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THE
PHYSICAL GEOLOGY
OF THE
GRAND CAÑON DISTRICT

BY
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CHAPTER I.

THE PLATEAU PROVINCE.

The investigations made by this division of the Geological Survey during the last two years have been pursued with the object of increasing our knowledge of the physical and historical geology of the West and have had little relation to economic interests. The field of labor is one of the most impressive and instructive in the world—impressive by reason of the magnificent scale on which certain processes of nature have operated, and instructive because the causes, methods, and results of those processes are revealed with a distinctness which is unparalleled. This field comprises the Grand and Marble Cañons of the Colorado and the regions which drain into them. To the entire tract, comprising an area of more than 13,000 square miles, I have given the name of the GRAND CAÑON DISTRICT.

The lessons which the geologist finds in this district are many, but the most conspicuous one embraces those subjects which are included under the nearly synonymous names "LAND SCULPTURE," "DENUDATION," "EROSION." These processes operate upon the land unceasingly, carving out mountains and valleys and giving shape and character to the earth's surface. They represent the work done upon the land by the winds and rains, by flowing water, by the chemical reactions of the atmosphere and of organic life. These processes are operative almost everywhere, and their results in the lapse of immense periods of time attain magnitudes, the statement of which may astonish the ordinary reader and perhaps excite his incredulity, but which at length appear veritable when tested by geological research and deduction. In no other portion of the world are the natural laws governing the processes of land sculpture exemplified so grandly; nowhere else are their results set forth so clearly. The interest excited by the grandeur of the subjects is intensified, and the value of the lessons enhanced, by the exceptionally intelligible manner in which their materials are presented for study.

For convenience of geological discussion Professor Powell has divided that belt of country which lies between the meridian of Denver, Colo., and the Pacific and between the 34th and 43d parallels into provinces, each of which possesses topographical features which distinguish it from the others. The easternmost he has named the Park Province. It is situated in the central and western parts of Colorado and extends north of that state into Wyoming and south of it into New Mexico. It is pre-eminently a mountain region, having several long ranges of the second order of magnitude. The structure and forms of these mountains are not exactly similar to those of any other region now well known, but possess some resemblance to the Alps, though not a very close one.

As we pass westward of these ranges in Colorado we enter, near the western boundary of that state, a region having a very different topography. The mountains disappear almost wholly, and in their stead we find platforms and terraces nearly or quite horizontal on their summits or floors and abruptly terminated by long lines of cliffs. They lie at greatly varying altitudes, some as high as 11,000 feet above the sea, others no higher than 5,000, and with still others occupying intermediate levels. Seldom does the surface of the land rise into conical peaks or into long narrow crested ridges; but the profiles are long, horizontal lines suddenly dropping down many hundreds or even two thousand feet upon another flat plain below. This region has been very appropriately named, by Powell, the Plateau Province. It occupies a narrow strip in the extreme western part of Colorado, a similar strip of western New Mexico, a large part of southern Wyoming, and rather more than half of Utah and Arizona.

West of the Plateau Province is the Great Basin, so named by Fremont because it has no drainage to the ocean. Its topography is wholly peculiar and bears no resemblance to either of the two just alluded to. It contains a large number of ranges, all of which are very narrow and short, and separated from each other by wide intervals of smooth, barren plains. The mountains are of a low order of magnitude for the most part, though some of the ranges and peaks attain considerable dimensions. Their appearance is strikingly different from the noble and picturesque outlines displayed in Colorado. They are jagged, wild, and ungraceful in their aspect, and, whether viewed from far or near, repel rather than invite the imagination.

The Wasatch, however, is an exception. This noble range is properly a part of the Basin Province, and is one of the finest and most picturesque of the West, but so completely does it contrast with the other Basin ranges that it may be regarded as an anomaly among them. The topographical features of this region are also found outside of the limits which Frémont assigned to the Great Basin, and reach southward into Arizona and northward into Idaho and Oregon. The Basin proper covers the western part of Utah, nearly the whole of Nevada, and a small portion of southern Oregon and Idaho. Its western boundary is the base of the Sierra Nevada.

No attempt will be made here to characterize the Sierra Nevada, partly because it is not thoroughly understood, but especially because it is remote from the region here to be discussed, and presents few considerations essential to that discussion. The Grand Cañon District is a part of the Plateau Province, and to this province as a whole we may now devote our attention.

As already indicated, it lies between the Park and Basin Provinces, and its topography differs in the extreme from those found on either side of it. It is the land of tables and terraces, of buttes and mesas, of cliffs and cañons. Standing upon any elevated spot where the radius of vision reaches out fifty or a hundred miles, the observer beholds a strange spectacle. The most conspicuous objects are the lofty and brilliantly colored

FIG. 2.—Butte of the Cross. Trias.

cliffs. They stretch their tortuous courses across the land in all directions, yet not without system; here throwing out a great promontory, there receding in a deep bay, and continuing on and on until they sink below the horizon or swing behind some loftier mass or fade out in the distant haze. Each cliff marks the boundary of a geographical terrace and marks also the termination of some geological series of strata, the edges of which are exposed like courses of masonry in the scarp-walls of the palisades. In the distance may be seen the spectacle of cliff rising above and beyond cliff, like a colossal stairway leading from the torrid plains below to the domain of the clouds above. Very wonderful at times is the sculpture of these majestic walls. There is an architectural style about it which must be seen to be appreciated. The resemblances to architecture are not fanciful or metaphorical, but are real and vivid; so much so that the unaccustomed tourist often feels a vague skepticism whether these are truly the works of the blind forces of nature or of some intelligence akin to the human, but far mightier; and even

FIG. 3.—A lateral cañon. Escalante.

the experienced explorer is sometimes brought to a sudden halt and filled with amazement by the apparition of forms as definite and eloquent as those of art. Each geological formation exhibits in its cliffs a distinct style of architecture which is not reproduced among the cliffs of other formations, and these several styles differ as much as those which are cultivated by different races of men.

The character which appeals most strongly to the eye is the coloring. The gentle tints of an eastern landscape, the pale blue of distant mountains, the green of vernal or summer vegetation, the subdued colors of hillside and meadow, are wholly wanting here, and in their place we behold belts of brilliant red, yellow, and white, which are intensified rather than alleviated by alternating belts of gray. Like the architect-

PLATEAU SCENERY —THE MESA VERDE —CRETACEOUS.

Reproduced from Hayden's Ninth Annual Report.

ure, the colors are characteristic of the geological formations, each series having its own group and range of colors. They culminate in intensity in the Permian and Lower Trias, where dark, brownish reds alternate with bands of chocolate, purple, and lavender, so deep, rich, and resplendent that a painter would need to be a bold man to venture to portray them as they are.

The Plateau country is also the land of cañons, in the strictest meaning of that term. Gorges, ravines, cañadas are found and are more or less impressive in every high region; and in the vernacular of the West all such features are termed cañons, indiscriminately. But those long, narrow, profound trenches in the rocks, with inaccessible walls, to which the early Spaniards gave the name of *cajon* or *cañon*, are seldom found outside the plateaus. There they are innumerable and the almost universal form of drainage channels. Large areas of the Plateau country are so minutely dissected by them that they are almost inaccessible, and some limited though considerable tracts seem wholly so. Almost everywhere the drainage channels are cut from 500 to 3,000 feet below the general platform of the immediate country. They are abundantly ramified and every branch is a cañon. The explorer upon the mesas above must take heed to his course in such a place, for once caught in the labyrinth of interlacing side gorges, he must possess rare craft and self-control to extricate himself. All these drainage channels lead down to one great trunk channel cleft through the heart of the Plateau Province for eight hundred miles—the *chasm of the Colorado*, and the cañons of its principal fork, the Green River. By far the greater part of these tributaries are dry during most of the year, and carry water only at the melting of the snow and during the brief periods of autumnal and vernal rains. A very few hold small, perennial streams, coming from the highlands around the borders of the province, and swelling to mad torrents in times of spasmodic floods.

The region is for the most part a desert of the barrenest kind. At levels below 7,000 feet the heat is intense and the air is dry in the extreme. The vegetation is very scanty, and even the ubiquitous sage (*Artemisia tridentata*) is sparse and stunted. Here and there the cedar (*Juniperus occidentalis*)* is seen, the hardiest of arborescent plants, but it is dwarfed and sickly and seeks the shadiest nooks. At higher levels the vegetation becomes more abundant and varied. Above 8,000 feet the plateaus are forest-clad and the ground is carpeted with rank grass and an exuberant growth of beautiful summer flowers. The summers there are cool and moist; the winters severe and attended with heavy snow-fall.

* Botanists inform me that the predominant upland juniper of the Plateau Province, as the species are now distributed according to Dr. Engelmann's revision published in 1877, would be *Juniperus Californica*, var. *Utahensis*, rather than *J. occidentalis*, some of the varieties of which may, however, occur there. Until that revision was made the western junipers were little known, and several distinct species were indiscriminately classed as *J. occidentalis*.

FIG. 4.—The Water Pocket Canon.

The Plateau Province is naturally divided into two portions, a northern and a southern. The dividing barrier is the Uinta range. This fine mountain platform is, in one respect, an anomaly among the western ranges. It is the only important one which trends east and west. Starting from the eastern flank of the Wasatch, the Uintas project eastward more than 150 miles, and nearly join perpendicularly the Park ranges of Colorado. Of the two portions into which the Plateau Province is thus divided, the southern is much the larger. Both have in common the plateau features; their topographies, climates, and physical features in general, are of similar types, and their geological features and history appear to be closely related. But each has also its peculiarities. The northern portion is an interesting and already celebrated field for the

study of the Cretaceous strata and the Tertiary lacustrine beds. The subjects which it presents to the geologist are most notably those which are embraced under the department of stratigraphy—the study of the succession of strata and co-related succession of organic life. Otherwise the region is tame, monotonous, and unattractive. The southern portion, while presenting an abundance of material for stratigraphical study, and in this respect fully rivaling, and perhaps surpassing, the northern portion, also abounds in the grandest and most fascinating themes for the student of physical geology. In respect to scenery, the northern portion is almost trivial, while the southern is the sublimest on the continent. With the former we shall have little to do; it is the latter which claims here our exclusive attention.

The southern part of the Plateau Province may be regarded as a vast basin everywhere bounded by highlands, except at the southwest, where it opens wide and passes suddenly into a region having all the characteristics of the Great Basin of Nevada. The northern half of its eastern rim consists of the Park ranges of Colorado. Its northern rim lies upon the slopes of the Uintas. At the point where the Uintas join the Wasatch, the boundary turns sharply to the south, and for 200 miles the High Plateaus of Utah constitute the elevated western margin of the Province.

It is from the summits of the High Plateaus that we gain our first comprehensive view of those grand facts which are the principal subjects of this discourse. But let me first ask the reader to endeavor to frame some conception, however crude, of three lines, each 200 miles long, placed in the positions of three sides of a square; the fourth side being for the moment neglected. Upon the eastern side conceive the Park ranges of Colorado; upon the northern, the Uintas; and upon the western side the southern portion of the Wasatch and the High Plateaus of Utah; and all these highlands having altitudes ranging from 9,000 to 12,000 feet above the sea, while the included area varies from 5,000 to 7,000 feet high. The space thus partially bounded may represent the northern part of the southern Plateau Province. Along the line required for the fourth and south side of the complete square there is no boundary. The topography continues on beyond it to the southward, and also widens out both west and east and overspreads an additional area more than twice as great as that already defined. From the eastern crests of the High Plateaus we may obtain an instructive overlook of the northern portion of the southern Plateau country.

The easiest line of approach is from Salt Lake City. Proceeding south from that town along the western base of the Wasatch, we reach the southern end of that fine range about 90 miles from Salt Lake. The last mountain pile is Mount Nebo, and skirting around its southern flank we soon perceive to the southeastward a long and very lofty ridge 20 to 30 miles distant. This is the Wasatch Plateau, the northernmost member of the group of High Plateaus. It has nothing in common with the

Wasatch Mountain range, being wholly disconnected from it and standing with a wide interval *en échelon* to the southeastward of it. The Wasatch Plateau presents a long, straight, horizontal summit projected against the sky without peaks or domes, resembling somewhat the ridges of Pennsylvania and Virginia, but on a grander scale. We perceive along its entire western front a rapid slope, descending to the bottom of the San Pete Valley at its foot. It is not deeply incised with ravines and amphitheatres, nor notched with profound transverse gorges, as are ordinary mountain ranges, but shows a slightly diversified slope in every part. As we draw nearer we begin to see the attitudes of the strata composing its mass, or, as the geologists say, its "structure." The strata are inclined at the same angle as the slope of its flank. In the valley below, the beds are horizontal; as they approach the base of the plateau they flex upwards and ascend the slope; as they reach the summit they flex back to horizontality. If we ascend the plateau and ride eastward a very few miles, there suddenly breaks upon the view a vast and impressive panorama. From an altitude of more than 11,000 feet the eye can sweep a semicircle with a radius of more than 70 miles, and reach far out into the heart of the Plateau country. We stand upon strata of Lower Tertiary age, and beneath our feet is a precipice leaping down across the level edges of the beds upon a terrace 1,200 feet below. The cliff on which we stand stretches far northward into the hazy distance, gradually swinging eastward and then southward through a course of more than a hundred miles, and vanishing below the horizon. It describes, as we well know, a rude semicircle, around a center about 40 miles east of our standpoint. At the foot of this cliff is a terrace of greatly varying width, rarely less than 5 miles, consisting of Upper Cretaceous beds nearly but not quite horizontal. They incline upwards towards the east at angles rarely so great as 3° , and are soon cut off by a second cliff plunging down 1,800 feet upon Middle Cretaceous beds. This second cliff describes a semicircle like the first, but smaller and concentric with it. From its foot the strata still rise gently towards the east, through a distance of about 10 miles, and are cut off as before by a third series of cliffs concentric with the first and second. For the fourth and fifth time this process is repeated. In the center of these girdling walls is an elliptical area about 40 miles long and 12 to 20 miles broad, completely surrounded by mural escarpments more than a thousand feet high. This central spot is called the SAN RAFAEL SWELL, and it is full of interest and suggestion to the geologist. From its central point the strata dip away in all directions, the inclinations, however, being always very small.* This configuration of the strata (dipping away from a central point in all directions) is technically termed "quaquaversal."

The accompanying diagram (Plate XI) shows the relative masses and positions of the strata as they would appear in vertical sections cutting

* Upon the eastern margin of the swell is one of those great "monoclinical flexures" with a high inclination so characteristic of the Plateau Country. These will be adverted to hereafter.

Sections from San Pete and Sevier Valleys across the Wasatch Monocline to the San Rafael Swell.

east and west through the Wasatch Plateau to the San Rafael Swell. It will be observed that the lower Tertiary is found only on the summit and western flank of the plateau. The Cretaceous extends further out, but is at last cut off in turn; and as lower and lower beds are exposed to daylight, they too are similarly cut off until the summit of the Carboniferous is nearly or quite exposed within the swell itself. The approximate length of the section here given is about 55 miles, and the thickness of the strata from the summit of the Carboniferous to the top of the Lower Tertiary is nearly 11,000 feet.

The geologist who becomes aware through observation of the general facts thus set forth quickly reaches the following conclusion: The beds which are successively terminated in the terrace cliffs once reached further eastward, and in all probability every one of them extended in full volume and without a break entirely over the *locus* of the swell to regions far beyond it. Upon the eastern side of the swell, and at varying distances from it, the missing strata reappear in inverse order, with terminal cliffs facing the westward. From the intervening space they have been swept away by erosion.

In restricted localities of a few square miles, in a river valley, in the open glades of a hill-country, the most unscientific observer may be easily convinced that the waste of thousands of years has broken the continuity of the strata and quarried away large masses of rock. But in the wide expanse before us even the mind of the geologist may falter before accepting a conclusion so portentous. The magnitude of the work is oppressive, and cautious philosophers are reluctant to take up and carry the burden of unusually large figures. They prefer to cast about in order to see whether some easier conclusion may not be discovered. The one already stated is to the effect that a body of strata more than 10,000 feet thick and more than 500 square miles in area have been swept off from the surface of the swell; that nearly 9,000 feet have been removed from a much larger annular space around it; 7,000 feet from a still larger and remoter space; and so on with expanding annuli, from which successively decreasing amounts have been denuded. It is needless to define just here the limits of the denuded region, even if it were possible. It is sufficient to say that its extent is much more than 10,000 square miles, and that the thickness of the strata removed varies from a few hundreds to more than 10,000 feet. Nor does the conclusion stop here. The San Rafael region is only one of a considerable number of the subdivisions of the Plateau Province where the same enormous extent of erosion has taken place. It is not the largest of those subdivisions, nor is the thickness of the removed strata the greatest there. It is merely an example, and whatsoever it reveals in regard to erosion is but a group of events common to the entire southern province with its vast area of nearly 100,000 square miles. I have selected it for discussion because its array of facts in evidence is more easily handled and can be more lucidly presented than those of the other subdivisions. Let us, then, examine in

detail the arguments upon which this deduction of a great denudation is based.

If we stand before one of the great marginal cliffs which bound the several terraces, we shall speedily detect abundant evidence that time and the elements are slowly robbing its face of the materials which compose its mass. Fragments have spawled off and fallen, and they now lie at its base in great quantities, forming a talus. Cliff and talus alike are seamed and scored with rain-gullies, and if we are fortunate enough to observe the effects of a shower we shall see the waters trickling, spouting, or rushing down through every seam and gully, carrying sand, mud, and small fragments with which they are charged to their utmost capacity. The meaning of this is that the cliff is wasting away, and its *locus* through the ages is farther and farther back. This backward movement of the line of frontage by slow waste is very happily named by Powell the *Recession of Cliffs*.

It may seem at first as if the rate of recession must be so exceedingly slow that when we are asked to consider the possibility of a recession of thirty or forty miles the argument would break down under the weight of its time-factor. But it will be shown hereafter that in the total process of denudation the rate of recession is rapid enough to satisfy the temper of such geologists as may be parsimonious or even very stingy in their allowances of time. It is sufficient here to advert to the very obvious fact that the cliffs are receding, and that at some former geological period they once stood nearer the center of the denuded district. Now, it is sufficiently obvious that if we allow the imagination to range back indefinitely into the past and reverse the process of recession, restoring the material which has been denuded, the continuity of argument will at length bring us to an epoch in which the cliffs which now face the center of the San Rafael Swell came together, and the strata which those cliffs now terminate stretched unbroken from west to east across the whole width of the Plateau Province. It is only a question of time and continuity of the process. The geologist may, however, raise a very pertinent inquiry. Admitting that the cliff-bound strata once reached out in advance of their present limits, may they not have grown thinner as they approached the center; may they not have attenuated rapidly so that their former thickness over the swell was but a small fraction of the aggregate thickness disclosed in the present escarpments? May not the higher beds have thinned out and disappeared entirely a few miles from their present boundaries? In all other well-studied regions it is a general and almost universal rule that the strata vary greatly in thickness when traced from place to place, and attenuate as they extend away from their shore-lines. May they not have done so here?

Answering the questions directly, it may be said that the Permian, Trias, and Cretaceous certainly did not grow perceptibly thinner as they approached the center of denudation. The Jurassic did thin out quite notably from west to east, and it is possible that the Tertiary may have

thinned a little; but this loss of thickness in the Jurassic and Tertiary has been abundantly discounted in the estimate given of the mass of strata denuded. As regards the general rule that strata vary greatly in thickness, it may be stated that the Plateau country is a remarkable exception to it. One of the most striking features in its stratigraphy is the wonderful persistency with which its formations maintain their volumes and lithological features over great areas. In this respect the province has no parallel, not even in the calm and undisturbed *terrains* of the Mississippi Valley.

Further support of this conclusion may be found by reverting to the section (Plate XI). On the eastern side of the swell the section shows a great monoclinical flexure where the strata extending eastward rapidly bend downward and subsequently flex back to horizontality. Before this flexure began to form, the Cretaceous strata had already been deposited. Possibly, also, the Tertiary had been laid down, but of this we are not as yet certain. But we know that it was formed after the Cretaceous age, for the strata abundantly betray it. If we could bend back the strata now inclined upward in that flexure, we should have a wall about 8,000 feet high or more, looking down from the east upon the central amphitheater, and in that wall would appear the broken edges of the Permian and Mesozoic beds, though the upper part of the Cretaceous and Tertiary would be wanting at the summit. Thus nearly four-fifths of the denuded strata appear upon the eastern side of the swell, in very close proximity to it, and the remainder make their appearance at varying distances beyond. There is no appreciable loss of volume in the exposed beds of the monocline as compared with the corresponding beds to the westward.

