the end of the volume, he will observe that the system of parallel ridges and valleys which follow the line of the Waterpocket flexure are very conspicuous features; but it is only by some such generalization as that given in the stereogram of the same region (Plate II) that the full structural significance of the flexures can be realized. Each map was obtained by photography from a model in relief, in which the proportionate heights of the several features were not exaggerated. The stereogram was produced by the restoration of the top of the Cretaceous, the Masuk sandstone, in the form and position it would have, had there been no erosion of the region, but displacement only.

I must caution the reader against an implication of rigidity which might attach to the meaning of the word "block", as I have used it in speaking

* For a definition of the Kaibab structure, see "Geology of the Uinta Mountains," pp. 14 and 17, and American Journal of Science for July and August, 1876, pp. 21 and 85.

of the great displaced rock-masses. To what extent they may be regarded as rigid is uncertain, but the presence upon their surfaces of numerous minor flexures, such as appear in the stereogram, would seem to imply that their rigidity is not of a high order.

In the northwest corner of the area represented by the stereogram are a few faults belonging to a system which occupies a large area in that direction. The system of faults and the system of flexures are independent, the latter having originated at the close of the Cretaceous period, and the former after the formation of the Tertiary rocks of the region, which are referred by Professor Powell to the Bitter Creek epoch. Over a large district the Tertiary strata were covered by a deep mantle of lava, which has protected them from erosion to such an extent that the structure of the district is portrayed in its topography. The district is its own stereogram, each uplifted block constituting a mountain and each depressed block flooring a valley.

Not all the displacements of the later system are by faulting, but by far the greater number. Of the earlier system of displacements none are simple faults, but a few are combinations of fault and flexure.

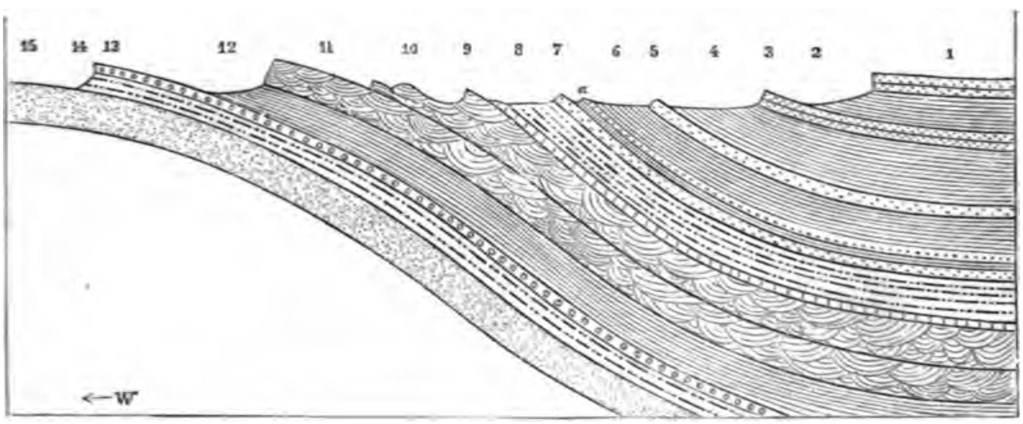

FIG. 2.—Cross-section of the Waterpocket Flexure, opposite the Masuk Plateau. Scale, one inch = 3,500 feet. 1, Masuk Sandstone. 2, Masuk Shale. 3, Blue Gate Sandstone. 4, Blue Gate Shale. 5, Tununk Sandstone. 6, Tununk Shale. *a*, Gryphea Sandstone. 7, Henry's Fork Conglomerate. 8, Flaming Gorge Shale. 9, Fossiliferous Limestone. 10, Gray Cliff Sandstone. 11, Vermilion Cliff Sandstone. 12, Upper Shinarump Shale. 13, Shinarump Conglomerate. 14, Lower Shinarump Shale. 15, Aubrey Sandstone.