But we may with advantage pursue the task of restoring the beds to the position they held during the period of their deposition by straightening out or bending back the strata in those parts where they have been tilted and flexed since their accumulation. This is readily done here. They were deposited originally in layers which were quite horizontal. We know this by reasoning upon the following facts. From the summit of the Permian, and I think we may say quite confidently from the summit of the Carboniferous upwards, the whole series was deposited in very shallow waters. The evidence of this is overwhelming. We find proof that the surfaces of deposition throughout Mesozoic time oscillated repeatedly a little below and a little above sea-level. The cross-bedded sandstones of the Trias and Jura, the sandy shales wonderfully ripple-marked, the occurrence of bands containing the silicified remains of forest trees, the occasional recurrence of contacts showing "unconformity by erosion" without any unconformity of dip,* the occurrence of brackish-water types of mollusca in the Jurassic, the

* There are throughout the series numerous instances of beds resting upon surfaces slightly eroded and channeled by streams without any discrepancy of dip in the apposed beds.

lignites, fossil leaves, and carbonaceous shales of the whole Cretaceous system, the brackish-water fossils of the lowest Tertiary, leave no doubt as to the verity of the foregoing inference. The final restoration, then, of the strata to their original positions leaves them horizontal.*

If we draw a section of the strata restored to horizontality, we shall find that the strata now remaining require, in order to perfect their continuity, the restitution of large masses fully equal to those which we have inferred to have been swept away by erosion. Any hesitation to do this would leave us without resource. Any other hypothesis, so far as I can conceive, would be not only without support in the facts presented, but in opposition to their entire tenor and purport.

The geologist who is familiar through long field-study with the physical problems presented in the West would not need further argument to become satisfied of the reality of the great erosion here inferred. Perhaps he would consider that too much has been said in support of it already; especially since the subject of this paper is not the San Rafael but the Grand Cañon district. But I have devoted so much discussion to the San Rafael district because it is a type of a congeries of districts which make up the Plateau Province, and because it exemplifies in the most intelligible, compact, and complete manner the broad facts and laws which are to engage our attention hereafter. These facts and laws apply to the Grand Cañon district; but to take the facts there presented and arrange them in a clear view before the mind of one who has never visited that region, and make them definite and convincing, would be extremely difficult without preparatory exercises on problems similar in kind but simpler in form. For this reason I propose, before leaving the San Rafael district, to bring out another category of facts which it exemplifies. They involve a generalization very interesting in itself, and of the greatest utility in solving many problems presented in all parts of the Plateau country. This generalization—or law in the sense of an observed order of facts—may be called the *Persistence of Rivers*.

The rivers of the Atlantic States, from the Hudson southward, cut through the Appalachian ridges by narrow gorges, or gaps, which seem to have been quarried out for the purposes. Geology, however, does not

* It would be very instructive, if space permitted, to elaborate this discussion of the original horizontality, and I am tempted to point out in the hastiest manner some obvious consequences of the deduction. It appears that if this deduction be true the deposits must have settled or subsided as rapidly (in the long run) as they were accumulated. The surface of deposition appears never to have varied much from sea-level. But the total accumulation of Permian, Mesozoic, and Tertiary beds was nearly 11,000 feet, and when the deposition ended (supposing that it ended in the Middle Eocene, though I think it more probably continued here until the close of the Eocene) the Permian must have sunken more than two miles below sea-level. The gradual subsidence of large bodies of sediment as they accumulate in strata is a fact now generally recognized, and is of universal application. That it is caused by the gross weight of the enormous masses of deposited material sinking into the yielding earth seems a most natural explanation.

take account of "purposes" or "design," but seeks its explanations in "natural" causes alone. It asks by what natural processes were those gorges made?

The answer it finds is, that the rivers themselves scoured them out, and that secular decay has widened them somewhat. A reader not versed in geology might be led to ask a further question. How can a river attack a mountain wall, or even a gentle declivity, and quarry though it a pathway giving a continuous descent for the flow of its waters? The reply is that no river ever does that. To understand how it all came about we must go back to the beginning. The rivers were born with the country itself. The land emerged from the sea; and when it emerged the rains or melting snow sought whatever channels were determined by the slight inequalities of the newly-risen surface and flowed seawards. These lofty ridges, gashed with noble ravines, had then no existence. The rivers are older than the mountains. As time ran on the mountains grew upward, athwart the courses of the streams. But a flowing river has a power to fight for and maintain its right of way, which becomes apparent only when we have carefully studied and analyzed it. This power is inherent in the descent of its waters—is literal water-power. The weapons or tools are the sand, gravel, and silt which the waters carry, and which act after the manner of a sand-blast, except that in the sand-blast the grit is impelled by air or steam, while in the river it is impelled by water. This power, inherent in the fall, increases rapidly as the fall increases. When the declivity is feeble the power to grind down the channel—to "corrade," as Powell terms it—is correspondingly feeble, or even annihilated. When a barrier like a ridge rises across the track of a stream the declivity is increased at that point. Increased velocity and corrasive power is at once developed in the stream, and it cuts down the barrier. Perhaps a lake may be formed above the barrier, but its outlet will be cut down and the lake drained.

In a low country the slopes are, with rare exceptions, feeble, and this corrasive power by which the stream maintains its *locus* is in such countries correspondingly feeble. Here we may expect to find many cases where streams have been deflected largely from their courses; but in a high country the reverse is the case. In a region newly risen from the waters the positions of the streams may be very inconstant; but as the elevation increases they gradually fasten their grip upon the land and hold it.

It would be difficult to point out an instance where a great river has ever existed under conditions more favorable to stability of position than those of the Colorado and its tributaries. Since the epoch when it began to flow it has been situated in a rising area. Its springs and rills have been among high mountains, and its slope since the earliest period of its history has always been great. The relations of its larger tributaries have, in these respects, been the same; and indeed the river

HORSESHOE CAÑON, GREEN RIVER.

From Powell's Exploration of the Colorado River.

and its tributaries have been a system, and not a mere aggregate; for the latter are dependent upon and responsive to the physical conditions of the former. And now we come to the point. The Colorado and its tributaries run to-day just where they ran after the region emerged from the waters. Since that time mountains and plateaus have risen across their tracks, whose present summits mark less than half their total amounts of uplift. The rivers have cleft them to their foundations.

The Green River, passing the Pacific Railway, enters the Uinta platform by the Flaming Gorge, and after reaching the heart of the chain turns eastward parallel to its axis for 30 miles, and then southward, cutting its way out by the splendid cañon of Lodore. Then following the base of the range for a few miles a strange caprice seizes it. Not satisfied with the terrible gash it has inflicted upon this noble chain, it darts at it viciously once more, and entering it, cuts a horseshoe cañon in its flank 2,700 feet deep, and emerges near the point of entrance; thenceforward, through a tortuous course of 300 miles, it flows southward through gently inclined terraces, which rise slowly as the river descends. Along this stretch it runs almost constantly against the dip of the beds, cutting through one after another, beginning with the Upper Eocene until its channel is sunk deep in the Carboniferous. Further down, the Kaibab Plateau rose up to contest its passage, and a chasm 5,000 to 6,000 feet deep is the result. It is needless to multiply instances; the whole province is a vast category of instances of river channels cutting through plateaus, mesas, and terraces where the strata dip up stream. The courses of the cañons are everywhere laid independently of the topographical inequalities, whether these inequalities be due to the broader features of land sculpture or to displacement and unequal uplifting. On the north and west side of the Colorado the tributaries generally run counter to the structural slopes; on the east and south sides, they ran more nearly with them.

It is clear then that the structural deformations of the surface, the uplifts and downthrows had nothing to do with determining the present distribution of the plateau drainage. The rivers are where they are, in spite of them. As irregularities rose up, the streams turned neither to the right nor to the left, but cut their way through in the same old places. The process may be illustrated by a feeble analogy with the saw-mill. The river is the saw and the rising strata are the timber which is fed against it. The saw-log moves while the saw vibrates in its place. The river holds its place as rigidly, and the rising strata are dissevered by its ceaseless wear. What, then, did determine the situations of the present drainage channels? The answer is that they were determined by the configuration of the surface existing at, or very soon after, the epoch of emergence. Then, surely, the water-courses ran in conformity with the surface of the uppermost (Tertiary) stratum. Soon afterwards that surface began to be deformed by unequal displacement, but the rivers had fastened themselves to their places and have ever since refused to be diverted.

This theorem is of great utility in the study of the Plateau Province, for it throws light upon many problems which would otherwise be obscure. The course of a river is the index of the slope, and, to a great extent, the configuration of the primitive unmodified surface of a tract. It betrays the amount of tilting or flexing which the strata have undergone, and also conveys information as to the amount of strata which have been denuded. This information, however, is in many cases incomplete, but when placed in relation with other facts it frequently becomes conclusive. The application of the theorem to the San Rafael district is a beautiful instance of its validity.

Across the San Rafael Swell extend two river channels, one crossing it near the northern and the other near the southern end. They head in the High Plateaus, and pass through the successive terraces in deep cañons; then crossing the swell, enter the high cliffs on the eastern side and flow on. The northern stream—the San Rafael River—ultimately joins the Green River; the southern one—Curtis Creek—enters the Frémont River, a tributary of the Colorado. A glance at the map and an interpretation of the topography as expressed by the contours will quickly show that these streams are quite independent of the existing topography and could not have had their situations determined by it. They must have been laid out upon some ancient surface differing widely from the present. To find that surface is not difficult. It must have had a continuous descent, though doubtless of slight declivity, from the western margin of the province to the line of the Green and Colorado Rivers. We shall obtain precisely that surface configuration by reducing or bending back the flexures, and depressing the tilted strata until the Cretaceous beds are everywhere horizontal, and then filling up the gaps made in the continuity of the strata by erosion. Thus we shall reach, by argument from the persistence of rivers, the same conclusion which we reached by studying the effects of the recession of cliffs, and by the independent study of the displacements.

The example of erosion thus given by the San Rafael Swell illustrates, as a sharply defined type, the denudation of the Plateau Province. The thickness of the strata removed varies greatly in different portions. In the High Plateaus it has amounted to only a few hundred feet. In large areas it amounts to two or three thousand feet and in others of considerable extent it reaches more than 10,000 feet. Preliminary comparisons of known facts derived from nearly the entire extent of the southern province lead to the conclusion that on the average 5,500 to 6,000 feet of strata have been removed from its entire expanse. Our knowledge of the geology of some portions of it is at present very imperfect. Still, enough is known to justify us in believing that this summary estimate will not be much affected by future investigation.

We may for special purposes of convenience regard the province as consisting of districts or spots of maximum erosion separated from each other by high mesas or dividing platforms where erosion has been at its

minimum. The San Rafael district may be regarded as one of these areas of which the central part is an area of maximum erosion while its peripheral parts are areas of minimum erosion. The Grand Cañon district is another, and there are still others which we need not here specify.

Before concluding the introductory part of this paper it will be desirable to recite briefly the succession of geological events which the study of the region has thus far brought to light, selecting only such as will hereafter be of special utility.

Throughout the great Carboniferous age the entire area of the Plateau Province was submerged beneath the ocean. Deposition of strata went on continuously. The thickness of the strata accumulated in that age appears to have varied greatly, and the deposits were laid down unconformably over the surface of a country which had been ravaged by a great erosion. Such exposures of the Carboniferous as now exist, however, exhibit for the most part a remarkable evenness of stratification. In the interior spaces of the province the beds are either horizontal, or if disturbed, give full evidence that the disturbances took place long after their deposition. The close of this age evidently left a subaqueous surface, which was exceedingly flat, and, except around the borders of the province, quite free, so far as we now know, from any appreciable inequalities.

The thickness of the Carboniferous system is from 4,500 to 5,000 feet in the interior of the province, but around its borders, and in the Uinta Mountains, it is sometimes found in far greater volume. Its strata consist of impure limestones, occasionally of enormous thickness in the individual beds, and alternating with fine-grained homogeneous sandstones. Extensive beds of gypsum also occur.

After the Carboniferous came the Permian age, in which were laid down from 800 to 1,500 feet of sandy shales. The stratification was wonderfully even and everywhere horizontal. The Permian beds are often ripple-marked and betray many evidences that they accumulated in shallow waters. Among these evidences are the appearance at several horizons of indications that for a time the sea-bottom was laid bare by the recession of the waters, or by the elevation of the platform itself; for we may discern evidences of slight erosion at the contacts of the beds. But the horizontality of the beds appears never to have been notably disturbed.

The same state of affairs continued through the Trias. There, too, we find evidence of alternations of emergence and submergence in the shape of slight unconformities by erosion, and in the occurrence of extensive remains of silicified forests. The Triassic series is composed almost wholly of sandstones, the only calcareous matter being thin seams of gypsum. The sandstone beds are very numerous and often shaly. They are usually of no great thickness individually, but there is one very notable member of which we shall see more when we come to view the Vermilion Cliffs.

Directly upon the Trias rests the Jurassic. A wonderful bed of sandstone 800 to 1,200 feet thick, and very white and sugary in color represents the principal part of this series. It is a very notable formation because of its remarkable homogeneity, the persistent way in which it preserves its lithological characters through great distances, and the absence of divisional planes of stratification—the mass being solid from top to bottom. But most striking of all is its wonderful cross-bedding, far surpassing in beauty, extent, and systematic character, any similar phenomenon elsewhere, with which I am acquainted. The summit of the Jurassic suddenly changes to calcareous and sandy shales, abounding in fossils. This series, as well as the Trias, appears to have been laid down horizontally in shallow waters.

Next comes the Cretaceous system—a mass of yellow sandstones with clayey and marly shales, aggregating from 4,000 to 5,000 feet thick. In this series we find an abundance of plant remains, many beds of good coal, and much carbonaceous shale. The conditions during the Cretaceous appear to have been quite similar to those which prevailed in the Appalachian region during the Carboniferous. Perhaps the conditions which attended and rendered possible the accumulation of coal are not sufficiently well understood to enable us to say confidently just what they were, but there seems to be a general agreement that they involved a flat, low, moist country lying almost exactly at mean sea-level, and subject to alternate emergence and submergence. No other supposition seems to meet the requirements of the case, or to be capable of explaining how a mass of strata could be so accumulated, consisting of alternations of thin seams of coal and carbonaceous shale with layers of sandstone containing marine fossils.

We have now the following remarkable state of affairs. From the close of the Carboniferous to the close of the Cretaceous there is strong evidence that the surface of deposition was always very near to sea-level, sometimes a few feet above it, but for the most part a little below it. And yet in the interval about 9,000 feet of strata accumulated with remarkable uniformity over the entire province, and always in a horizontal position. From this it necessarily follows that the mass of material thus deposited sank or “subsided” at a rate which, in the long run, was exactly or sensibly equal to the rate of deposition.

At the close of the Cretaceous we find evidence that the long calm which had characterized the action of the physical processes was invaded. Some extensive disturbances took place, resulting at some places in the dislocation and flexing of the strata, and the elevation of some portions of the region to considerable altitudes. Erosion at once attacked the uplifted portions, and around the borders of the province we find numerous localities, usually not very extensive, which were greatly devastated. At some of these places the entire local Cretaceous series was denuded, and even a portion of the Jurassic; and the Tertiary is seen lying upon the Jurassic and across the beveled edges of the

flexed Cretaceous strata. But even these localities were again submerged, as the presence of the Tertiary fully attests. These disturbances were not general—did not extend to the entire province, but appear to have occurred around, or a little within, its marginal portions.

The last period of deposition was marked by the accumulation of the Eocene beds, which form such a striking feature in the stratigraphy of the peripheral parts of the Plateau country. Around the southern flanks of the Uintas their aggregate thickness exceeds 5,000 feet, but southward the upper members disappear, and 80 miles north of the Grand Cañon only about 1,000 to 1,200 feet, representing the lowest portion of the series, make their appearance. It is highly probable that the middle and upper portions of the Eocene were never deposited there. But the lowest beds, most probably, once covered the entire province, while the middle and late Eocene were confined to its more northerly portions. The lowest members were deposited in brackish water, as their fossils amply attest; but in the succeeding beds the fossil forms are entirely those which live in fresh water. From that epoch to the present time there has been no recurrence of marine conditions.

We now reach a turning point in the history of this region. That long continuance of marine conditions lasting from the beginning of Carboniferous time to the close of the Cretaceous came gradually to an end. The waters became brackish and then fresh. During the prevalence of the marine condition it seems to be a necessary conclusion that the waters which covered it had abundant access to the ocean. Whether its waters were wide open to the ocean, like the Gulf of Mexico or Hudson's Bay, or whether they formed a broad expanse, with a comparatively narrow outlet, like the Mediterranean, we do not know, and it would be useless to conjecture at present. At all events the communication was sufficiently free to maintain a degree of saltiness suitable to the existence of molluscan forms of the ordinary marine types. When the waters became brackish, we infer that the straits became greatly narrowed; when they became quite fresh, we infer that the access of the ocean to the area was wholly shut off, and that the water brought by the rivers and rains merely outflowed, and the region became an inland lake of vast proportions. For the deposition still went on. Through Eocene time from 1,000 to 5,000 feet of lacustrine beds, containing an abundance of fresh-water fossils, were deposited. Among them are also found layers of coal and carbonaceous shales, and sandstones thickly imprinted with the traces of arboreal vegetation.

But at length the deposition of lacustrine strata ceased; not, however, at one and the same time in all parts of the province. The evidence indicates that in the southern and southwestern portions it stopped after about one-fourth or one-third of the Eocene horizons had been laid down. In the central portions it appears to have ceased after about one-half to two-thirds of those horizons had been deposited. In the northern portions, in the vicinity of the Uintas, the entire system of Eocene

strata is found in immense volume. These facts lead us to infer that the great Eocene lake, soon after its waters became quite fresh, began to shrink its area, and that its bottom became through a slow progression dry land. The southern and southwestern portions were the first to emerge; then the middle portions; the lake gradually retracting its boundary to the northward, until in the latter part of the Eocene it occupied a greatly diminished area in the vicinity of the San Rafael country and the southern base of the Uinta Mountains. At the close of the Eocene this remnant of the lake also disappeared.

We now reach another turning point in the history of the region. Hitherto and for an immense stretch of geological time it had been an area of deposition and of subsidence. It now became an area of elevation and denudation, and these processes have been in operation ever since. In the periods of deposition and subsidence, from the Carboniferous to the Eocene, both inclusive, the thickness of the strata accumulated varied from 14,000 to 20,000 feet, and the subsidence of the base of the Carboniferous was of nearly equal extent. In the periods of elevation and denudation these vast masses of strata rose bodily up again; the amount of elevation varying according to locality from 6,000 to 18,000 feet. The havoc wrought by erosion has been, as already shown, stupendous; the thickness of strata removed exceeding 10,000 feet in some considerable areas, and averaging probably 5,500 to 6,000 feet over the entire province.

The points which it is desirable to notice in this chapter concerning the progress of the Tertiary and Quaternary erosion of the province, are few and of the broadest nature. In truth it is necessary to speak very guardedly. For while the most general features of the work have left well-marked traces which can be interpreted, yet when we come to details the vast erosion has swept away so much of its mass that a large portion of the evidence of the details has vanished with the rocks. There is reason to believe that the greater part of the denudation was accomplished in Miocene time. This was a period of slow but continuous uplifting, reaching a great amount in the aggregate, and it was most probably also a period of rapid erosion. The uplifting, however, was unequal in the different parts of the province. The comparatively even floor of the old lake was deformed by broad swells and plateaus rising above the surrounding country. As we shall see hereafter, the action of the denuding agents is much more vigorous and efficient upon the higher than upon the lower parts of a region; and consequently these up-swells at once became the objects of special attention from the destroying forces and were wasted more rapidly than the lower regions around them. Here were formed centers or short limited axes, from which erosion proceeded radially outwards, and the strata rising gently towards them from all directions were beveled off. Thus were formed those areas of maximum erosion, already spoken of, and of which the San Rafael Swell is the most perfect and simplest type.

We have also reason to believe that the climate of the Miocene was moist and subtropical, conditions favorable under the circumstances to a rapid rate of erosion. We do not indeed find the proof of this in the province itself, for it contains no Miocene strata or fossils; but in surrounding regions the strata and fossils of that age are found in abundance, and they clearly indicate that the climate had that character; and it would be quite untenable to suppose that so limited a tract as the Plateau Province was an anomaly in respect to the climate of the broader regions of which it is a part, unless special reasons for it could be adduced. I know of no such special reasons. But near the close of the Miocene, or not long thereafter, the climate of almost the entire West underwent a change, becoming arid, as it is at present. In this change the Plateau country no doubt shared. The more important results of the Pliocene and Quaternary erosion, however, will be among the principal themes of the following chapters.

CHAPTER II.

GEOGRAPHY OF THE GRAND CAÑON DISTRICT.

The Grand Cañon District—the region draining into the Grand and Marble Cañons—is the westernmost division of the Plateau Province. Nearly four-fifths of its area are situated in Northern Arizona. The remaining fifth is situated in Southern Utah. Let us turn our attention for a moment to the portion situated in Utah. It consists of a series of terraces quite similar to those which we have already seen descending from the summit of the Wasatch Plateau to the San Rafael Swell like a colossal stairway. At the top of the stairs are the broad and lofty platforms of the High Plateaus of Utah; at the bottom is the inner expanse of the Grand Cañon District. The summits of the High Plateaus are beds of Lower Eocene age. Descending southward we cross, step by step, the terminal edges of the entire Mesozoic system and the Permian, and when we reach the inner floor of the Grand Cañon District we find that it consists of the summit beds of the Carboniferous series patched here and there with fading remnants of the Permian.

Far beyond the remotest limits of vision stretches the great expanse of Upper Carboniferous beds, flecked with Permian outliers, and rising or falling to form the broader inequalities of level in the surface of the region. The terraces of Southern Utah are the border land between the High Plateaus on the north and the Carboniferous platform of the Grand Cañon on the south, and may be regarded as the appanage of either district. Their nature and meaning may become clearer by glancing a moment at the District of the High Plateaus.

Let us conceive a right-angled triangle in which the acutest angle is regarded as the apex and the shortest side as the base. Place the apex about 25 miles east of Mount Nebo, the great mountain which marks the southern end of the true Wasatch Range; place the right angle 170 or 180 miles due south of the apex, and the other acute angle about 100 to 110 miles due west of the right angle. This figure would include pretty nearly all of the summit areas of the High Plateaus. Consider now the north-and-south side reaching from the apex to the right angle. It runs along the crest lines and terraces which look down eastwardly upon the San Rafael district and upon other enormously eroded districts further south. The base reaching westward from the right angle to the other acute angle runs among the terraces which descend from the southern termini of the High Plateaus to the Grand Cañon District. The hypotenuse looks northwestward over a portion of the Basin Province. The High Plateaus themselves are large remnants of Mesozoic

and Tertiary strata which have been spared in the enormous denudation which has eaten out the heart of the Plateau Province. Their preservation has been largely due to extensive outpours of lavas, which have overspread most of their summits, and the energy of the eroding agencies has there spent itself upon the more obdurate materials of volcanic origin.

Starting from the right angle and reaching out south-southeast is a rather lofty mass, named the Kaiparowits Plateau. It reaches to the Colorado River, where it is cleft asunder by the mighty gorge of the Glen Cañon, but resumes its course on the other side, extending into Arizona, where it spreads out. It is composed of Cretaceous strata. Its western flank forms a part of the eastern boundary of the Grand Cañon, or more restrictedly of the Marble Cañon, district. Here again is the same old arrangement—terraces with their marginal cliffs rising from the Carboniferous platform step by step to the Middle Cretaceous—the cliffs all looking westward over the great region from which the former extensions of the strata they terminate have been swept away.

Thus we may note that the northern and eastern boundaries of the Grand Cañon District are cliff-bound terraces. Crossing the district either longitudinally from north to south, or transversely from east to west, we find as we approach the southern or western border that the Carboniferous platform ascends very gradually. There are broad and feebly marked (sometimes well marked) undulations, or ups and downs; but, on the whole, the country gains in altitude as we approach its western and southern limits. At last it terminates in a giant wall plunging down thousands of feet to the platform of a country quite similar to that of the Great Basin of Nevada. Those who have traveled on the Central Pacific Railway will recall the features of that very desolate region which lies between Great Salt Lake and the Sierra Nevada; and all those features are repeated and their desolation intensified in the dreadful region which lies west and south of the Grand Cañon District.

The district may be conveniently divided into parts. The northernmost portion is the area comprising the southern terraces of the High Plateaus. A description of these sufficient for preliminary purposes has already been given. At the foot of these terraces stretches away to the southward the great Carboniferous platform of the heart of the district. That portion of the platform which lies north of the Colorado River may be subdivided into five distinct plateaus. Naming them in regular order from west to east, they are: 1, the Sheavwits; 2, the Uinkaret; 3, the Kanab; 4, the Kaibab; 5, the Paria. These five plateaus are separated from each other by natural boundaries, which are for the most part quite distinct. These boundaries are great faults or dislocations of the main platform, which have produced cliffs by hoisting the platform on one side of the fault line or dropping it on the other. To show how these dislocations have affected the topography, the reader is referred to the east and west section delineated in the accompanying dia-

gram. (Pl. XIII.) Immediately south of the Paria Plateau extends the Marble Cañon, with a southwestward course. Directly across the remaining four plateaus winds the Grand Cañon of the Colorado. South of the river is a vast expanse of nearly flat surface, but little diversified, called the Colorado Plateau. Upon its southern borders rise abruptly a group of great volcanic piles called the San Francisco Mountains, the largest or dominant cone being of an impressive order of magnitude. There are still other portions beyond, but the entire region south of the Colorado has been reconnoitered rather than surveyed; and though we have a general knowledge of pretty nearly the whole of it, our knowledge of details is not as yet precise.

The entire expanse of the Grand Cañon platform within the terraces consists of a flat surface, interrupted at wide intervals by cliffs or sharp flexures produced by the great displacements which traverse the land in a prevailing north to south direction.* On the whole, it is a smooth country in comparison with the other districts of the Plateau Province. It is not dissected or honeycombed by the ramifications of innumerable side gorges, as is the case with most of the other districts, for the Grand Cañon has on the north side only one lateral or tributary cañon of any considerable length, and this tributary has but few branches. In truth, one of its remarkable features is the paucity of lateral chasms. The southern side is not more diversified than the northern, and I think we may say that it is somewhat less so. Between the great cliffs of displacement and between the foot of the terraces and the brink of the chasm the country is not more uneven than the Great Plains of Western Nebraska and Kansas, and not much more so than Indiana and Illinois. But the traveler is seldom out of sight of the palisades reared at the fault-lines, or of the gigantic and gorgeously colored walls which bound the terraces of the High Plateaus.

The Grand Cañon will be described at some length in subsequent chapters. Here will be noted only those more general features which may be made to appear on the map. It crosses transversely the four western plateaus of the district, while the Marble Cañon traverses the eastern or fifth plateau. The two cañons are only nominally separated, for there is no gap between them. The Marble Cañon begins at the base of the eastern terraces. The Colorado River, after traversing the central mesas of the Plateau country in a series of profound chasms, at length emerges from the Echo Cliffs of Triassic and Permian age. Here for an instant the river is in comparatively open country. But within a mile or two it begins to sink another chasm in the Carboniferous rocks, and in the course of 65 miles the depth steadily increases until it becomes about 3,500 to 4,000 feet. This is the Marble Cañon. It is

* It will be noted here that cliffs may be produced (1) by faults lifting the country on one side of the fault-line or depressing it on the other; (2) by the denudation of the strata in front of the cliff. The former are called *Cliffs of Displacement*; the latter, *Cliffs of Erosion*.

a gorge of very simple form, and its width is about twice as great as its depth. Its course is at first southwest, but gradually deflects to the southward. Its lower end is arbitrarily fixed at the junction of the Little Colorado or Colorado Chiquito, a stream coming in from the southeast and entering by a lateral chasm as deep as the main gorge itself. Below this junction the river turns westward, the walls grow rapidly higher, the great chasm widens out to six or eight times its width in the Marble Cañon, and the valley of the river is filled with buttes as large as mountains and wonderfully sculptured. Here the river enters the Kaibab, and its walls soon attain the altitude of about 6,000 feet. After a tortuous course of sixty miles in a prevailing northwest direction the river passes out of the Kaibab and at once changes its trend to west southwest. It passes without a break from the Kaibab to the Kanab Plateau. Here its depth diminishes to about 5,000 feet and its topography changes in character, becoming more simple. Preserving its new features and the direction of its course throughout the Kanab and Uinkaret plateaus, it at length crosses the Hurricane fault where the whole platform of the country suddenly drops more than a thousand feet, correspondingly diminishing the height of the walls. But the lost altitude is steadily and rather rapidly regained as the river enters the Sheavwits Plateau. Soon after crossing the fault the river turns abruptly to the south, and after describing a great curve in the heart of the Sheavwits platform it turns northwestward again. The great chasm suddenly terminates in the face of the giant wall which forms the western boundary of the Sheavwits Plateau. Here the river emerges through a mighty gateway a mile in depth, and is almost in open country, its banks dropping at once to altitudes of only a few hundred feet. This is the western bound, not only of the Grand Cañon District, but of the Plateau Province itself. Thenceforth the course of the Colorado to the ocean is through and across that dismal, torrid sierra region, which is the southward extension of the features of the Great Basin.

For convenience of discussion the Grand Cañon is divided into four divisions, (1) the Kaibab, (2) the Kanab, (3) the Uinkaret, (4) the Sheavwits, divisions. The last three are much alike in all their features and dimensions. The Kaibab division is a little deeper, notably wider, and very much grander and more diversified than the others. The total length of the Grand Cañon, as the river runs, is about 218 miles, and its depth varies from 4,500 to 6,000 feet, averaging 5,000. Its width, from crestline to crestline, varies from $4\frac{1}{2}$ to 12 miles—the widest portions being always the grandest.

It is also necessary to advert to the tributaries of the Colorado lying within the district. Upon the northern side there is but one now entering the Grand Cañon; but there are on this side two others, one of which, named the Paria, enters at the head of the Marble Cañon, and the other, the Virgen, which enters it about 40 miles west of the lower end of the

SECTION FROM EAST TO WEST ACROSS THE GRAND CAÑON DISTRICT.

Grand Cañon. Kanab Creek joins the Colorado on the north side in the heart of the great chasm. These three streams, the Virgen on the west, Kanab Creek in the middle, and the Paria on the east, all have their sources in the terraces of the High Plateaus. They are very important factors in the problem of reconstructing the history of the region.

On the south side of the river are (1) the Colorado Chiquito or Little Colorado, entering at the foot of Marble Cañon, (2) Cataract Creek, entering near the middle of the Kanab division, (3) Diamond Creek, joining at the elbow of the great bend in the Sheavwits division. These, too, have their bearing upon the general problem.

CHAPTER III.

THE TERRACES.

In describing those subdivisions of the Grand Cañon district which are of greatest moment to the present discussion, I shall begin with the terraces terminating the High Plateaus.

Before the observer who stands upon a southern salient of the Maricágunt Plateau is spread out a magnificent spectacle. The altitude is nearly 11000 feet above the sea, and the radius of vision reaches to the southward nearly a hundred miles. In the extreme distance is the calm of the desert platform, its surface mottled with indistinct lights and shades, too remote to disclose their meaning. Against the southeastern horizon is projected the pale-blue escarpment of the Kaibab, which stretches away to the south until the curvature of the earth carries it out of sight. To the southward rise in merest outline, and devoid of all visible details, the dark mass of Mount Trumbull and the waving cones of the Uinkaret. Between these and the Kaibab the limit of the prospect is a horizontal line, like that which separates the sea from the sky. To the southwestward are the Sierras of the Basin Province, and quite near to us there rises a short but quite lofty range of veritable mountains, contrasting powerfully with the flat crestlines and mesas which lie to the south and east. It is the Pine Valley range, and though its absolute altitude above the sea is smaller than many other ranges of the West, yet since their bases are comparatively low (3,000 to 3,500 feet above the sea), the mountain masses themselves are very high.

THE EOCENE.

The foreground of the picture is full of strength and animation. At our feet is the brink of a precipice where the profiles descend 800 feet upon rugged slopes which shelve away downwards and mingle with the inequalities of a broad platform deeply indented with picturesque valleys. The cliff on which we stand is of marvelous sculpture and color. The rains have carved out of it rows of square obelisks and pilasters of uniform pattern and dimensions, which decorate the front for many miles, giving the effect of a giantic colonnade from which the entablature has been removed or has fallen in ruins. The Plateau Country abounds in these close resemblances of natural carving to human architecture, and nowhere are these more conspicuous or more perfect than in the

PINK CLIFFS—EOCENE—PAUNSAGUNT.

scarps which terminate the summits of the Markágunt and Paunságunt Plateaus. Their color varies with the light and atmosphere. It is a pale red under ordinary lights, but as the sun sinks towards the horizon it deepens into a rich rose color, which is seen in no other rocks and is beautiful beyond description. These cliffs are of lower Eocene age, consisting of lake marls very uniformly bedded. At the base of this series the beds are coarser, and contain well-marked, brackish-water fossils; but as we ascend to the higher beds we find the great mass of the Eocene to consist of fresh-water deposits.

These beds are identical in age with the lower divisions of the Eocene which are seen in great volume both north and south of the Uinta Mountains, in the basins of the Green River, of Bitter Creek, and of the White and Uinta Rivers. Their geological relations and associations, too, are quite the same, for the same lake bottom received the deposits of the southern Uinta slopes and those of the Markágunt. Those of the Green River basin north of the Uintas appear to have accumulated in a separate lake basin communicating with the one which submerged the southern Plateau province. The interval separating the Markágunt from the Uinta region is 250 miles and more, but the lower Eocene is continuous between them. It occupies a marginal belt sometimes narrow, but more frequently wide, which was once the locus of the northwestern portion and shore line of the great lake. The summits of the High Plateaus, wherever the volcanic masses are absent, disclose this formation, and its presence is decisively inferred beneath the lavas and their débris. A common bond between the two regions is also indicated by the physical conditions attending the deposition of these strata. The lower Eocene rests upon the underlying formations, conformably in some places, unconformably in others. Where conformity prevails, both the upper and lower series were at the time of deposition sensibly horizontal. But in many places the Cretaceous, prior to the deposition of the Eocene, was greatly disturbed and greatly eroded. And in general the base of the Eocene marks an epoch in the geological history of the country, in which an old order of events was closing and a new order was making its advent. This revolution was the transition of the region from the oceanic condition to that of an estuary and lake, and subsequently to that of dry land. The Lower Eocene beds are brackish-water deposits in the basal members, while higher up they become fresh-water. The basal members are coarse and even conglomeratic in their texture, while the middle and higher ones are fine and marly. Thus is indicated the complete severance of the lake from the access of oceanic waters. Both in the Uinta district and throughout the High Plateaus these events are recorded in the same order and their meaning is the same in both.

The beds now found in the southern extremities of the High Plateaus represent less than half of the duration of Eocene time. No middle and no upper Eocene strata are found there. But as we go northward towards the Uintas we find later and later formations suc-

cessively appearing until upon the flanks of the Uintas we find the whole Eocene series in enormous volume, exceeding perhaps 5,000 feet. Could these middle and Upper Eocene masses once have existed upon the southern portion of the High Plateaus and been swept away by erosion? There is strong evidence to the contrary.* The facts, then, indicate that when the desiccation of the lake took place, the portion which first emerged was the southern and southwestern—or the Grand Cañon district; that its shore line gradually receded northward during middle and upper Eocene time, leaving dry land behind it; and the last remnant of the lake disappeared near the base of the Uintas. Wherever the physical geology and evolution of the Grand Cañon district touches the question of time, the earlier date of its emergence than that of other portions of the Plateau Province appears—sometimes dimly, sometimes forcibly.

The principal mass of the Eocene terminates at the “Pink Cliffs,” as they are called, in the southern margins of the Markágunt and Paunságunt Plateaus. There are a few outliers beyond. Around the base of the Pine Valley Mountains to the southwest, and beyond them in the same direction, some remnants have escaped destruction. But this part of the country has not been sufficiently explored to indicate more than the bare fact of their existence. Far to the eastward a single outlier stands upon the summit of the great Kaiparowits Plateau, forming the apex of Kaiparowits Peak. But generally speaking, the Eocene is wholly absent, so far as known, from the country south of the terraces.

THE CRETACEOUS.

The platform immediately below the Pink Cliffs is picturesque rather than grand. Rough rolling ridges of yellow sandstone, long sloping hillsides, and rocky promontories clad with large pines and spruces, surround the valleys. These rocks are of Cretaceous age. Upon the southward slopes of the Paunságunt and Markágunt Plateaus, they nowhere present the serried fronts of cliffs, but break down into long irregular slopes much like those of common hill countries. In those superficial and merely scenic aspects which make the terraces so impressive, the Cretaceous is for the most part notably deficient; but in those deeper studies, which are of most significance to the geologist, it holds an importance not inferior to that of any other formation. It is never wanting at its proper place in the terraces, but always displays a vast series of sandstones and clay-shales, varying from 4,000 to 5,000 feet in thickness. Around the western and southern flanks of the Markágunt, and just beneath the summit platform, they occupy a belt varying in width from 4 to 10 miles. Around the Paunságunt their relative positions and re-

*This evidence will be fully discussed in my monograph on the Geology of the Grand Cañon district.—C. E. D.

lations are quite the same. But as we pass eastward into the great amphitheater of the Paria Valley they at length take the form of cliffs of very striking aspect. The numerous ledges rise in quick succession, step by step from the valley bottom to the base of the Eocene mass of Table Cliff, which stands as a glorious Parthenon upon the summit of a vast Acropolis. The many superposed cliffs which constitute this stairway are severally of moderate dimensions, but their cumulative altitude is more than 4,000 feet, tier above tier, and their composite or multiple effect, intensified by the exceeding sharpness of the infinite details of repetitive sculpture, places it among the grander spectacles of the Plateau country. In their coloring, these cliffs are quite peculiar. There are no red, purple, orange, and chocolate hues, such as prevail in other formations, but pale yellow and light brown in the sandstones and blue-gray to dark iron-gray in the heavy belts of shale. The tones are very light and brilliant on the whole, the darker belts playing the part of a foil which augments rather than diminishes their luminosity.

THE JURASSIC.

Beyond the Cretaceous, as we descend the stairway of terraces, the Jurassic comes to daylight. It forms a belt encircling the Cretaceous and outside of the latter. It is composed of two groups of strata; the upper consisting of red sandy shales with belts of impure limestone; the lower a great mass of white sandstone, nearly a thousand feet thick. The red shales contain abundant fossils, strongly characteristic of their Jurassic age, while the sandstone below is wholly barren of organic remains. The sandstone, however, is full of interest on account of its remarkable lithological characters. From summit to base, it is apparently one indivisible stratum. Here and there signs of a division are suspected, but closer scrutiny shows that they are produced by the contact of one plexus of cross-bedding with another, or by some other cause not affecting the dominant fact. It is remarkably homogeneous throughout its whole mass. On a near view of the rock faces they are seen to be covered with a wonderful filagree of cross-bedding. On every cliff and headland, on every butte or rocky knoll where this huge stratum is exposed, the rock faces are etched with an arabesque as beautiful as frostwork. Along hundreds of miles of linear extent, and over thousands of square miles of surface of the country, this graceful waving of myriads of curves is displayed. Cross-bedding is common enough in other regions and other formations, but nowhere in the world, I fancy, can such a profusion of it be seen.