The Waterpocket flexure, represented in the stereogram (Plate II), is better known in detail than any other of the great flexures of Southern Utah. It is far from following a straight line, but like most lines of oro-

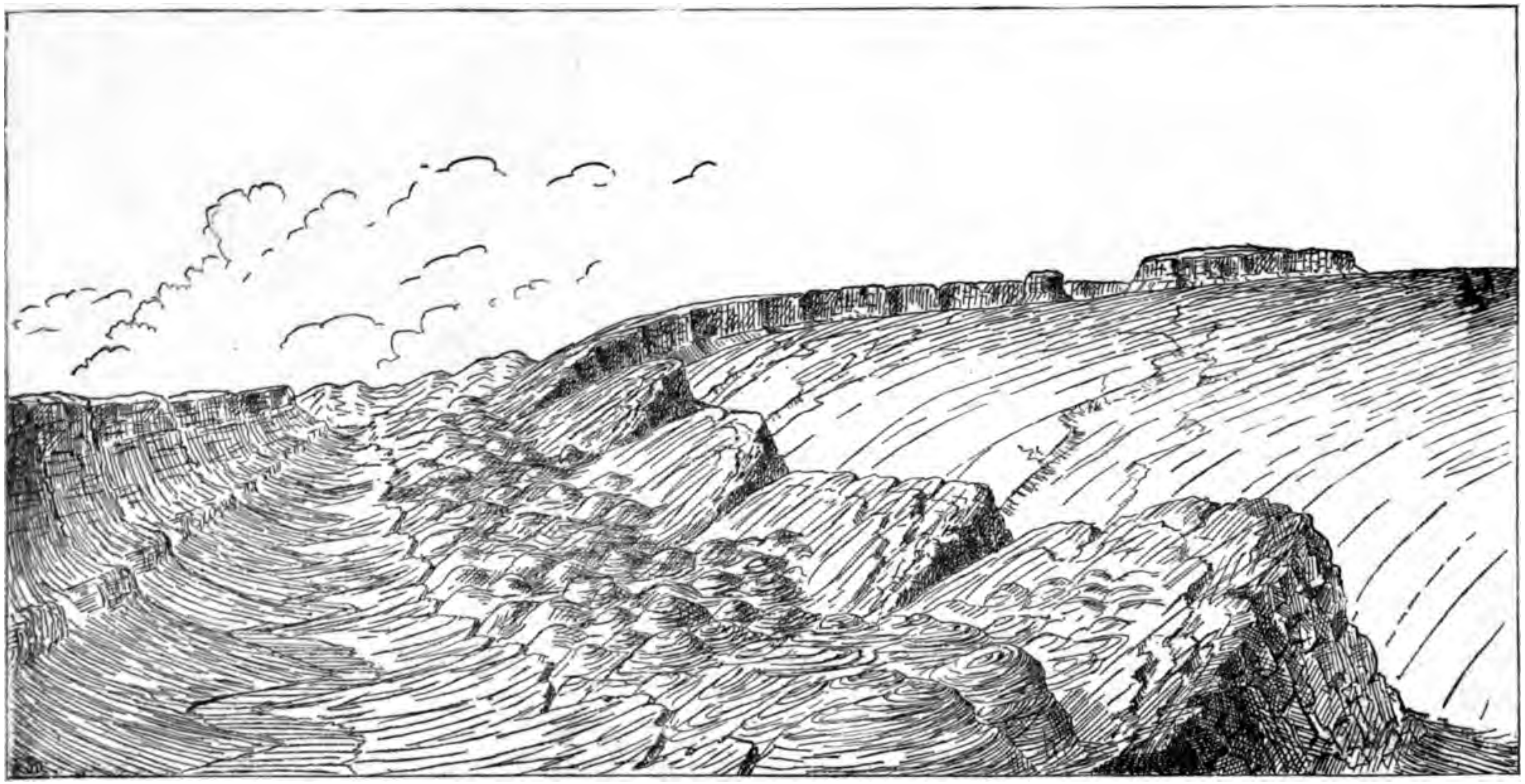

FIG. 3.—View of the Waterpocket Cañon and the Waterpocket Flexure. The clift at the left is capped by the Henry's Fork Conglomerate. The arched rocks at the right are the Gray and Vermilion Cliff Sandstones.

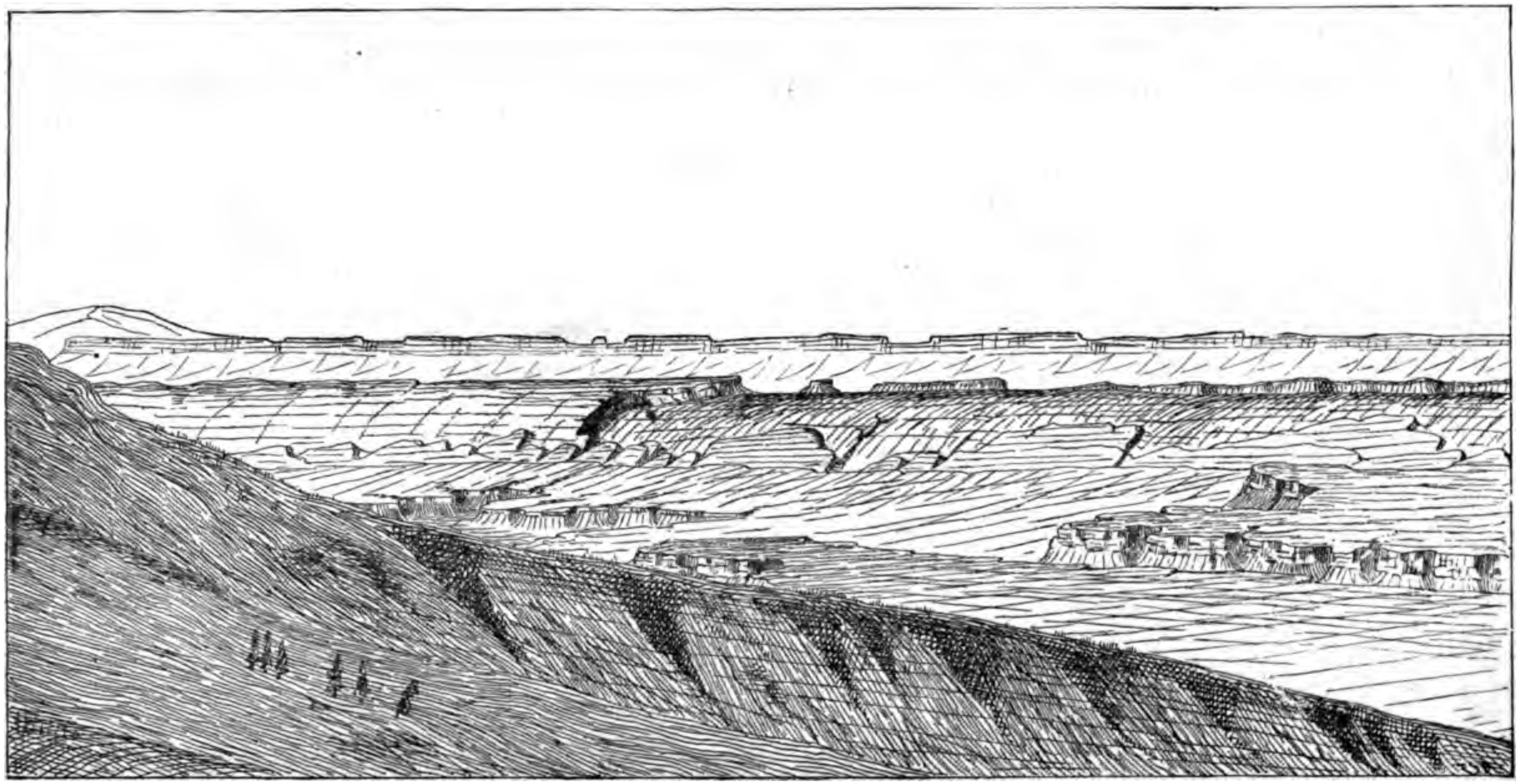

FIG. 4.—Waterpocket Flexure, as seen from the south end of Mount Ellen.

graphic disturbance swerves to the right and left, while maintaining a general trend. The amount of its "throw", or the difference in level between adjacent parts of the two blocks which it divides, is inconstant, its maximum being 7,000 feet. At some points the flexed strata are inclined at an angle of 50° while at others their greatest dip is but 15°. Toward the north the flexure twice divides. One of its branches, the Blue Gate flexure, has a throw in the same direction, and by its separation diminishes the throw of the main flexure. The other, the Red Gate flexure, has a throw in the opposite direction, and by its separation increases the throw of the main flexure. Or in other words, the blocks at the west of the main flexure stand higher than those at the east; and of two blocks which lie at the west, that at the north of the Red Gate flexure stands higher than that at the south; while of two blocks at the east, that which lies northwest of the Blue Gate flexure is higher than the one at the southeast.