The Jurassic sandstone is also conspicuous for its cliffs. Here every formation has its own style of architecture and sculpture, which are as distinctive as the lithological constitution, for upon that constitution

the style depends. The Jurassic forms are characterized by a peculiar massiveness and boldness and by an extreme simplicity which is even severe. Its walls are quite plain, without horizontal or vertical mouldings, and the only decoration is the cross-bedding which becomes invisible at distances sufficient to render a general view of the fronts effective. A notable feature also is the absence of talus—or, if it be present, its small proportions. This simplicity usually gives a dull slumberous aspect to the escarpments, suggesting on a vast scale the structures of the Peruvian Incas. But it is not always so. Occasionally the austerity of these forms is relaxed or replaced by a strange kind of animation which sometimes becomes amusing. Looking southward from the brink of the Markágnnt the eye is attracted to the features of a broad middle terrace upon its southwestern flank, named The Colob. It is a veritable wonderland. It lies beyond the Cretaceous belt and is far enough away to be obscure in its details, yet exciting curiosity. If we descend to it we shall perceive numberless rock-forms of nameless shapes, but often grotesque and ludicrous, starting up from the earth as isolated freaks of carving or standing in clusters and rows along the white walls of sandstone. They bear little likeness to anything we can think of, and yet they tease the imagination to find something whereunto they may be likened. Yet the forms are in a certain sense very definite, and many of them look merry and farcical. The land here is full of comedy. It is a singular display of Nature's art mingled with nonsense. It is well named the Colob, for the word has no ascertainable meaning and yet sounds as if it ought to have one.

Nor are these the only forms which the Jurassic discloses. Here and there blank faces of the white wall are brought into view as the sinuous line of its front advances and recedes. Isolated masses cut off from the main formation, and often at considerable distances from it, lie with a majestic repose upon the broad expanse of the terrace. These sometimes become very striking in their forms. They remind us of great forts with bastions and scarps nearly a thousand feet high. The smaller masses become regular truncated cones with bare slopes. Some of them take the form of great domes where the eagles may build their nests in perfect safety. But noblest of all are the white summits of the great temples of the Virgen gleaming through the haze. Here Nature has changed her mood from levity to religious solemnity, and revealed her fervor in forms and structures more beautiful than anything in human art. But we shall see more of this hereafter and from much more advantageous stand-points than the summit of the Markágnnt. There only faint suggestions of the reality are given. We only perceive in imperfect detail some throngs of towers, snow-white above and red below, the bristling spires of ornate buttes, or a portion of the grand sweep of a wing-wall thrust out from some unseen façade. None of them appear in their full relations to the whole, and all of them are weakened, faded, and flattened by the distance.

A MIDSUMMERDAY'S DREAM.—JURASSIC.—ON THE COLOB.

At the border of the Jurassic the profile drops upon the summit of the Trias, but from the summit of the Markágunt nothing is visible in detail of that formation. The faces of the escarpments are turned away from us and only the crestlines are visible. The view from the Markágunt, however, is memorable because it is characteristic. To study the Trias we must leave the verge of that Plateau and descend the terraces to the southward.

On our way we may note several things of some importance. We may observe, first, that the strata all have a very slight dip to the north. This dip on the average is less than two degrees, but here and there inclinations as great as four or five degrees may be seen. This dip is very general throughout the terraces. Its effect is to make the altitudes of the higher or more northerly platforms less—or, conversely, to make the altitudes of the lower and more southerly terraces greater—than they would be if the entire series were horizontal. In the entire series of beds which are exposed, the aggregate thickness from the top of the Carboniferous to the summit of the local Eocene is not far from 10,000 feet, but the summit of the Eocene at present lies only about 5,000 to 6,000 feet above the Carboniferous platform of the Grand Cañon District. Thus, if the strata were horizontal, we should in ascending the terraces go up 10,000 feet, but the dip to the northward gradually carries down the horizons so that in crossing the edges of 10,000 feet of strata we only gain 5,000 to 6,000 feet in altitude. We find this same northward dip prevailing in the Carboniferous to the southward, and it is a feature of great moment in the studies which are to follow.

Another point to be noted is that the strata slowly diminish in thickness from west to east. The attenuation, however, is ordinarily very slow and gradual, and the observer would have to travel many miles along the escarpments exposing the edges of the strata before he became aware of it. It is most noticeable in the Trias, and in the sequel this will be more fully discussed. The meaning of this attenuation of the strata towards the east is as follows.

It is a common fact that the greatest thickness of a group of strata is usually found near the shorelines of the mainlands from which their materials came. As we recede from these ancient shorelines we generally find that the strata diminish in thickness, at first quite rapidly, but afterwards more slowly. The materials deposited near the shores are, in many cases, of coarser texture than those deposited at a distance from them. This is not always true of every distinct bed, but if we consider any group of strata with many members we shall usually find it true of the group as a whole. In the case of the Mesozoic strata of the terraces, they are remnants of beds deposited in a sea or bay, the shoreline of which lay to the westward and northwestward. The position of this shoreline, no doubt, varied during the Mesozoic periods, now advancing and now receding; but in general terms its mean position appears to have been nearly along what is now the boundary of the Basin

Province. The Great Basin was then dry land, undergoing denudation, and its detritus was washed down on this side into the sea, where the Mesozoic strata of the Plateau Province accumulated. The position of this ancient shoreline in the Sierra country south of the Great Basin and west of the Grand Cañon district we do not as yet know; the presumed location not being explored as yet. This attenuation of the strata and their relation to the shoreline of the mainland, from which they were in great part at least derived, is another important factor which must be kept in mind in the course of the discussion.

It will be well to bestow also a glance at the distribution of the more important drainage channels. The western portion of the terraces is

FIG. 5.—Entrance to the Parí-nu-weap.

drained by the branches of the Virgen River. Upon the Colob heads the northern fork of the Virgen, sometimes called the Mu-kún-tu-weap, sometimes Little Zion River. It flows due south. East of this is the eastern fork, called the Pa-rú-nu-weap. Both branches have their sources at the base of the Pink Cliffs (Eocene), and at length unite to form the

THE PARUNUWEAP.

From Powell's Exploration of the Colorado River.

Virgen. Their channels are surely very wonderful freaks of nature. The Parínuweap, after collecting its several filaments on the slopes of the Cretaceous terrace, at length begins to burrow into the Jurassic, cutting a very deep and remarkably narrow gap in the white sandstone, and then into and through the Trias. For many miles it flows in a mere cleft barely fifty feet wide at the bottom and sometimes narrower, and attaining a depth of more than 2,500 feet. In scouring down its channel into the sandstones the stream did not cut always vertically, but swayed from side to side, so that now great bulges of the wall overhang the bottom of the abyss, and in some places shut out the sky overhead. The Minkúntuweap, or Little Zion fork, is even more remarkable. For a considerable distance this stream also runs in a profound and exceptionally narrow chasm, but it at length widens out, and just where it joins the Parínuweap is a scene which must ultimately become, when the knowledge of it is spread, one of the most admired in the world. Of this hereafter. Below the junction of the forks the Virgen flows westward, and passes out of the terraces and out of the Plateau Province. At length it joins the Colorado.

East of the drainage area of the Virgen is that of Kanab Creek. It heads in the broad valley of Upper Kanab, which occupies an indentation of the southern margin of the High Plateaus between the Markágunt and Paunságunt. The bulk of the drainage passes through the upper cañon of Kanab Creek, and at length emerges upon the desert to the southward. Further on it sinks another chasm in the Carboniferous, which becomes a mighty side gorge of the Colorado, and unites with the Grand Cañon in the middle of the Kanab division.

Still eastward is the great amphitheater which gives rise to the branches of the Paria. This stream flows southeastward and ultimately enters the Colorado at the head of the Marble Cañon.

In these three subordinate drainage basins of the terraces it is well to notice some features of importance, common more or less to all, but most distinctly seen in Kanab Creek. They all run contrary to the dip of the strata. The summits of the terraces dip to the northward, while the streams run southward. They thus form each a chain of cañons. Thus, Kanab Creek with its upper tributaries flowing in open valleys soon begins to cut into the Jurassic, and its gorge, ever deepening, at length becomes nearly a thousand feet in depth. Suddenly the cañon walls swing to right and left to form the mural front which terminates the Jurassic terrace, and the river, now at the summit of the Trias, is once more in open country; but only for a short distance, for it soon begins to cut into the Trias, forming a great cañon as before. The same process is repeated and the river flows out of its Triassic chasm into the open again, while its walls swing in either direction to form the terminal escarpment of the Triassic terrace.

The three streams just mentioned are not the only drainage channels in the terraces, though they are the principal ones, and sooner or later

gather the greater part of the drainage. There are many cañons in the terraces, and they all have the same relation to the cliffs and to the dips of the strata. They cut into the terraces and emerge from them at the bases of their several cliffs. All except the three first mentioned are dry, carrying no streams except spasmodic floods during heavy rains and the melting of the snows. Many of them are actually filling up, the floods being unable to carry away all the sand and clay which the infrequent rains wash into them.

It is through the dry and partially refilled chasms that we may easily descend from the High Plateaus to the Carboniferous platform of the Grand Cañon district. To study the Trias, we may best go to the little village of Kanab and prepare for a journey along the base of the Vermilion Cliffs.

THE TRIAS.

Kanab village is situated under the eaves of the Vermilion Cliffs, in the jaws of the cañon of Kanab Creek. It has for several years been the base of operations of the surveying parties working in the Grand Cañon district, and is well located for the purpose. After due preparation, we may leave the village, proceeding about twenty miles southward to the southernmost promontory of the Triassic escarpment. Here is Pipe Spring, famous in this far-off region as a watering place. The reader would do well to find the locality on the map, for it is a notable point. The Vermilion Cliffs here change their trend to the northward, and we shall presently follow them to admire their beauty and magnitude; but before doing so it is well to take a brief view of their geological relations.

The Trias is in most places separated from the Jura by a purely provisional horizon which marks a change in the lithological aspect of the strata, and in the grouping and habit of the series. Sometimes the passage from one to the other is obscured, but more frequently it is abrupt. The Jurassic sandstone is without a likeness in any other formation, and the sandstones of the Trias can ordinarily be distinguished from it miles away. One of the most conspicuous distinctions is the color, and it is a never-failing distinction. The Jurassic is white; the Trias is flaming red. Equally conspicuous is the difference in bedding and in the architecture. The Jura is a solid indivisible mass of 800 to 1,000 feet in thickness; the Trias is composed of a very great number of beds, most of which are only a few feet in thickness. One bed, however, attains vast proportions. The majority of the layers are common sandstones, and they predominate most in the upper portion of the series. In the middle part the sandstones still predominate but are individually thinner, and are more often separated by shaly layers and by bands of gypsum. In the lower portions, sandy and argillaceous shales of won-

VERMILLION CLIFFS AT KANAB. TRIASSIC.

derful colors predominate. Lime is found in these rocks, and in notable quantity, but it is almost always in the form of gypsum or selenite. No fossils in these parts have yet been found which are of paleontological value; but fish-scales, and fragments of bony scutes are sometimes obtained, which are useless for the purposes of the geologist. In the lower shales we find a great abundance of fossil trees completely silicified and several bulky layers are composed very largely of their fragments.

The Trias makes its appearance upon the outermost western flank of the Markágunt, a little north of the Mormon town Cedar, rising by a fault out of the valley alluvium. With a constantly expanding exposure, it extends southward along the west flank of the Markágunt and along the upthrow of the Hurricane fault, until the whole of its mass comes to the surface; then broadening out into a wide terrace, it sweeps around the southwestern limit of the Colob and over into the valley of the Virgin, where it breaks into cliffs, temples, towers, and buttes of ineffable splendor and beauty. Thence, with a still wider terrace, bounded by a giant wall, it stretches to the southeast as far as Pipe Spring. Here is its southernmost promontory, from which its front trends away north-east and east in proportions diminished somewhat, but still imposing, as far as the Paria River. Thus far the distance is more than 120 miles, in which the sinuosities of the front are not reckoned. Throughout this entire sweep it presents to the southward a majestic wall richly sculptured and blazing with gorgeous colors. The cliff line is very tortuous, advancing in promontories, with intervening bays and broad cañon valleys setting far back into the terrace, and resembling a long stretch of coast-line gashed with fiords. Perhaps also the contour of a maple-leaf may be a suggestive analogy. The altitudes of the cliffs are greatest in their western portions, for there we find greater thickness of strata. They often exceed 2,000 feet, while in the portion extending from Pipe Spring to the Paria the altitude ranges from 1,000 to 1,400 feet.

THE VERMILION CLIFFS.

To this great wall, terminating the Triassic terrace and stretching from the Hurricane Ledge to the Paria, Powell has given the name of The Vermilion Cliffs. Their great altitude, the remarkable length of their line of frontage, the persistence with which their proportions are sustained throughout the entire interval, their ornate sculpture and rich coloring, might justify very exalted language of description. But to the southward, just where the desert surface dips downward beneath the horizon, are those supreme walls of the Grand Cañon, which we must hereafter behold and vainly strive to describe; and however worthy of admiration the Vermilion Cliffs may be we must be frugal of adjectives, lest in the chapters to be written we find their force and meaning ex-

hausted. They will be weak and vapid enough at best. Yet there are portions of the Vermilion Cliffs which in some respects lay hold of the sensibilities with a force not much less overwhelming than the majesty of the Grand Cañon; not in the same way, not by virtue of the same elements of power and impressiveness, but in a way of their own and by attributes of their own. In mass and grandeur and in the extent of the display there is no comparison; it would be like comparing a private picture gallery containing a few priceless treasures with the wealth of art in the Vatican or Louvre. All of the really superlative portions of the Vermilion Cliffs could be comfortably displayed in any one of half a dozen amphitheaters opening into the Kaibab division of the Grand Cañon. These portions occur in the beautiful valley of the Virgen, and they, as well as the features which characterize the entire front of the Vermilion Cliffs, merit some attempt at description.

Each of the greater sedimentary groups of the terraces from the Eocene to the Permian inclusive, has its own style of sculpture and architecture; and it is at first surprising and always pleasing to observe how strongly the several styles contrast with each other. The elephantine structures of the Nile, the Grecian temples, the pagodas of China, the cathedrals of Western Europe, do not offer stronger contrasts than those we successively encounter as we descend the great stairway which leads down from the High Plateaus. As we pass from one terrace to another the scene is wholly changed; not only in the bolder and grander masses which dominate the landscape, but in every detail and accessory; in the tone of the color-masses, in the vegetation, and in the spirit and subjective influences of the scenery. Of these many and strong antitheses, there is none stronger than that between the repose of the Jura and the animation of the Trias.

The profile of the Vermilion Cliffs is very complex, though conforming to a definite type and made up of simple elements. Although it varies much in different localities it never loses its typical character. It consists of a series of vertical ledges rising tier above tier, story above story, with intervening slopes covered with talus through which the beds project their fretted edges. The stratification is always revealed with perfect distinctness and is even emphasized by the peculiar weathering. The beds are very numerous and mostly of small or moderate thickness, and the partings of the sandstones include layers of gypsum or gypsiferous sand and shale. The weathering attacks these gypseous layers with great effect, dissolving them to a considerable depth into the wall-face, producing a deeply engraved line between the including sandstones. This line is always in deep shadow and throws into strong relief the bright edges of the strata in the rock-face, separating them from each other with uncommon distinctness. Where the profiles are thrown well into view the vertical lines, which bound the faces of the ledges, are quite perpendicular and straight, while the lines of the intervening slopes are feebly concave, being, in fact, descending

branches of hyperbolas. They are graceful in form and indeed genuine lines of beauty. The angles where the straight and curved lines meet, at the bases and summits of the ledges, are very keen and well cut. The composite effect thus given by the multiple cliffs and sloping water-tables rising story above story, by the acute definition of the profiles and horizontal moldings, and by the refined though unobtrusive details, is highly architectural and ornate, and contrasts in the extreme with the rough, craggy, beetling aspect of the cliffs of other regions. This effect is much enhanced by the manner in which the wall advances in promontories or recedes in alcoves, and by the wings and gables with sharp corners and Mansard roofs jutting out from every lateral face where there is the least danger of blankness or monotony. In many places cañons have cut the terrace platform deeply, and open in magnificent gateways upon the broad desert plain in front. We look into them from afar, wonderingly and questioningly, with a fancy pleased to follow their windings until their sudden turns carry them into distant, unseen depths.

Northwestward of the southernmost promontory at Pipe Spring, the cliffs steadily increase in grandeur and animation, and also assume new features. Near the summit of the series is a very heavy stratum of sandstone, which is everywhere distinguishable from the others. This member is seen at Kanab with a thickness of about 200 feet. It increases westward, becoming 400 feet at Pipe Spring. Beyond that it still increases, reaching a thickness of more than 1,200 feet in the valley of the Virgin. It has many strong features, and yet they elude description. One point, however, may be seized upon, and that is, a series of joints nearly vertical with which the mass is everywhere riven. The fissures thus produced have been slowly enlarged by weathering, and down the face of every escarpment run the dark shadows of these rifts. They reach often from top to bottom of the mass and penetrate deeply its recesses. Wherever this great member forms the entablature—and west of Pipe Spring it usually does so—its crest is uneven and presents towers and buttresses produced by the widening of these cracks. Near Short Creek it breaks into lofty truncated towers of great beauty and grandeur, with strongly emphasized vertical lines and decorations, suggestive of cathedral architecture on a colossal scale. Still loftier and more ornate become the structures as we approach the Virgin. At length they reach the sublime. The altitudes increase until they approach 2,000 feet above the plain. The wall is recessed with large amphitheatres, buttressed with huge spurs and decorated with towers and pinnacles. Here, too, for the first time, along their westward trend, the Vermilion Cliffs send off buttes. And giant buttes they verily are, rearing their unassailable summits into the domain of the clouds, rich with the aspiring forms of Gothic type, and flinging back in red and purple the intense sunlight poured over them. Could the imagination blanch those colors, it might compare them with vast

TOWERS AT SHORT CREEK. VERMILION CLIFFS.

icebergs, rent from the front of a glacier and floating majestically out to sea; only here it is the parent mass that recedes, melting away through the ages, while its off-spring stands still. Yet the analogy would be a feeble one, for the buttes are grander, more definite in form, and many times loftier. But the climax of this scenery is still beyond.

Late in the autumn of 1880 I rode along the base of the Vermilion Cliffs, from Kanab to the Virgen, having the esteemed companionship of Mr. Holmes. We had spent the summer and most of the autumn among the cones of the Uinkaret, in the dreamy parks and forests of the Kaibab, and in the solitudes of the intervening desert; and our sensibilities had been somewhat overtaken by the scenery of the Grand Cañon. It seemed to us that all grandeur and beauty thereafter beheld must be mentally projected against the recollection of those scenes, and be dwarfed into commonplace by the comparison; but as we moved onward the walls increased in altitude, in animation, and in power. At length the towers of Short Creek burst into view, and, beyond, the great cliff in long perspective thrusting out into the desert plain its gables and spurs. The day was a rare one for this region. The mild, sub-tropical autumn was over, and just giving place to the first approaches of winter. A sullen storm had been gathering from the southwest, and the first rain for many months was falling, mingled with snow. Heavy clouds rolled up against the battlements, spreading their fleeces over turret and crest, and sending down curling flecks of white mist into the nooks and recesses between towers and buttresses. The next day was rarer still, with sunshine and storm battling for the mastery. Rolling masses of cumuli rose up into the blue to incomprehensible heights, their flanks and summits gleaming with sunlight, their nether surfaces above the desert as flat as a ceiling, and showing, not the dull neutral gray of the east, but a rosy tinge caught from the reflected red of rocks and soil. As they drifted rapidly against the great barrier, the currents from below, flung upward to the summits, rolled the vaporous masses into vast whorls, wrapping them around the towers and crest-lines, and scattering torn shreds of mist along the rock-faces. As the day wore on the sunshine gained the advantage. From overhead the cloud-masses stubbornly withdrew, leaving a few broken ranks to maintain a feeble resistance. But far in the northwest, over the Colob, they rallied their black forces for a more desperate struggle, and answered with defiant flashes of lightning the incessant pour of sun-shafts.