CLIFFS AND PLATEAUS.

Let us now return to the topographic map (Plate I) and examine the forms into which erosion has wrought the disturbed strata. Thanks to the aridity of the climate, the erosion has been greatly influenced by the varying texture of the rocks. Every hard stratum, if inclined, stands forth in a ridge, or if level, caps a plateau. The Masuk Sandstone, undermined by the weathering of the Masuk Shale, breaks off everywhere in a cliff which completely encircles the Masuk Plateau. The plateau stands upon the Blue Gate Sandstone, and this breaking off in a cliff upon all sides constitutes another plateau. The Blue Gate Plateau, in turn, rests upon the Tununk, and that again upon the Henry's Fork. Passing either to the north or to the south from the Masuk Plateau, one descends a great geological stairway, of which each step is a hard sandstone and each riser a soft shale. Toward the Waterpocket flexure the edge of each plateau is upturned, and if one goes westward from the Masuk Plateau, he will cross in the first mile the upturned rocks of all the lower tables.

The preservation of the Masuk Plateau is due in part to the fact that it lies in a slight synclinal, but chiefly to the arrangement of the drainage-lines. No streams cross the Henry Mountains, but all go around, and the plateau occupies the divide between those which flow southward to the Colorado and those which flow northward to the Fremont.

The antithesis of the Masuk Plateau is to be seen in the Circle Cliffs, on the summit of the Waterpocket fold. At the lowest point of the Masuk synclinal a circling cliff has been formed, which facing outward surrounds a plateau. At the highest point of the Waterpocket fold, which is in a certain sense anticlinal, a circling cliff has been formed which, facing inward, surrounds a valley. The two phenomena are alike illustrations of the law that in regions of inclined strata cliffs face toward districts of elevation and away from districts of depression.

HOW TO REACH THE HENRY MOUNTAINS.

No one but a geologist will ever profitably seek out the Henry Mountains, and I will therefore, in marking out a route by which they may be reached, select whenever there is option those paths which will give *him* the best introduction to this wonderful land. There is no wagon-road to the mountains, and although a wagon might carry his baggage the greater part of the way, he must provide himself with other means of transportation At Salt Lake City he can procure pack-mules and pack-saddles, or *apparejos*, and everything necessary for a mountain "outfit." His route southward follows the line of the Utah Southern Railway to Juab, and then touches the Mormon towns of Gunnison and Salina. At Salina he halts his train for a day while he rides a few miles up the creek to see the unconformity between the Tertiary above and the Jura-Trias and Cretaceous below. This is at present the last settlement on the route, but there are "ranches" as far as Rabbit Valley, and if he delays a few years he will find a town there. By way of the "Twist" road and King's Meadows he goes to Grass Valley, and thence to Fish Lake. The lake lies between two upheaved blocks of trachyte, and covers one which is relatively depressed and tilted to the north. At the south end of the lake he stands on the higher end of the depressed block, and if he follows the shore to the outlet at the north he will find that the water is contained by a moraine, which has been thrown across the valley by an ancient glacier, descending from the mountain at the west. From Fish Lake he goes to Rabbit Valley and there delays a day or two to climb Thousand Lake Mountain. Looking west from the summit, he sees the lava-capped plateaus of the faulted district among which he has journeyed since he left the "Twist"—huge tables of trachyte bounded by cliffs of displacement, of which only the sharpest edges have been worn away; and when his eye has become accustomed to the *facies* of the faults, he perceives that there is an identity in structure between the great and the small features. Just as the whole district is divided into blocks, of which the dimensions are measured by miles, and