Superlative cloud effects, common enough in other countries, are lamentably infrequent here; but, when they do come, their value is beyond measure. During the long, hot summer days, when the sun is high, the phenomenal features of the scenery are robbed of most of their grandeur, and cannot or do not wholly reveal to the observer the realities which render them so instructive and interesting. There are few middle tones of light and shade. The effects of foreshortening are

excessive, almost beyond belief, and produce the strangest deceptions. Masses which are widely separated seem to be superposed or continuous. Lines and surfaces, which extend towards us at an acute angle with the radius of vision, are warped around until they seem to cross it at a right angle. Grand fronts, which ought to show depth and varying distance, become flat and are troubled with false perspective. Proportions which are full of grace and meaning are distorted and belied. During the mid-day hours the cliffs seem to wilt and droop as if retracting their grandeur to hide it from the merciless radiance of the sun whose very effulgence flouts them. Even the colors are ruined. The glaring face of the wall, where the light falls full upon it, wears a scorched, overbaked, discharged look; and where the dense black shadows are thrown—for there are no middle shades—the magical haze of the desert shines forth with a weird, metallic glow which has no color in it. But as the sun declines there comes a revival. The half-tones at length appear, bringing into relief the component masses; the amphitheaters recede into suggestive distances; the salients silently advance towards us; the distorted lines range themselves into true perspective; the deformed curves come back to their proper sweep; the angles grow clean and sharp; and the whole cliff arouses from lethargy and crests itself in grandeur and power, as if conscious of its own majesty. Back also come the colors, and as the sun is about to sink they glow with an intense orange-vermilion that seems to be an intrinsic luster emanating from the rocks themselves. But the great gala-days of the cliffs are those when sunshine and storm are waging an even battle; when the massive banks of clouds send their white diffuse light into the dark places and tone down the intense glare of the direct rays; when they roll over the summits in stately procession, wrapping them in vapor and revealing cloud-girt masses here and there through wide rifts. Then the truth appears and all deceptions are exposed. Their real grandeur, their true forms, and a just sense of their relations are at last fairly presented, so that the mind can grasp them. And they are very grand—even sublime. There is no need, as we look upon them, of fancy to heighten the picture, nor of metaphor to present it. The simple truth is quite enough. I never before had a realizing sense of a cliff 1,800 to 2,000 feet high. I think I have a definite and abiding one at present.

As we moved northward from Short Creek, we had frequent opportunities to admire these cliffs and buttes, with the conviction that they were revealed to us in their real magnitudes and in their true relations. They awakened an enthusiasm more vivid than we had anticipated, and one which the recollection of far grander scenes did not dispel. At length the trail descended into a shallow basin where a low ledge of sandstones, immediately upon the right, shut them out from view; but as we mounted the opposite rim a new scene, grander and more beautiful than before, suddenly broke upon us. The cliff again appeared, presenting the heavy sandstone member in a sheer wall nearly a thou-

sand feet high, with a steep talus beneath it of eleven or twelve hundred feet more. Wide alcoves receded far back into the mass, and in their depths the clouds floated. Long, sharp spurs plunged swiftly down, thrusting their monstrous buttresses into the plain below, and sending up pinnacles and towers along the knife edges. But the controlling object was a great butte which sprang into view immediately before us, and which the salient of the wall had hitherto masked. Upon a pedestal two miles long and a thousand feet high, richly decorated with horizontal moldings, rose four towers highly suggestive of cathedral architecture. Their altitude above the plain was estimated at about 1,800 feet. They were separated by vertical clefts made by the enlargement of the joints, and many smaller clefts extending from the summits to the pedestal carved the turrets into tapering buttresses, which gave a graceful aspiring effect with a remarkable definiteness to the forms. We named it Smithsonian Butte, and it was decided that a sketch should be made of it; but in a few moments the plan was abandoned or forgotten. For over a notch or saddle formed by a low isthmus which connected the butte with the principal mesa there sailed slowly and majestically into view, as we rode along, a wonderful object. Deeply moved, we paused a moment to contemplate it, and then abandoning the trail we rode rapidly towards the notch, beyond which it soon sank out of sight. In an hour's time we reached the crest of the isthmus, and in an instant there flashed before us a scene never to be forgotten. In coming time it will, I believe, take rank with a very small number of spectacles each of which will, in its own way, be regarded as the most exquisite of its kind which the world discloses. The scene before us was

THE TEMPLES AND TOWERS OF THE VIRGEN.

At our feet the surface drops down by cliff and talus 1,200 feet upon a broad and rugged plain cut by narrow cañons. The slopes, the winding ledges, the bosses of projecting rock, the naked, scanty soil, display colors which are truly amazing. Chocolate, maroon, purple, lavender, magenta, with broad bands of toned white, are laid in horizontal belts, strongly contrasting with each other, and the ever-varying slope of the surface cuts across them capriciously, so that the sharply defined belts wind about like the contours of a map. From right to left across the further foreground of the picture stretches the inner cañon of the Virgen, about 700 feet in depth, and here of considerable width. Its bottom is for the most part unseen, but in one place is disclosed by a turn in its course, showing the vivid green of vegetation. Across the cañon, and rather more than a mile and a half beyond it, stands the central and commanding object of the picture, the western temple, rising 4,000 feet above the river. Its glorious summit was the object we had seen an hour

before, and now the matchless beauty and majesty of its vast mass was all before us. Yet it was only the central object of a mighty throng of structures wrought up to the same exalted style, and filling up the entire panorama. Right opposite us are the two principal forks of the Virgen, the Parínuweap coming from the right or east, and the Mukúntuweap or Little Zion Valley, descending towards us from the north. The Parínuweap is seen emerging on the extreme right through a stupendous gateway and chasm in the Triassic terrace, nearly 3,000 feet in depth. The further wall of this cañon, at the opening of the gateway, quickly swings northward at a right angle and becomes the eastern wall of Little Zion Valley. As it sweeps down the Parínuweap it breaks into great pediments, covered all over with the richest carving. The effect is much like that which the architect of the Milan Cathedral appears to have designed, though here it is vividly suggested rather than fully realized—as an artist painting in the “broad style” suggests many things without actually drawing them. The sumptuous, bewildering, mazy effect is all there, but when we attempt to analyze it in detail it eludes us. The flank of the wall receding up the Mukúntuweap is for a mile or two similarly decorated, but soon breaks into new forms much more impressive and wonderful. A row of towers half a mile high is quarried out of the palisade, and stands well advanced from its face. There is an eloquence in their forms which stirs the imagination with a singular power, and kindles in the mind of the dullest observer a glowing response. Just behind them, and rising a thousand feet higher, is the eastern temple, crowned with a cylindric dome of white sandstone; but since it is, in many respects, a repetition of the nearer western temple, we may turn our attention to the latter. Directly in front of us a complex group of white towers, springing from a central pile, mounts upwards to the clouds. Out of their midst, and high over all, rises a dome-like mass, which dominates the entire landscape. It is almost pure white, with brilliant streaks of carmine descending its vertical walls. At the summit it is truncated, and a flat tablet is laid upon the top, showing its edge of deep red. It is impossible to liken this object to any familiar shape, for it resembles none. Yet its shape is far from being indefinite; on the contrary, it has a definiteness and individuality which extort an exclamation of surprise when first beheld. There is no name provided for such an object, nor is it worth while to invent one. Call it a dome; not because it has the ordinary shape of such a structure, but because it performs the function of a dome.

The towers which surround it are of inferior mass and altitude, but each of them is a study of fine form and architectural effect. They are white above, and change to a strong, rich red below. Dome and towers are planted upon a substructure no less admirable. Its plan is indefinite, but its profiles are perfectly systematic. A curtain wall 1,400 feet high descends vertically from the eaves of the temple and is succeeded by a steep slope of ever-widening base courses leading down to

FIG. 6.—The Mu-kún-tu-weap.

the esplanade below. The curtain-wall is decorated with a lavish display of vertical moldings, and the ridges, eaves and mitered angles are fretted with serrated cusps. This ornamentation is suggestive rather than precise, but it is none the less effective. It is repetitive, not symmetrical. But though exact symmetry is wanting, nature has here brought home to us the truth that symmetry is only one of an infinite range of devices by which beauty can be materialized.

And finer forms are in the quarry
Than ever Angelo evoked.

Reverting to the twin temple across Little Zion Valley, its upper mass

THE TEMPLES AND TOWERS OF THE VIRGEN.

is a repetition of the one which crowns the western pile. It has the same elliptical contour, and a similar red tablet above. In its effect upon the imagination it is much the same. But from the point from which we first viewed them—and it is by far the best one accessible—it was too distant to be seen to the fullest advantage, and the western temple by its greater proximity overpowered its neighbor.

Nothing can exceed the wondrous beauty of Little Zion Valley which separates the two temples and their respective groups of towers. Nor are these the only sublime structures which look down into its depths, for similar ones are seen on either hand along its receding vista until a turn in the course carries the valley out of sight. In its proportions it is about equal to Yo Semite, but in the nobility and beauty of the sculptures there is no comparison. It is Hyperion to a satyr. No wonder the fierce Mormon zealot, who named it, was reminded of the Great Zion, on which his fervid thoughts were bent—"of houses not built with hands, eternal in the heavens."

From these highly wrought groups in the center of the picture the eye escapes to the westward along a mass of cliffs and buttes covered with the same profuse decoration as the walls of the temples and of the Parunuweap. Their color is brilliant red. Much animation is imparted to this part of the scene by the wandering courses of the mural fronts which have little continuity and no definite trend. The Triassic terrace out of which they have been carved is cut into by broad amphitheatres and slashed in all directions by wide cañon valleys. The resulting escarpments stretch their courses in every direction, here fronting towards us, there averted; now receding behind a nearer mass and again emerging from an unseen alcove. Far to the westward, twenty miles away, is seen the last palisade lifting its imposing front behind a mass of towers and domes to an altitude of probably near 3,000 feet and with a grandeur which the distance cannot dispel. Beyond it the scenery changes almost instantly, for it passes at once into the Great Basin, which, to this region, is as another world.

THE PERMIAN.

The idea of a terrace is not so typically represented in the Permian as it is in the superior formations. In many parts of the great stairway it clearly forms the lowest step; in others it forms one cliff with the Trias; in still others it is beveled off and covered with alluvium. On the whole it is more frequently presented as a distinct terrace. There is another qualification which requires some mention, because when we refer to the geological map to study the surface distribution of the strata, we should find some anomalies unless the point referred to were duly explained.

Wherever we encounter a cliff which discloses the upper Permian beds we find at the summit of the escarpment a band of pale-brown

sandstone of very coarse texture, often becoming a conglomerate. Its thickness is usually from 40 to 75 feet. In a few places it is wanting from its proper horizon, and in some others its thickness becomes more than 100 feet. But on the whole it is a remarkably persistent bed, and its persistence is all the more striking when we consider the coarseness of its texture; for no beds are so variable as the coarse ones. This member has been named by Powell the Shin-á-rump Conglomerate. The name Shinarnmp he also applies provisionally to a large group of beds in which the conglomerate is included.* For several years it was thought very probable that these beds were a part of the Triassic system, though no positive proof could be cited to sustain that presumption. In the summer of 1879 Mr. C. D. Walcott, of this survey, at length found some limestone bands near the base of Powell's Shinarnmp, which seem to establish pretty conclusively their Permian age. But the fossils so far discovered have only a small vertical range, and lie near the base of the group. Above them are many hundred feet of beds which yield no fossils at all. While some of them are unquestionably Permian, it still remains to find the horizon where the Permian ends and the Trias begins. The Trias is as destitute of fossils as the Permian, excepting, however, some which are useless for determining age. In cases like this the geologist finds himself in trouble. He is quite sure that he has beds of two distinct ages; and he must, for purposes of discussion, separate them somehow; if not by a natural and unmistakable dividing horizon, then by an arbitrary and provisional one, subject to amendment by future research. But he must look very carefully for a natural horizon of separation. His course of procedure would be somewhat as follows. Starting, for instance, with those strata which he was sure were Triassic, he would examine the beds downwards and finding no fossils would pay attention to their lithological characters. Finding no marked difference in the beds, and finding a strict parallelism or "conformity" in the several members, he would infer that they were deposited under conditions which were substantially identical throughout the period of deposition. But if he at length reached a stratum of very different character, say, for instance, after passing down through a great series of sandstones and shales, he came to a heavy mass of limestone or a bulky conglomerate, he would have found at last a "break" in the continuity or homogeneity of the group. Here, at last, is something which he can use. It may or it may not be synchronous with the dividing horizon used in Russia, England, or Kansas, but it is at all events not far from it; and it is something palpable, distinct, and recognizable by those who come after him. In this way Mr. Walcott

* For the information of the general reader it may be explained that when the geologist entering a new region discovers a well-defined group of beds which either yield no fossils at all or yield such as do not enable him to determine conclusively the age of the series, he does not assign the beds to any definite age or system, but gives them a purely provisional and local name which is dropped as soon as the true age is established.

PERMIAN BUTTE NEAR KANAB.

seized upon the Shinarump conglomerate as a divisional stratum between the Trias and Permian. But another perplexing question arose. To which of the two series should the conglomerate itself be assigned? And the question is not at first an easy one to answer. Immediately above it is a series of sandy shales such as beggar description on account of their gorgeous colors. Immediately below it is another series of sandy shales so similar to the one above that we never know which of the two we are looking at unless the conglomerate is in sight as a "bench-mark." Mr. Walcott settled the question (provisionally, of course) in the following way. The summit of the lower series shows in many places that immediately after it was deposited it was slightly eroded, and the contact of the conglomerate shows an "unconformity by erosion." The contact of the conglomerate with the upper series shows no such unconformity. Now, an unconformity means to the geologist a break in the continuity of deposition, and in the absence of reasons to the contrary, and with no better divisional criterion at hand, it may be used to separate two series of beds. He therefore assigned the conglomerate to the Trias, and the beds below he placed in the Permian.

Mr. Walcott's conclusion is no doubt the best which can be reached with our present knowledge, but it is very inconvenient and awkward to the geologist who is required to map the distribution of the strata and their topographical features. In all of the other formations each group forms its own terrace or series of terraces. As we descend them we find ourselves, when we reach the foot of the Eocene cliff, upon the summit of the Cretaceous. Reaching the foot of the Cretaceous cliffs, or slopes, we are upon the broad expanse of the Jurassic platform. Descending the Jurassic, we find the Trias coming out from the base of the Jurassic Cliffs; but when we descend the Vermilion Cliffs, we have not reached the Permian. The Trias is still beneath us, pushing out its basal member, the Shinarump conglomerate, clear to the crest-line of the Permian wall. In the Jurassic terrace and in its terminal cliff we find none but Jurassic strata. Similarly, also, on the cliffs and terrace platforms of the Cretaceous and Eocene; but the Permian terrace is everywhere sheeted over with a solitary stratum of the Trias. Somehow we cannot help thinking that the conglomerate has no business there, and that it ought to have been cut off at the base of the Vermilion Cliffs, or else it ought to be relegated to the Permian. In delineating the distribution of the formations by means of colors on the map, the ordinary practice would require us to extend the Trias to the brink of the Permian Cliffs, for in such delineations we only profess to show the surface exposures of the several groups; but this would confound the Permian terrace with the Trias, and obliterate the individuality of the former, whereas in the topography both are as distinct as land and water. To preserve this distinction the Shinarump is denoted by a special modification of the

LAND OF THE STANDING ROCKS.

color, which is to be interpreted as meaning an arbitrary subdivision of the Trias.

The Permian beds consist of sandy clay-shales in very many thin beds and a few thin beds of impure limestone. They are very striking on account of their dense, rich colors, which are sometimes also wonderfully delicate. They are belted in a surprising way. Horizontal streaks of chocolate, purple and red-brown are interstratified with violet, lavender, and white. Perhaps the richest tone is the red-brown, which is almost exactly like the color of the fumes of nitrous acid. Lower in the series are layers of a very peculiar shade of Indian red, alternating with grayish white. In the lower Trias and Permian the colors reach their climax. Surely no other region in the world, of which I have any knowledge, can exhibit anything comparable to it. Wonderfully even is the bedding. Thin layers may be traced for miles without showing any variation of thickness, color, or texture. In the escarpments the weathering has etched out the harder layers, leaving a line of shadow in the places of the softer layers, and this greatly emphasizes the stratification and gives it finer detail.

The Permian series is of considerable magnitude. In the western portion of the district its thickness is greater than elsewhere, reaching, probably, 1,400 feet, and possibly 1,600 feet, while in the vicinity of Kanab it is less than 1,000 feet. It gives rise to terminal cliffs, which in the northern part of the Uinkaret are from 800 to 1,000 feet high, while around Kanab their height seldom exceeds 500 or 600, and is often less than 300. But what they lack in magnitude they make up in refinement and beauty of detail and in sumptuous color. It is in the Permian that we find the most remarkable buttes. They are never large, but their resemblances to human architecture or works of design are often amazing. Very few Permian buttes are found in the Grand Cañon district, but further eastward, especially in the neighborhood of the junction of the Grand and Green Rivers, they are innumerable and of such definiteness that the geologist feels as if he were taxing the credulity of his hearers when he asks them to believe that they are the works of nature alone, and not of some race of Titans.

At the foot of the Permian cliffs begins the Carboniferous platform of the interior region of the Grand Cañon district. It stretches southward without visible bound, an almost featureless plain. It terminates beyond the San Francisco Mountains in the Aubrey Cliffs.

CHAPTER IV.

THE GREAT DENUDATION.

Before leaving the terraces we may with advantage pause to contemplate the great lesson in geology which they lay open to us. The subject of the lesson is EROSION. In a preliminary way we examined the type of it in the San Rafael district, which was briefly treated of in the first chapter. The same fact confronts us again in the Grand Cañon district. Here, however, the attendant facts are more complex, more difficult to grasp, and less easy to summarize. And vast as the erosion has been in the San Rafael it has been many times greater in the Grand Cañon district. In this discussion three classes of facts will be utilized: 1st, the stratification; 2d, the faults and flexures, or vertical displacements; 3d, the drainage. Each class furnishes its quota of evidence. Yet, so intimately are the several threads of argument interwoven, that it is almost impossible to separate them and view each independently of the others. Hence if the argument skips about from one to another before the one is fully developed, it is because no other method of treatment seems practicable.

The geologist seeing the series of Mesozoic and Eocene strata suddenly terminating in the terraces in the faces of the cliffs, would at once say that these strata formerly extended further southward. For he is ever mindful of the fact that in the lapse of long periods the rocks decay, and the rains and rills gather up the débris and carry it away. He also has had impressed upon his mind the general fact that the most rapid waste takes place on the edges of the strata exposed in vertical wall-faces. Every year the rains wash away something from the mural fronts. In a single year it may be a mere film, but in the lapse of thousands of centuries the amount whittled off becomes a vast aggregate. Like the motion of the fixed stars the change is not perceptible to a generation; but a million years would change the aspect of a denuding country as profoundly as they would change the aspect of the heavens. How long in terms of years this "Recession of the Cliffs" has been going on, the geologist does not know, though he presumes the period to have been certainly hundreds of thousands of years and very probably some millions. Feeling assured, then, that the terraces once projected further south, the inquiry arises, how far? Let me answer at once. They extended southward over the entire Grand Cañon district, into central Arizona, where they ended along the shore of the ancient mainland

from which their materials were in part derived. The distance of that shore-line, from the summit of the Pink Cliffs, is from 130 to 180 miles, and the width of the denuded district is from 120 to 140 miles. From the base of the Vermilion Cliffs the distance is 25 to 30 miles less. The area of maximum denudation is from 13,000 to 15,000 square miles, and the average thickness of the strata removed from it was about 10,000 feet.

The general reader will no doubt feel a strong aversion to such prodigious figures on their first presentation, and even the geologist whose credulity has been shocked so often that he has gotten used to it may wince once more. It is not from a love of the marvelous or dramatic; it is not without a full sense of the oppression of unaccustomed magnitudes that these assertions are made. They are made because they follow inexorably from the facts, and because they are necessary conclusions from clear premises. But, in order that the reader may not be obliged to carry a heavy burden of prejudice as he follows the various steps of the argument, it is well to anticipate some part of the discussion, and thus relieve him of a great part of the load at the outset, for it can be shown that the figures, while they are certainly very large, are in no respect abnormal, and in only one respect are they at all unusual.

Erosion, viewed in one way, is the supplement of the process by which strata are accumulated. The materials which constitute the stratified rocks were derived from the degradation of the land. This proposition is fundamental in geology—nay, it is the broadest and most comprehensive proposition with which that science deals. It is to geology what the law of gravitation is to astronomy. We can conceive no other origin for the materials of the strata, and no other is needed, for this one is sufficient and its verity a thousand times proven. Erosion and “sedimentation” are the two half phases of one cycle of causation—the debit and credit sides of one system of transactions. The quantity of material which the agents of erosion deal with is in the long run exactly the same as the quantity dealt with by the agencies of deposition; or, rather, the materials thus spoken of are one and the same. If, then, we would know how great have been the quantities of material removed in any given geological age from the land by erosion, we have only to estimate the mass of the strata deposited in that age. Constrained by this reasoning, the mind has no escape from the conclusion that the effects of erosion have indeed been vast. If, then, these operations have achieved such results, our wonder is transferred to the immensity of the periods of time required to accomplish them; for the processes are so slow that the span of a life-time seems too small to render those results directly visible. As we stand before the terrace cliffs and try to conceive of them receding scores of miles by secular waste, we find the endeavor quite useless. There is, however, one error against which we must guard ourselves. We must not conceive of erosion as merely sapping the face of a straight serried wall a hundred miles long; the locus of the wall

receding parallel to its former position at the rate of a foot or a few feet in a thousand years; the terrace back of its crest line remaining solid and uncut; the beds thus dissolving edgewise until after the lapse of millions of centuries their terminal cliffs stand a hundred miles or more back of their initial positions. The true story is told by the Triassic terrace ending in the Vermilion Cliffs. This terrace is literally sawed to pieces with cañons. There are dozens of these chasms opening at intervals of two or three miles along the front of the escarpment and setting far back into its mass. Every one of them ramifies again and again until they become an intricate net-work, like the fibers of a leaf. Every cañon wall, throughout its trunk, branches, and twigs, and every alcove and niche, becomes a dissolving face. Thus the lines and area of attack are enormously multiplied. The front wall of the terrace is cut into promontories and bays. The interlacing of branch cañons back of the wall cuts off the promontories into detached buttes, and the buttes, attacked on all sides, molder away. The rate of recession therefore is correspondingly accelerated in its total effect.

The largeness of the area presents really no difficulty. The forces which break up the rocks are of meteoric origin. The agency which carries off the débris is the water running in the drainage channels. Surely the meteoric forces which ravage the rocks of a township may ravage equally the rocks of the county or state, provided only the conditions are uniform over the larger and smaller areas. And what is the limit to the length of a stream, the number of its branches and rills, and to the quantity of water it may carry? It is not the area, then, which oppresses us by its magnitude, but the vertical factor—the thickness of the mass removed. But upon closer inspection the aspect of this factor also will cease to be forbidding.

For if the rate of recession of a wall fifty feet high is one foot in a given number of years, what will be (*ceteris paribus*) the rate of recession in a wall a thousand feet high? Very plainly the rate will be the same.* If we suppose two walls of equal length, composed of the same kind of rocks, and situated under the same climate, but one of them much higher than the other, it is obvious that the areas of wall-face will be proportional to their altitudes. In order that the rates of recession may be equal, the amount of material removed from the higher one must be double that removed from the other, and since the forces operating on the higher one have twice the area of attack, they ought to remove from it a double quantity, thus making the rates of recession equal. In the same way it

* The geologist will no doubt recognize that this is a simple and unqualified statement of a result which is in reality very complex, and sometimes requiring qualification. But a candid review of it in the light of established laws governing erosion will, I am confident, justify it for all purposes here contemplated. Though some qualifying conditions will appear when the subject is analyzed thoroughly, they are of no application to this particular stage of the argument. The statement is amply true for the proposition in hand, and it would be hardly practicable, and certainly very prolix, to give here the full analysis of it.

may be shown that the rate of recession is substantially independent of the magnitude of the cliff, whatever its altitude. Here a momentary digression is necessary.

We have hitherto spoken of the recession of cliffs as if it comprised the whole process of erosion, and have hardly alluded to the possible degradation of the flat surfaces of plateaus, terraces, and plains. Is it meant that there is no degradation of the horizontal surfaces, and that the waste of the land is wholly wrought by the decay of cliffs? Approximately that is the meaning, but some greater precision may be given to the statement.

Erosion is the result of two complex groups of processes. The first group comprises those which accomplish the disintegration of the rocks, reducing them to fragments, pebbles, sand, and clay. The second comprises those processes which remove the debris and carry it away to another part of the world. The first is called disintegration; the second, transportation. We need not attempt to study these processes in all their scope and relations, but we may advert only to those considerations which are of immediate concern. When the debris produced by the disintegration of rocks is left to accumulate upon a flat surface it forms a protecting mantle to the rocks beneath, and the disintegration is greatly retarded, or even wholly stopped. In order that disintegration may go on rapidly the debris must be carried away as rapidly as it forms. But the efficiency of transportation depends upon the declivity. The greater the slope the greater the power of water to transport. When the slope is greater than 30° to 33° ("the angle of repose") loose matter cannot lie upon the rocks, and shoots down until it finds a resting place. Hence the greater the slope the more fully are the rocks exposed to the disintegrating forces, and the more rapidly do they decay. This relation is universal, applying to all countries, and explains how it comes about that the attack of erosion is highly effective against the cliffs and steep slopes, and has but a trifling effect upon flat surfaces.

Reverting to the main argument, it now appears that erosion goes on by the decay and removal of material from cliffs and slopes; that the recession of high cliffs is as rapid as the recession of low ones, and that the quantity of material removed in a given time increases with the altitudes of the cliffs and slopes. In other words, the thickness of the strata removed in a given period of erosion should be proportional to the amount of *relief* in the profiles of the country. But in the Plateau country, and especially in the Grand Cañon district, these reliefs are very great. It is a region of giant cliffs and profound cañons, and, as will ultimately appear, it has been so during a very long stretch of geological time. The thickness of the strata removed from it is only proportional to the values of those conditions which favor rapid erosion. In the foregoing discussion it may appear that the area of denudation in the Grand Cañon district, though large, and the thickness of the strata denuded,

though very great, are not so excessive as to impose such a heavy burden upon the credulity as the first announcement of the figures portended.

In drawing inferences from the stratification the geologist is obviously bound to presume that the strata cut off in the terraces extended originally without a break until they reached some locality where the conditions of deposition failed. There are two, and only two, cases to be considered. The first case is that in which the extension is towards the shore line of the sea or lake in which the strata were deposited. At the shore line the strata, of course, end. In the present case no shore line could have existed southward, between the terraces and the Aubrey Cliffs, beyond the San Francisco Mountains. This is quite certain. We know the country so well that if there had been such a shore line in this interval its traces would have been discovered. We are quite sure that no such traces exist. The second case arises when sediments gradually thin out seawards and either vanish entirely or become so thin that their bulk is only nominal. We have already noted that the strata in the terraces (p. 79) grow thinner from west to east, and we know that the shore line of the marine basin, in which they were deposited, lay to the west and northwest. But here we are considering their extensions towards the south, and we already know that more than one hundred miles in that direction was another part of the shore line surrounding the basin trending northwest and southeast. Supposing strata to attenuate as they recede from, and to thicken as they approach, their shore lines, the case we are considering would perhaps be about as follows. Southward as far as the Grand Cañon, *i. e.*, half way or thereabout between the terraces and the southern shore, there might be some slight reason for inferring a very little attenuation, but beyond the Grand Cañon we might with equal reason infer a thickening. But this reasoning is obviously precarious, since the attenuation of strata as they approach or recede from shore lines does not follow any rigorous law—does not conform to any definite proportion. The best and apparently the only use we can make of it is rather of a negative character, leading us to infer merely that the stratification does not offer any reason for presuming that their original southward extensions were notably thinner than the portions preserved in the terraces. But there is another class of facts which is somewhat more to the purpose.

Of the denuded formations, some outliers are preserved at a considerable distance from the terraces. In the case of the Permian there is no doubt. The great Carboniferous platform of the Grand Cañon district is spotted in many places with Permian remnants, though rarely is the whole series preserved. One important remnant shows very nearly the whole series—at Mount Logan, in the Uinkaret Plateau, near the Grand Cañon. A conspicuous knoll, called the Red Butte, south of the Kaibab and about 30 miles from the San Francisco Mountains, also preserves a large part of the series, and innumerable patches of lower Permian beds are found on both sides of the great chasm. They show no attenuation

whatever, and indeed the Mount Logan mass is one of the thickest exposures of Permian beds thus far discovered. The former extension of this series over the entire district in full volume may therefore be regarded as proven. In the case of the Trias the evidence is from this point of view not quite so clear. South of the Vermilion Cliffs two or three remnants of it have been seen. One lies in the Grand Wash, a lateral valley joining the Colorado from the north just where it issues from the lower end of the Grand Cañon. Another has been recognized by Mr. Gilbert under the protection of lavas in the gigantic pile of San Francisco Mountain. But in neither of them is the entire Triassic series represented. These may be held to prove also the extension of the Trias over the entire district, and they give no sign of any attenuation in the beds preserved. But of the Jura and Cretaceous not a solitary outlier has yet been detected at any considerable distance from their principal terraces. As to these two later formations we can only reason from general considerations. The Jura and Trias, wherever found, appear to be merely different portions of one period of deposition; the physical conditions attending the accumulation of both appear to have been almost identical. Nor have we any reason to doubt that the same considerations apply to the Cretaceous and Eocene.

Still more forcibly is the same conclusion presented to us when we come to the study of the faults and flexures. The Grand Cañon district, the High Plateaus, and indeed the entire Plateau country, has been hoisted during Tertiary time far above the Sierra region lying west of it. At the western border of the plateaus are found gigantic faults where the strata have been sheared, and the country on the eastern side presents beds lying thousands of feet higher than the continuations of the same strata on the western side of the faults. These faults have been studied, and the amounts of the displacements are very approximately known. Owing to the remarkably clear manner in which all the facts are displayed, we are able, theoretically, to restore the country to the position and configuration existing before these beds were faulted and flexed. In this treatise, only the results can be given. The discussion and treatment of the problem is too purely technical for popular explanation. This restoration, so far as it has progressed, shows, without reasonable doubt, that throughout Mesozoic time, and very probably during a part of Tertiary time, the Carboniferous and Permian strata of the Grand Cañon district were horizontal and unbroken, the greatest possible discrepancies being very small. Thus another and important point is gained, for it supports the conclusion that the configuration of the Mesozoic sea-bottom, as well as its relations to the adjoining coasts, was, in the middle and southern portions of the Grand Cañon district, favorable to the reception of the same mass of sediments as we now find in the terraces of the High Plateaus.

The argument from the drainage system is, in principle, the same as that applied to the San Rafael Swell, though different in details. The

Colorado River and its tributaries entering the Grand Cañon had their origin at the time the country emerged from the waters and became land. This was in early Tertiary time. The rivers then must have had their courses laid out in conformity with the very feeble slopes of the newly risen country and in conformity with the surfaces of the newest strata. In the progress of Tertiary time this surface, originally as level as the prairies of Illinois, or more so, began to deform by unequal uplifting; but the rivers remained unchanged, and some of them are flowing to-day along the same routes as of old. Others have dried up, and the very strata which contained their troughs have been swept away. Those which remain occupy a very different relation to the strata from that which they held at first. The tributaries on the north side now run *against* the dips; those on the south side run *with* the dips, or nearly so. But the change has been in the attitudes of the strata and not in the positions of the rivers. And if we theoretically reconstruct the attitudes of the strata to conform to the courses of the drainage channels we reach a reconstruction exactly the same as that which we deduced from a restoration of the faults and flexures.

Thus the stratification, the outliers, the faults and flexures, and the drainage all yield their quotas of testimony to the great fact of denudation, and indicate that at some initial epoch the whole Mesozoic system and the lower Eocene once extended over the entire platform of the Grand Cañon district, with a thickness varying somewhat, no doubt, but on the whole differing but little, from that which we now find in the terraces of the High Plateaus. It is to be noted that the evidence of this former extension is more complete in the older formations than in the younger ones. In the case of the Permian it is quite perfect; in the case of the Trias very nearly so; in the case of the Jura it is very little less cogent than in that of the Trias; and in the Cretaceous practical certainty is exchanged for a very high degree of probability barely distinguishable from certainty. In the case of the Eocene there still remains a strong probability, but there is room for reservation. No reason to the contrary can be shown at present, and it may be regarded as one of those cases where "the tail goes with the hide"; but we cannot promise that future research will not develop reasons for a different conclusion. As the evidence now stands we are impelled to accept the full extension of the Eocene with some reservations, arising not from conflicting evidence, but from want of perfection in the evidence known to us.

BASE LEVELS OF EROSION.

In his popular narrative of Explorations of the Colorado River, Powell has employed the above term to give precision to an idea which is of much importance in physical geology. The idea in some form or other

has, no doubt, occurred to many geologists, but, so far as known to me, it had not before received such definite treatment nor been so fully and justly emphasized. It may be explained as follows.

Whenever a smooth country lies at an altitude but little above the level of the sea, erosion proceeds at a rate so slow as to be merely nominal. The rivers cannot corrade their channels. Their declivities are very small, the velocities of their waters very feeble, and their transporting power is so much reduced that they can do no more than urge along the detritus brought into their troughs from highlands around their margins. Their transporting power is just equal to the load they have to carry, and there is no surplus left to wear away their bottoms. All that erosion can now do is to slowly carry off the soil formed on the slopes of mounds, banks, and hillocks, which faintly diversify the broad surrounding expanse. The erosion is at its base-level or very nearly so. An extreme case is the State of Florida. All regions are tending to base-levels of erosion, and if the time be long enough each region will, in its turn, approach nearer and nearer, and at last sensibly reach it. The approach, however, consists in an infinite series of approximations like the approach of a hyperbola to tangency with its asymptote. Thus far, however, there is the implied assumption that the region undergoes no change of altitude with reference to sea-level; that it is neither elevated nor depressed by subterranean forces. Many regions do remain without such vertical movements through a long succession of geological periods. But the greater portion of the existing land of the globe, so far as known, has been subject to repeated throes of elevation or depression. Such a change, if of notable amount, at length destroys the pre-existing relation of a region to its base-level of erosion. If it is depressed it becomes immediately an area of deposition. If it is elevated new energy is imparted to the agents and machinery of erosion. The declivities of the streams are increased, giving an excess of transporting power which sweeps the channels clear of débris; corrasion begins; new topographical features are literally carved out of the land in high relief; long rapid slopes or cliffs are generated and vigorously attacked by the destroying agents; and the degradation of the country proceeds with energy.

It is not necessary that a base-level of erosion should lie at extremely low altitudes. Thus a large interior basin drained by a trunk river, across the lower portions of which a barrier is slowly rising, is a case in point. For a time the river is tasked to cut down its barrier as rapidly as it rises. This occasions slackwater in the courses above the barrier and stops corrasion, producing ultimately a local base-level. Another case is the Great Basin of Nevada. It has no outlet, because its streams sink in the sand or evaporate from salinas. Its valley bottoms are rather below base-level than above it. The general result of causes tending to bring a region to an approximate base-level of erosion is the obliteration of its inequalities.

During the progress of the great denudation of the Grand Cañon District the indications are abundant that its interior spaces have occupied for a time the relation of an approximate base-level of erosion. Throughout almost the entire stretch of Tertiary and Quaternary time the region has been rising, and in the aggregate the elevation has become immense, varying from 11,000 to 18,000 feet in different portions. But it seems that the movement has not been at a uniform rate. It appears to have proceeded through alternations of activity and repose. Whether we can point to more than one period of quiescence may be somewhat doubtful, but we can point decisively to one. It occurred probably in late Miocene or early Pliocene time, and while it prevailed the great Carboniferous platform was denuded of most of its inequalities, and was planed down to a very flat expanse. Since that period the relation has been destroyed by a general upheaval of the entire region several thousands of feet. The indications of this will appear when we come to the study of the interior spaces of the Grand Cañon District and of the Grand Cañon itself. To this study we now proceed.

CHAPTER V.

THE TOROWEAP AND UINKARET.

The present chapter will contain an account of a journey from the village Kanab to the Toroweap Valley, and a description of the middle portion of the Grand Cañon; also of the Uinkaret Plateau. Kanab is the usual rallying place and base of operations of the survey in these parts, being located on the only living stream between the Virgen and the Paria.

The first stage of the journey from Kanab to Pipe Spring is an easy one. It leads southwestward to a gap cut through the low Permian terrace, and out into the open desert beyond. The road, well traveled and easy, then turns westward and at length reaches the spring twenty miles from Kanab. Pipe Spring is situated at the foot of the southernmost promontory of the Vermilion Cliffs, and is famous throughout Southern Utah as a watering place. Its flow is copious and its water is the purest and best throughout that desolate region. Ten years ago the desert spaces outspreading to the southward were covered with abundant grasses, affording rich pasturage to horses and cattle. To-day hardly a blade of grass is to be found within ten miles of the spring, unless upon the crags and mesas of the Vermilion Cliffs behind it. The horses and cattle have disappeared, and the bones of many of the latter are bleached upon the plains in front of it. The cause of the failure of pasturage is twofold. There is little doubt that during the last ten or twelve years the climate of the surrounding country has grown more arid. The occasional summer showers which kept the grasses alive seldom come now, and through the long summer and autumn droughts the grasses perished even to their roots before they had time to seed. All of them belong to varieties which reproduce from seed, and whose roots live but three or four years. Even if there had been no drought the feeding of cattle would have impoverished and perhaps wholly destroyed the grass by cropping it clean before the seeds were mature, as has been the case very generally throughout Utah and Nevada.

Northeastward the Vermilion Cliffs extend in endless perspective towards Kanab, and beyond to the Paria. Northwestward, with growing magnitude, they extend towards the Virgen, ever forming a mighty background to the picture. To the southward stretches the desert, blank, lifeless, and as expressionless as the sea. For five or six miles south of the Pipe Spring promontory there is a gentle descending slope, and thence onward the surface feebly ascends through a distance of

thirty miles to the brink of the Grand Cañon. Thus the range of vision is wide, for we overlook a gentle depression of great extent. Though the general impression conveyed is that of a smooth or slightly modulated country, yet we command a far greater expanse than would be possible among the prairies. To the southeastward the Kaibab looms up, seemingly at no great distance, and to the southwestward the flat roof of Mornit Trumbull is more than a blue cloud in the horizon. Towards this latter mountain we take a straight course. The first few miles lie across drifting sands bare of all vegetation. The air is like a furnace, but so long as the water holds out the heat is not enervating and brings no lassitude. Everything is calm and still, except here and there a hot whirling blast which sends up a tall, slender column of dust diffusing itself in the air. At a slow pace the sand-hills at length are passed and we enter upon a hard, firm soil, over which we move more rapidly. Just here, and for three or four miles in either direction, the Permian terrace has been obliterated. It has been beveled off by erosion and buried beneath the wash brought down from the foot of the Vermilion Cliffs to the northward. But seven miles from Pipe Spring, the Permian terrace springs up out of the earth, scarped by its characteristic cliff. Stretching northwestward it increases in altitude, becoming at last 800 to 1,000 feet high. At its summit is seen the Shinarnmp conglomerate, of a pale brown color, and beneath are the gorgeous hues of the shales. Nothing can surpass the dense, rich, and almost cloying splendor of the red-brown seen in these shales. They suggest the color of old mahogany, but are much more luminous and quite uniform. Under them are belts of chocolate, slate, lavender, pale Indian red, and white. Very wonderful, too, is the evenness of the bedding, which is brought out in great clearness and sharpness by the etching of minute layers of clays holding selenite. Between the shales and overlying conglomerate careful scrutiny enables us to detect an unconformity by erosion without any unconformity of dip. As stated in a preceding chapter, Mr. Wolcott fixed provisionally the separating horizon between the Permian and Trias at this unconformable contact. .

Along the route the vegetation is scanty indeed. Several forms of cactus are seen looking very diseased and mangy, and remnants of low desert shrubs browsed to death by cattle. Yet strangely enough there is one plant and one alone that seems to flourish. It is the common sunflower (*Helianthus lenticularis*), found anywhere from Maine to Arizona, and seeming indifferent to the vicissitudes of climate.