Fig. 6.—The Unconformity of the lower cañon of Salina Creek. The horizontal strata are Tertiary; the inclined, Cretaceous.

the displacements by thousands of feet, so the greater blocks are sometimes divided into smaller, of which the dimensions are measured by rods and furlongs and the displacements by tens and hundreds of feet. Looking eastward, he sees the region of the great flexures spread out before him like a map. The Waterpocket flexure starts from the very mountain beneath him, and, curving to the right, runs far to the south and is lost in the distance. Beyond it are the Henry Mountains, springing abruptly from the desert; and against the horizon are outlined other island mountains, gray in the distance. To the left is the San Rafael Fold, the rival of the Waterpocket in grandeur; and all about are tables and cliffs. The vivid hues of the naked rocks are obscured only by the desert haze, and the whole structure is pictured forth by form and color.

To reach the Henry Mountains from Rabbit Valley, he must cross the Waterpocket flexure; and so continuous and steep are the monoclinal ridges which follow the line of flexure, that there are but four points known where he can effect a passage. Except at these points, the barrier is impassable from Thousand Lake Mountain to the Colorado River, a distance of eighty miles. The most difficult and circuitous route I will not describe. The remaining three diverge but slightly from each other. Starting from Rabbit Valley, he follows for a few miles the valley of the Fremont, which here, through the "Red Gate," passes from the trachyte plateaus and enters the land of cañons. He does not follow it far, but where the river enters a cañon in the Aubrey Sandstone bears to the left, and by the aid of a trail which the Indians have made finds a sinuous but easy pathway along a monoclinal valley, following the outcrop of the lower Shinarump. At his right the Aubrey Sandstone rises to form the plateau through which the river defiles. At his left the Vermilion Sandstone stands in a vertical wall. Beneath his feet are the shaly sandstones of the Shinarump Group, bare of vegetation, and displaying a profusion of ripple-marks, such as is rarely if ever equaled. A ride of twelve miles brings him once more to the Fremont River, which, emerging from its Carboniferous cañon, dives at once into a still deeper cañon through the Vermilion and Gray Cliff Sandstones He can follow the river if he tries, and emerge with it beyond the flexure; but the way is difficult and the Indian trail he has followed thus far leads on to another cañon. The monoclinal valley which has opened so easy a way continues for fifteen miles farther, and in that distance is crossed by four water-ways, each of which leads by a narrow cañon through the great sandstones. The first and fourth are impassable. The second carries no permanent stream, and is called the "Capitol Cañon". The third, affords passage to Temple Creek. The smoothest road lies through Capitol Cañon, but the Temple Creek Cañon has an advantage in the presence of water, and is furthermore attractive by reason of the picture-writings on the walls.

He has now to cross the Blue Gate flexure, and to do this he leaves Temple Creek a little below the mouth of its cañon. Seeking once more the guidance of a trail, he journeys southeastward over the gypsum and sand of the Flaming Gorge Group to a pass which from a distance he has detected in the monoclinal ridge marking the Henry's Fork conglomerate. Through this pass Tantalus Creek sometimes runs on its way to join the Fremont, and he may find a stream of muddy water; but the bottom is more likely to be dry, with the exception of a few pools. Passing through the gap, he finds before him a similar opening in the Tununk Ridge, and beyond that a break in the Blue Gate Cliff. From Tantalus Creek he ascends to the pass in the Blue Gate Cliff, and, climbing to the summit of a sharp divide in the shales, descends again to Lewis Creek, which there follows a cañon through the Blue Gate Plateau. Here he finds bowlders of the Henry Mountain trachyte—for Lewis Creek rises in the Henry Mountains—and a few hours' ride toward the sources of the stream brings him to the base of Mount Ellen.

Distances.

From Salt Lake City to Salina	155 miles.
From Salina to Fish Lake	38 miles.
From Fish Lake to Rabbit Valley	27 miles.
From Rabbit Valley to Temple Creek Cañon	27 miles.
From Temple Creek Cañon to Lewis Creek	18 miles.
Thence to the base of Mount Ellen	10 miles.
Total from Salt Lake City to the Henry Mountains	275 miles.