About 18 miles from Pipe Spring the trail leads gently down into a broad shallow valley known as the Wild Band Pockets. The drainage from the fronts of the Permian cliffs now far to the northward here collects into a gulch, which gradually deepens and becomes a tributary of Kanab Cañon. In every stream-bed may be found many depressions which would hold water even though the sources of supply were cut off. This is as true of wet-weather channels as of perennial streams. After

the infrequent showers, and after the surface waters have ceased to run, the bed of the stream will still retain pools of water, provided the bottom of it is of a consistency which will prevent it from filtering away. To these pools the people of the west have given the name of "water-pockets." They are very common in the stream-beds which bear away the wash from the Permian and lower Triassic shales. These shales yield a very fine impervious clay, which forms an excellent "puddling" for water holes and basins. The Wild Band Pockets have received their name from the fact that they are the resort of bands of wild horses that roam over these deserts, far from human haunts, ranging from spring to spring, which they visit by stealth only at night, and never so long as they can find chance water in these and other pockets. Beyond the Wild Band Valley there is a slight ascent to a rocky platform, consisting of the summit beds of the Carboniferous. In the course of 20 miles we have crossed the entire Permian series, which now lies to the north of us. A few stunted cedars, most of which are dead or dying of drought, are scattered over this platform and give us until nightfall some slight shelter from the sun. It is as good a camping place as we are likely to find, and if we are fortunate enough to reach it after a copious shower, the hollows and basins in the flat rocks may contain a scanty supply of clear rain-water. It is a good locality, also, from which we may overlook the outspreading desert, which is not without charms, however repulsive in most respects.

To the northward rises the low escarpment of the Permian, forming a color picture which is somewhat indistinct through distance, but weird because of its strange colors and still stranger forms. Beyond and in the far distance rise the towering fronts of the Vermilion Cliffs, ablaze with red light from the sinking sun. To the eastward they stretch into illimitable distance, growing paler but more refined in color until the last visible promontory seems to merge its purple into the azure of the evening sky. Across the whole eastern quarter of the horizon stretches the long level summit of the Kaibab as straight and unbroken as the rim of the ocean. To the southwestward rises the basaltic plateau of Mount Trumbull, now presenting itself with somewhat imposing proportions. Around it a great multitude of basaltic cinder cones toss up their ominous black waves almost as high as Trumbull itself. Their tumultuous profiles and gloomy shades form a strong contrast with the rectilinear outlines and vivid colors of the region roundabout.

At dawn we move onward, reaching soon the summit of a hill which descends two or three hundred feet to a broad flat depression called the Wonsits Plain. It is a smooth and very barren expanse, dotted with a few moldering buttes of Upper Carboniferous rocks, now wasted to their foundations. The plain is about seven miles in width, and on the further side rises a low mesa of great extent capped with basalt. It is the Uinkaret. Beyond the nearer throng of basaltic cones Mount Trumbull rises with a striking aspect dominating strongly the entire western

landscape. The smaller cones are now seen to be very numerous, and all of them are apparently perfect in form, as if time had wrought no great ravage among them. The *lapilli* and *peperino* with which they are covered, has become dull red by the oxidation of the iron, and this peculiar color is easily recognized though the cones are still far away. Just before reaching the basaltic mesa we must make our choice between two routes to the Toroweap, one direct, the other very circuitous. No spring is to be found until we reach the further side of Mount Trumbull, but we know of a large water-pocket on this side, which has never been known to dry up. The spring water is sure to be good, but the water in the pocket will depend for its quality upon the length of time which has passed since the last heavy rain. Let us here choose the shorter one, and go to the water-pocket.

Ascending the mesa which rises abruptly about 200 feet above the Wonsits Plain, we find ourselves at once upon the basalt. The ground is paved with cinders and fragments half buried in soil, the débris of decaying lava sheets. These sheets are rarely of any great thickness, seldom exceeding 30 or 40 feet, and often much less, and none of the individual eruptions of lava seem to have covered any very great expanse. Probably the area covered by the largest would be less than a square mile. They show no perceptible differences in composition or texture, and all are basalts of the most typical variety—very black and ferruginous in the unweathered specimens and speckled with abundant olivine. At the time of eruption they appear to have been in a state of perfect liquidity, spreading out very thin and flowing rapidly and with ease. In none of them has erosion wrought much havoc, though here and there some local destruction has been effected, most conspicuously upon the edges of the principal mesa where the sheets have been undermined and their fragments scattered upon the plain below. The cones, which stand thick around us, are still in good preservation. They are of ordinary composition—mere piles of cinders thrown out of central vents and dropping around it. The fume and froth of the lava surfaces, the spongy inflated blocks, the lapilli and peperino, are not greatly changed, though all of them here show the oxidation of the iron. We wonder what their age may be; what time has elapsed since they vomited fire and steam. But there is no clew—no natural record by which such events can be calendared. Historically they have doubtless stood in perfect repose for very many centuries. Not a trace of activity of any kind is visible, and they are as perfectly quiescent as the dead volcanoes of the Auvergne or of Scotland. Geologically, they are extremely recent; yet even here where historic antiquity merges into geologic recency the one gives us no measure of the other.

Following a course which winds among the silent cones and over rough, flat surfaces of lava beds half buried in drifting sands, we at length reach the border of a slight depression, into which we descend. It is hardly noteworthy as a valley just here, and might be confounded

with any one of the innumerable shallow-water courses which occur round about; only when we look beyond we see it growing broader and much deeper. It is the head of the Toroweap. Upon its smooth bottom is a soft clayey soil, in which desert shrubs and stunted sage-brush grow in some abundance. Here and there a cedar, dwarfed indeed, but yet alive, displays a welcome green, and upon the valley slopes are a few sprays of grass. The valley bottom descends at a noticeable rate to the southward, and as we put the miles behind us we find the banks on either side rising in height, becoming steeper, and at last displaying rocky ledges. In the course of six or seven miles the left side has become a wall 700 feet high, while the other side, somewhat lower, is much broken and craggy. Huge piles of basalt lie upon the mesa beyond, sheet upon sheet, culminating in a cluster of large cones. At length the course of the valley slightly deflects to the left, and as we clear a shoulder of the eastern wall, which has hitherto masked its continuation, a grand vista breaks upon the sight. The valley stretches away to the southward, ever expanding in width; the walls on either side increase in altitude, and assume profiles of wonderful grace and nobility. Far in the distance they betoken a majesty and grandeur quite unlike anything hitherto seen. With vast proportions are combined simplicity, symmetry, and grace, and an architectural effect as precise and definite as any to be found in the terraces. And yet these walls differ in style from the Trias and Jura as much as the Trias and Jura differ from each other. In the background the vista terminates at a mighty palisade, stretching directly across the axis of vision. Though more than 20 miles distant it reveals to us suggestions of grandeur which awaken feelings of awe. We know instinctively that it is a portion of the wall of the Grand Cañon.

The western side of the valley is here broken down into a long slope descending from the cones clustered around the base of Mount Trumbull, and covered with broad flows of basalt. Turning out of the valley we ascend the lava bed, which has a very moderate slope, and about a mile from the valley we find the Witches' Water Pocket. In every desert the watering places are memorable, and this one is no exception. It is a weird spot. Around it are the desolate Phlegrean fields, where jagged masses of black lava still protrude through rusty, decaying cinders. Patches of soil, thin and coarse, sustain groves of cedar and piñon. Beyond and above are groups of cones, looking as if they might at any day break forth in renewed eruption, and over all rises the tabular mass of Mount Trumbull. Upon its summit are seen the yellow pines (*P. ponderosa*), betokening a cooler and a moister clime. The pool itself might well be deemed the abode of witches. A channel half-a-dozen yards deep and twice as wide, has been scoured in the basalt by spasmodic streams, which run during the vernal rains. Such a stream cascading into it has worn out of the solid lava a pool twenty feet long, nearly as wide, and five or six feet deep. Every flood

FIG. 7.—The Witches' Water Pocket.

fills it with water, which is good enough when recent, but horrible when old. Here, then, we camp for the night.

Filling the kegs at daylight, we descend again into the Toroweap and move southward. Our attention is strongly attracted by the wall upon the eastern side. Steadily it increases its mass and proportions. Soon it becomes evident that its profile is remarkably constant. We did not notice this at first, for we saw in the upper valley only the summit of the palisade; but as the valley cuts deeper in the earth the plan and system begin to unfold. At the summit is a vertical ledge, next beneath a long Mansard slope, then a broad plinth, and last, and greater than all, a long, sweeping curve, descending gracefully to the plain below. Just opposite to us the pediments seem half buried, or rather half risen out of the valley alluvium. But beyond they rise higher and higher until in the far distance the profile is complete. In this escarpment are excavated alcoves with openings a mile wide. As soon as we reach the first one new features appear. The upper ledge suddenly breaks out into a wealth of pinnacles and statues standing in thick ranks. They must be from 100 to 250 feet high, but now the height of the wall is more than a thousand feet, and they do not seem colossal. Indeed,

PANORAMA FROM MOUNT TRUMBULL.

Upper view looking East, with the Grand Cañon in the distance. Lower view looking down the Toroweap.

they look like a mere band of intricate fretwork—a line of balustrade on the summit of a noble façade. Between the alcoves the projecting pediments present gable-ends towards the valley plain. Yet whithersoever the curtain wall extends the same profile greets the eyes. The architect has adhered to his design as consistently and persistently as the builders of the Thebaid or of the Acropolis. As we pass alcove after alcove, and pediment after pediment, they grow loftier, wider and deeper, and their decoration becomes more ornate. At length we pass one which is vast indeed. It is recessed back from the main front three-fourths of a mile, and shows three sides of an oblong room with walls 1,800 feet in height. The fourth side is obliterated and the space opens into the broad valley. Wonderfully rich and profuse are the pinnacles and statues along the upper friezes. The fancy is kindled as the eye wanders through the inclosure.

We look across the valley, which is here three miles in width, and behold the other wall, which presents an aspect wholly different, but quite as interesting. The western wall of the Toroweap is here lower than the eastern, but still is more than a thousand feet high. The geologist soon surmises that along the valley bottom runs a fault which drops the country on the west several hundred feet, and the conjecture soon becomes certainty. Above and beyond the western escarpment is the platform of the Uinkaret Plateau. Upon its summit is a throng of large basaltic cones in perfect preservation. Streams of lava larger than any hitherto seen have poured from their vents, flooding many a square mile of mesa land, and in the wide alcoves they have reached the brink of the wall and cascaded over it. Still pouring down the long taluses they have reached the valley bottom below and spread out in wide fields, disappearing underneath the clayey alluvium, which has buried much of their lower portions. The appearance of these old lava cascades, a mile or more wide, a thousand feet high, and black as Erebus, is striking in the extreme. There are five of these basaltic cataracts, each consisting of many individual *coulées*. Between them the bold pediments of brightly-colored Carboniferous strata jut out into the valley.

At length we approach the lower end of the Toroweap. The scenery here becomes colossal. Its magnitude is by no means its most impressive feature, but precision of the forms. The dominant idea ever before the mind is the architecture displayed in the profiles. It is hard to realize that this is the work of the blind forces of nature. We feel like mere insects crawling along the street of city flanked with immense temples, or as Lemuel Gulliver might have felt in revisiting the capital of Brobdingnag, and finding it deserted. At the foot of the valley the western wall is nearly 1,500 feet high, the eastern about 2,000, and the interval separating them is about three miles. Suddenly they turn at right angles to right and left, and become the upper wall of the Grand Cañon of the Colorado. The Toroweap now opens into the main passageway of the great chasm. The view, however, is much obstructed.

FIG. 8.—The brink of the Inner Gorge at the foot of the Toroweap, looking east.

At the foot of the eastern gable is a medley of rocky ledges of red sandstone, while around the base of the western gable are large masses of basalt reaching more than half-way across the valley. In front rises a crater, which is about 600 feet high, seemingly a mere knoll in the midst of this colossal scenery. Beyond it, and five miles distant, rises the palisade which forms the southern upper wall of the chasm, stretching athwart the line of vision interminably in either direction. Its altitude is apparently the same as that of the palisade above us, and its profile is also identical. Climbing among the rocky ledges which lie at the base of the escarpment, we at length obtain a stand-point which enables us to gain a preliminary view of the mighty avenue. To the eastward it stretches in vanishing perspective forty miles or more. Between symmetric walls 2,000 feet high and five miles apart is a plain, which in

THE GRAND CAÑON AT THE FOOT OF THE TOROWEAP—LOOKING EAST.

comparison with its limiting cliffs might be regarded as smooth, but which in reality is diversified by rocky hummocks and basins, and by hillocks where patches of soil give life to scattered cedars and piñons. Of the inner chasm nothing as yet is to be seen. Moving outward into this platform we find its surface to be mostly bare rock, with broad shallow basins etched in them, which hold water after the showers. There are thousands of these pools, and when the showers have passed they gleam and glitter in the sun like innumerable mirrors. As we move outward towards the center of the grand avenue the immensity and beautiful proportions of the walls develop. The vista towards the east lengthens out and vanishes against the blue ramp of the Kaibab, which lies as a cloud upon the horizon. To the west the view is less symmetric and regular, and the eye wanders vaguely among cliffs and buttes of stupendous magnitude, displaying everywhere the profile with which we have become of late familiar. Much of the distance towards the west is obstructed by the crater, but the portions in view bewilder us by the great number of objects presented, and oppress us by their magnitudes. At a distance of about two miles from the base of the northern wall we come suddenly upon the inner chasm. We are not conscious of its proximity until we are within a few yards of it. In less than a minute after we have recognized the crest of the farther wall of this abyss we crane over its terrible brink and gaze upon the waters of the river full 3,000 feet below.

The scene before us is a type of the Grand Cañon throughout those portions which extend through the Kanab, Uinkaret, and Sheavwits Plateaus. The plan and section here presented are quite simple. They consist of a broad upper chasm from five to six miles in width with walls varying in altitude but little from 2,000 feet. Between these escarpments is a rocky plain, rough indeed, but in the overpowering presence of such walls seeming relatively smooth and uniform. In this floor is cut the inner chasm 3,000 feet deep and from 3,500 to 4,000 feet wide from crest to crest. The true profile will be best understood by consulting the diagram, Fig. 10, which is drawn to scale. The strata in which the chasm is excavated are all of Carboniferous age excepting three or four hundred feet at the bottom of the gorge. The strata beneath the Carboniferous are at present believed to be Lower Silurian, and their contact with the Carboniferous is unconformable, both by dip and by erosion. In the upper part of the palisades which form the wall of the upper chasm we find at the summit two series of limestones. The upper contains an abundance of siliceous matter, one portion of which is intimately disseminated through the mass while another portion is aggregated into myriads of cherty nodules varying from two to ten inches in diameter. The lower one is a purer limestone with few nodules. The cherty members form a nearly vertical band at the summit of the wall; the purer members form a Mansard slope beneath, covered with talus. The total thickness of the limestones is about 700 to 750 feet. Beneath them come

FIG. 9.—The brink of the Inner Gorge at the foot of the Toroweap, looking west.

sandstones a little more than 250 feet thick, which form everywhere a vertical plinth or frieze. They are very adamantine in texture, and one of the members, about 160 feet thick, is in every exposure seen to be uniformly cross-bedded. Under the cross-bedded sandstone is a mass of thinly bedded and almost shaly sandstones, having an aggregate thickness very closely approximating to 1,000 feet. They are of an intensely brilliant red color, but are, in greatest part, covered with a heavy talus of imperishable cherty nodules, fragments of the cross-bedded sandstones, and spalls of limestone shot down from above. The color of these is pale gray, with occasionally a yellowish or creamy tinge.

S G A

The brilliant red sandstones form the long curved slope which descends from the plinth of cross-bedded sandstone to the plain below.

The walls of the inner gorge have at the summit about 325 feet of hard sandstone of a brown-red color. Beneath the sandstone are about 1,800 feet of impure limestone in layers of the most massive description. Very few such ponderous beds of limestone are found in any part of the world. The color is deep red with a purplish tone, but the brilliancy of the coloring is notably weakened by weathering. Still lower are red-brown sandstones again having a dark and strong shade and lying in very massive beds. The strata forming the walls of the outer chasm from the summit to the plain below are designated the Aubrey group, and this is again subdivided at the base of the cross-bedded plinth into Upper and Lower Aubrey groups. The two subdivisions are believed to be the equivalents, in age, of the Coal Measures of Pennsylvania and England. The strata disclosed in the inner gorge correspond in age to the Lower Carboniferous of those countries, and are here termed the Red Wall group. Some uncertainty exists regarding the beds which lie at the base of the conformable series deep down in the chasm, but they are regarded at present as being just what they seem and just what they would naturally be inferred to be—a part of the Carboniferous system. Of the strata at the bottom of the cañon, we shall have more to say hereafter. They are regarded at present as being of Lower Silurian or Primordial age.

The observer who, unfamiliar with plateau scenery, stands for the first time upon the brink of the inner gorge, is almost sure to view his surroundings with commingled feelings of disappointment and perplexity. The fame of the chasm of the Colorado is great; but so indefinite and meager have been the descriptions of it that the imagination is left to its own devices in framing a mental conception of it. And such subjective pictures are of course wide of the truth. When he first visits it the preconceived notion is at once dissipated and the mind is slow to receive a new one. The creations of his own fancy no doubt are clothed with a vague grandeur and beauty, but not with the grandeur and beauty of nature. When the reality is before him the impression bears some analogy to that produced upon the visitor who for the first time

FIG. 10.—Section of the Grand Cañon at the foot of the Torowap Valley. 1, Upper Aubrey; 2, Lower Aubrey; 3, Red Wall; 4, Base of the Carboniferous; 5, Lower Silurian and Archean unconformable. Scale one mile to the inch.

enters St. Peter's Church at Rome. He expected to be profoundly awe-struck by the unexampled dimensions, and to feel exalted by the beauty of its proportions and decoration. He forgets that the human mind itself is of small capacity and receives its impressions slowly, by labored processes of comparison. So, too, at the brink of the chasm, there comes at first a feeling of disappointment; it does not seem so grand as we expected. At length we strive to make comparisons. The river is clearly defined below, but it looks about large enough to turn a village grist-mill; yet we know it is a stream three or four hundred feet wide. Its surface looks as motionless as a lake seen from a distant mountain-top. We know it is a rushing torrent. The ear is strained to hear the roar of its waters and catches it faintly at intervals as the eddying breezes waft it upwards; but the sound seems exhausted by the distance. We perceive dimly a mottling of light and shadow upon the surface of the stream, and the flecks move with a barely perceptible cloud-like motion. They are the fields of white foam lashed up at the foot of some cataract and sailing swiftly onward.

Perhaps the first notion of the reality is gained when we look across the abyss to the opposite crest-line. It seems as if a strong, nervous arm could hurl a stone against the opposing wall-face; but in a moment we catch sight of vegetation growing upon the very brink. There are trees in scattered groves which we might at first have mistaken for sage or desert furze. Here at length we have a stadium or standard of comparison which serves for the mind much the same purpose as a man standing at the base of one of the sequoias of the Mariposa grove. And now the real magnitudes begin to unfold themselves, and as the attention is held firmly the mind grows restive under the increasing burden. Every time the eye ranges up or down its face it seems more distant and more vast. At length we recoil, overburdened with the perceptions already attained and yet half vexed at the inadequacy of our faculties to comprehend more.

The magnitude of the chasm, however, is by no means the most impressive element of its character; nor is the inner gorge the most impressive of its constituent parts. The thoughtful mind is far more deeply moved by the splendor and grace of Nature's architecture. Forms so new to the culture of civilized races and so strongly contrasted with those which have been the ideals of thirty generations of white men cannot indeed be appreciated after the study of a single hour or day. The first conception of them may not be a pleasing one. They may seem merely abnormal, curious, and even grotesque. But he who fancies that Nature has exhausted her wealth of beauty in other lands strangely underestimates her versatility and power. In this far-off desert are forms which surprise us by their unaccustomed character. We find at first no place for them in the range of our conventional notions. But as they become familiar we find them appealing to the æsthetic sense as powerfully as any scenery that ever invited the pencil of Claude or of Turner.

The inner gorge, as we sit upon its brink, is indeed a mighty spectacle; but as we withdraw a little, it fades out of view, and, strangely enough, the sublimity of the scene is not very greatly impaired. It is, after all, a mere detail, and the outer chasm is the all-engrossing feature. On either side its palisades stretch away to the horizon. Their fronts wander in and out, here throwing out a gable, there receding into a chamber, or gaping widely to admit the entrance of a lateral chasm. The profile is ever the same. It has nothing in common with the formless, chaotic crags, which are only big and rough, but is definite, graceful, architectural, and systematic. The width of the space inclosed between the upper walls is one of the most essential elements of the grandeur. It varies from five to six miles. If it were narrower the effect would be impaired; nor could it be much wider without diluting and weakening the general effect. This proportion seems quite just. It is a common notion that the distinctive and overruling feature of the great chasm is its narrowness relatively to its depth. No greater mistake could be made. Our highest conceptions of grandeur are most fully realized when we can see the greatest mass. We must have amplitude in all of the three dimensions, distance, breadth, and depth, and that spectacle is in point of magnitude the grandest which has the three dimensions so proportioned and combined as to make the most of them. Another common and mistaken idea is that the chasm is pervaded by a deep, solemn gloom. The truth is almost the reverse. In the depths of the inner gorge there is a suggestion of gloom, but even in the narrower portions there is seldom less than sixty degrees of sky from crest to crest, and a hundred and sixty along the track of the river. In the outer chasm the scene is unusually bright. The upper half of the palisades have a pale, ashy, or pearl-gray color, which is very lustrous, and this sometimes gives place to a creamy or Naples yellow tint in the frieze of cross-bedded sandstone. The Lower Aubrey sandstones are bright red, but they are in great part masked by the talus shot down from the pale gray limestones above, and peep out in lustrous spots where the curtain of the talus is drawn aside. There is nothing gloomy about such colors. Under a burning sun that is rarely clouded they have a brilliancy seldom seen in any rocks, and only surpassed by the sugary whiteness of the Jurassic sandstone or the brilliant red of the Vermilion Cliffs.

Directly in the southward prolongation of the axis of the Toroweap Valley there stands a basaltic cinder-cone immediately upon the brink of the inner gorge. Its altitude above the surrounding plain is 580 feet. The summit is readily gained, and it is an admirable stand-point from which the entire panorama may be viewed. We named it Vulcan's Throne. To the eastward about forty miles of the main chasm are well in view. The altitude of the cone, though small in comparison with surrounding objects, is sufficient to bring into view about twelve miles of the opening of the inner gorge, while in the foreground its depths are seen. To the westward the scenery is much more broken and

diversified. The chasm is seen through the entire stretch in the Uinkaret Plateau and reaching a few miles into the Sheavwits. But about twenty miles westward it makes a southward turn and disappears. From the north the Toroweap Valley descends from near Mount Trumbull. It is cut down only to the base of the upper cañon wall and opens into the main chasm on the level of the plain above the inner gorge. There is reason to believe that at some prior epoch it was cut a few hundred feet deeper than its present floor, and was subsequently built up by many floods of basalt coming from the cones on the Uinkaret and by considerable quantities of alluvium washed from its cliffs and overlooking mesas. On the south side of the Grand Cañon is a valley quite the counterpart of the Toroweap. It enters the main chasm directly opposite to the Toroweap, so that the two form the arms of a transept, the main chasm being regarded as the nave. Vulcan's Throne is situated almost exactly at the intersection of the axes of nave and transept.

It would be difficult to find anywhere else in the world a spot yielding so much subject-matter for the contemplation of the geologist; certainly there is none situated in the midst of such dramatic and inspiring surroundings. The chasm itself, with its marvelous story of erosion, and the two lateral valleys adding their quotas of information are grand subjects indeed; but other themes are disclosed which are scarcely less surprising and suggestive. The cone stands immediately upon the line of a large fault. And never was a fault and its consequences more clearly displayed. The Toroweap fault is one of six which at wide intervals traverse the Grand Cañon district from north to south with a rude approximation to parallelism. It is the smallest of the six. Twenty miles north of the chasm no trace of it is visible. Its beginning there is small, but as it approaches the chasm it increases in the amount of displacement; and at the crossing of the river the shear or "throw" is between 600 and 700 feet. In the wall-face of the inner gorge it is disclosed as clearly as a draughtsman could delineate it on paper. The masses of horizontal limestones and sandstones, displaying their fretted edges and lines of bedding, advance from the eastward in the face of the wall until they reach the vertical fault plane. Then they "break joints" and drop at once six or seven hundred feet, and continue westward as before, but at a lower level. The whole topography goes with it. Looking beyond to the upper wall of the outer chasm the "jog" where the break occurs is plainly seen. The whole platform of the country is dropped to the westward. The plain between the upper palisades descends by a single step from east to west across the fault by an amount equal to the displacement, and the inner gorge and the whole chasm becomes by so much reduced in depth.

Excepting the dislocation itself, the faulting does not appear to have been accompanied by any injury to the strata. Not a trace of shattering, crumbling, or mashing of the beds is discernible. All looks as clean and sharp as if it had been cut with a thin saw and the smooth

LOOKING UP THE TOROWEAP VALLEY. LAVA CASCADES.

faces pressed neatly together. But the only attainable view of it is from the distance of a mile. Yet miles here are less than furlongs in other countries, and all details as well as broader features are upon the Brobdingnagian scale. What a nearer view might disclose is of course impossible to conjecture. The plane of the fault is about vertical, though there seems to be a slight inclination to the east, which may be apparent only and a result of perspective.

After a careful study of the surroundings of the fault, it becomes apparent that it is of recent occurrence in comparison with other events which have been in progress here. The tenor of all evidence bearing upon the subject goes to show that these faults were not suddenly produced by violent convulsions, but gradually developed through long stretches of time, and inch by inch or foot by foot. The Toroweap fault gives no evidence of being exceptional in this respect. Its recency is disclosed by many facts. It is seen that the amount of erosion in the face of the transverse "cliff of displacement" produced by the faulting is very small. This cliff has not receded from the fault plane to any considerable extent. Yet the giant palisades which wall the outer chasm have receded from the median line of the cañon more than two miles since the corrasion of the river laid bare the edges of their strata. It seems very plain that the outer chasm had been formed and attained very nearly its present condition before the fault started. But there is still more conclusive evidence of recency. At the foot of the southern palisade and at the jaws of the lateral valley are several basaltic craters. They look like mere bee-hives under the eaves of such an escarpment, though in truth they are four or five hundred feet high. From their vents streams of basalt are seen flowing down into the lateral valley across the fault plane, and clear to the brink of the inner abyss. The fault shears the lava floods as neatly as it does the Red Wall limestone.* Many other facts might be cited to the same purport, but this one is so conclusive that nothing further is necessary. We shall find similar evidences of recency when we come to the study of the great Hurricane fault.

Another subject which will awaken the enthusiasm of the geologist who visits this unique spot is the volcanic phenomena. Turning to the northwestward he beholds the heights of the Uinkaret. Upon its broad expanse stand many basaltic craters in perfect preservation. We know of about a hundred and fifty distinct cones in this plateau, included in the space which lies between the Grand Cañon and a limit forty miles north of it. But it is in the vicinity of the chasm that they cluster most thickly together and present the largest proportions. This part of the Uinkaret is thickly covered with basalt, above which rises the tumultu-

* It seemed to me, so far as could be judged from a distance, that a part of the faulting had been accomplished before the lava outflowed. The main fact, however, is clear that most of the faulting took place after the eruption, and of course settles the question of relative age or recency.

ous throng of craters. Very many wide and deep floods of basalt have poured over the edge of the plateau into the lower Toroweap Valley and upon the great esplanade of the cañon, 1,500 to 1,800 feet below, and, spreading out into wide fields, have reached the brink of the inner gorge. Pouring over its brink, the fiery cascades have shot down into the abyss and pursued their way many miles along the bed of the river. At one epoch they had built up the bed of the Colorado about 400 feet, but the river has seoured out its channel again and swept them all away, regaining its old level, and is now cutting the sandstones below. The spectacle of the lava floods descending from the Uinkaret, as seen from Vulean's Throne, is most imposing. It tells the story so plainly that a child could read and understand it. Compared with many classic volcanic regions the volcanism of the Uinkaret is a small affair. In those classic regions the mind does not come into direct contact with the enormity of the facts by a single glance of the eye. But here, if kind Asmodeus were to lift the basaltic roof of the plateau, we should see no more than we do now. The boldness of the picture is much increased by the pediments of Carboniferous strata projecting from the body of the plateau, showing the brilliant colors of the strata and their sharply-defined architecture, with the dark masses of basalt wrapping around them. Hard by, and almost within hail, is a superb gable projecting between two broad floods of lava, and so beautifully proportioned and richly colored that we cannot help wishing to transport it by magic to some more habitable region.

The Toroweap Valley has a significance to the geologist which might not be at once apparent to the tourist. Even the geologist would be slow to discern it unless familiar with cognate facts displayed in the country at large bordering the Grand Cañon. In the effort to interpret its meaning it becomes necessary to take a hasty view of one or two broad facts relating to the lateral drainage of the chasm. Upon the north side, in all the distance between the head of the Marble and the foot of the Grand Cañons, there is but one side cañon carrying drainage from distant regions. This single exception is Kanab Cañon. In this respect the Colorado is much like the lower courses of the Nile; and the cause is plainly the same. The region is too arid to sustain any living streams or even to keep open the conduits which in former periods might have sustained them. Yet upon the assumption that at some former period the climate was much more humid all analogy compels us to believe that the Colorado once received many tributaries which are now extinct, and upon examination we find good evidence that this was really the case. The Toroweap Valley is the modified channel of an ancient river. On the west side of the Uinkaret is another. A third is seen upon the south side of the Colorado, directly opposite the Toroweap; and a few others may be easily designated. It appears that all these rivers dried up before the inner gorge was excavated. For if they had continued to carry water we may be sure that they would have cut their chasms as

deep as the Grand Cañon itself—just as the Little Colorado, Kanab Creek, and Cataract Creek have done. For we have only to look at the great multitude of lateral chasms of the upper courses of the Colorado and of its forks, the Grand and Green, to be deeply impressed with the fact that so long as a tributary river carries, we will not say a living stream, but even occasional floods, its channel will be scoured down to the same level as the trunk river itself. It is apparent, then, that the Toroweap dried up before the cutting of the inner gorge of the Grand Cañon began, and hence we infer that the arid climate which caused it to dry up existed before the beginning of the inner gorge.

By the application of other homologous facts, and by the same method of reasoning, we infer that the outer chasm has also been excavated during the prevalence of an arid climate. The platform of country adjoining the cañon is at present devoid of lateral chasms, yet traces are often found of ancient channels which became dry at about the time the excavation of the outer cañon began, or very soon thereafter. They are cut to comparatively slight depths—from one hundred to three or four hundred feet. That they are not of recent origin is proved by the fact that they often have slopes away from the river, though it is clear that they formerly sloped towards it. In truth, the entire chasm betrays everywhere the continued action of an arid climate through the entire period of its formation. This arid period is limited, approximately, to Pliocene and Quaternary time. The general tenor of the facts is to the effect that the Miocene was a humid period and the Pliocene a dry one throughout the greater part of the West. This is one of the reasons which lead us to the very probable conclusion that the age of the Grand Cañon is not older than the beginning of Pliocene time. We might also draw a similar inference from a consideration of the enormous erosion which took place here before the excavation of the chasm was begun. The denudation of the Mesozoic system was an incomparably greater work, and yet that denudation could not have begun until the last strata (the Lower Eocene) were deposited. If these inferences are well founded, we may assign the greater part of Eocene and the whole of Miocene time for the principal denudation of the Mesozoic, and the Pliocene and Quaternary for the excavation of the entire cañon. The proportion thus suggested between the portions of the work done and the divisions of time required to accomplish them seems very fair and reasonable. But the strongest evidence of all it would be almost impossible to recite here in detail. In general terms, it may be characterized as that internal evidence which appears when a vast array of facts, at first disjointed and without obvious relation, are subsequently grouped aright into a coherent system. Each constituent fact is then seen to admit of one intelligible interpretation and no other; and each subsidiary proposition has an overwhelming justification and an evidence of verity far stronger than any which could be summoned if we endeavored to prove it independently.

Another question which the geologist asks here is, how happens it that the outer chasm is so broad while the inner one is so narrow? The outer chasm is five to six miles wide and 2,000 feet deep; the inner is about 3,500 feet wide and 3,000 feet deep. The disparity is great. We have seen enough to say at once that the widening of the outer chasm was effected by the recession of its cliffs. If the corrasion of the cañon went steadily onward without a halt or respite this disparity demands some explanation. Although we should expect less recession in the cliffs of the inner gorge than in those of the outer, we should not expect it to be so much less if the only variable concerned was length of time. We might explain it by assuming the rocks of the inner gorge to be much more obdurate than those above. This is true in part, but still the difference in this respect is insufficient. A much more satisfactory explanation is found in the supposition that the broad esplanade of the cañon between the upper palisades was an ancient base-level of erosion (page 101). We might imagine that when the Colorado had cut its channel down to that level, it had reached the limiting depth of corrasion for the time being. Then for a long period the palisades on either side wasted and receded from the river. At last another epoch of upheaval set in; the entire platform of the district was lifted several thousand feet; the power of the river to corrade was restored; and with comparative rapidity it sank the inner gorge. This becomes more than a mere guess when we take account of its relation to the general category of facts. Thus the great faults attest the fact that such an upheaval did occur; that it occurred, too, just at the time supposed; and that in amount it was quite equal and probably not more than equal to the amount required. Other evidences might also be produced, but they are too intricate to be discussed here.*

We leave the Toroweap Valley and the Grand Cañon, regretting that all its wonderful and instructive subjects should receive such brief notice. Retracing our steps up the Toroweap for a distance of about six miles, we at length select one of the great lava streams on the western side. Although quite steep, we may ascend it with the animals and packs without serious difficulty. At the end of an arduous climb upon the rugged slope, we find ourselves upon the platform of the Uinkaret. Around us are the old cinder-cones, most of which are of considerable dimensions. All of them have given vent to floods of basalt, which have

* I would, if space admitted, be glad to describe the remarkable phenomena presented in the wall of the inner gorge directly across from Vnlean's Throne. Upon the very brink stands the remnant of an old crater (cinder-cone) which has been partially undermined and destroyed by the sapping of the wall-face. A lateral gorge sets back into the esplanade from the river to a distance of a mile or more. In the wall-faces are disclosed the dikes through which the lava came up. Their "strike" is parallel to the course of the river, and perpendicular to the course of the Toroweap fault. Two of them protrude from the face of the wall about 600 to 1,400 feet below the summit; others protrude just at the brink. It is extraordinary that none are seen in the depths of the gorge. All of the attendant circumstances are surprising and curious, and yet it has frequently been noted that basalts habitually seek improbable places to erupt.

spread out thinly over extensive surfaces, but as the number of superposed sheets is considerable in this part of the plateau, the aggregate thickness, though somewhat roughly inferred, must be three or four hundred feet, and occasionally much more. There is not much to add to this description. The lava is apparently all of one kind, but some of it much older than other portions. In truth, it soon becomes apparent that the period of volcanic activity was a long one. A few miles from the point where we attained the summit of the plateau and in a north-west direction from it, we come upon the termination of a lava stream which has the appearance of being extremely recent. It looks as fresh as the emanations from Vesuvius or *Ætna* which have cutflowed within the last fifty years. Its surface is intensely black, and only here and there can we perceive that weathering has even impaired its freshness. Two miles away is seen the cone from which it emanated. The last eruptions from it have almost destroyed it, and melted down the greater part of its mass.

Skirting the edge of this lava-sheet, we find at the eastern base of Mount Logan a small spring, named the Oak Spring. It is a central point, from which the southern part of the plateau may be visited. There is another very small spring high up on the southwestern side of Mount Trumbull, and its waters have been brought down by a wooden pipe to the plain below, to supply the wants of a saw-mill. A third and much larger spring is found on the western side of the Uinkaret. These are the only available sources of supply, and each may be used as occasion requires for the examination of different parts of the plateau.

It will be necessary here to advert, with the greatest brevity, to the facts which the Uinkaret presents. Its most conspicuous subject is its volcanism. Almost as striking a subject is the great Hurricane fault, which forms the western boundary of the plateau. It also presents many other features of interest, but only the briefest allusion to them can be made here.

The lavas of the Uinkaret are all basaltic, and are quite typical of their class. They appear to vary but little in their constitution, and, so far as the cursory examination hitherto made indicates, the only differences are such as are incident to varying conditions under which they solidified after eruption, or to subsequent weathering. But it also appears that the period of volcanic activity has covered a considerable duration of geological time. There are old lavas and young lavas; perhaps we may say there are middle-aged lavas. The older lavas are presented in the largest masses, the largest individual *coulées*. Another noteworthy feature is that the oldest lavas are now found upon the summits of the loftiest portions of the plateau, while the younger lavas are found chiefly on the lower levels. It is well worth studying to see how this comes about. The facts and explanation are best presented in the fine mass of Mount Trumbull.

This mountain is in reality a gigantic butte; that is to say, a mass of

sensibly horizontal strata left by the denudation of the same beds from the platform surrounding. It is roofed over with a ponderous lava-cap, 500 to 800 feet thick. Under this lava-cap are seen in numerous places the horizontal edges of the strata, though the flanks of the mountain are so thickly covered with the *débris* formed by the disintegration of the basalts at the summit that these strata are for the most part buried. The beds beneath the lava are of Permian age, and it is evident that nearly the whole and possibly quite all of the Permian series remains in the mountain mass. That these basalts are very old is evident at a glance. The evidences of erosion are seen on every hand, and their aspect is strikingly different from that of the younger or middle aged basalts. On the summit of the mountain we find a cluster of old vents, from which a great part at least of these lavas were expelled. They are simply large craters torn down, dissolved and rotted away to their very roots by the ravage of time. It is evident, too, that the lava-cap itself is as a whole a mere remnant of a mass of superposed sheets which once extended much beyond the steep ledge which now limits them all around the mountain. The geologist draws his conclusion very quickly. These basalts in the lava-cap were extravasated at a time when the aspect of the surrounding country was very different from that which is now presented. At that time large bodies of Permian strata, since swept away extended continuously from the edges now exposed in the mountain flanks over spaces far away from it. We cannot indeed affirm that the great denudation had not already begun its havoc in the Permian, but we may be sure that it had not reached nearly its present stage. Mount Trumbull then is a remnant of a platform of lava-capped Permian beds, which was once of much greater extent. What was the extent of this platform at the time of the eruptions, we do not yet know, nor are we likely to know.

Around the base of the mountain on all sides the more recent craters are thickly clustered. The cones are for the most part in an admirable state of preservation; though here and there one may be found which has suffered considerable ravage. About two miles north of the base of Trumbull, especially, is an old cone, which has been laid open in such a manner as to disclose its interior structure very clearly. It is in all respects similar to the cones of the Mediterranean islands and countries. All of these craters were built at a much later period than the lava-cap of the mountain.

Mount Logan which lies near Trumbull to the southwestward, presents a similar state of affairs. It is a tabular mass capped with the more ancient basalts and with a great body of Permian beds beneath. South of Logan is another mass of ancient basalts, overlying Permian strata. Upon this southern table, however, are planted some well preserved craters which belong to the middle age of eruptions. Chief among these is Mount Emma, whose summit has been used as a primary topographical station. In general, these more ancient basalts

LOOKING NORTHEAST FROM MOUNT EMMA. MOUNTS LOGAN AND TRUMBULL IN THE DISTANCE.

descend the Queantoweap a few miles, and turning about we see the effects of the fault so plainly that a child could hardly mistake them. Right in the bottom of the valley is the lower branch with a displacement of about 1,300 feet. (Plate XXVIII). On the cliff to the right is a second smaller displacement of about 350 feet. Still farther to the right is a third of about 700 feet. Beyond the limits of the diagram is a fourth of about 500 feet. Twenty-five miles north of the Colorado the branches have disappeared and a single fault remains, with a shear of about 1,800 feet, and this amount continues nearly constant to the northward for a few miles. At length the fault rapidly increases. Seventy-five miles north of the river, and at the point where the Virgen River crosses it, the throw has become colossal. We stand upon the brink of the cliff with our feet upon the summit of the Carboniferous, and within musket range, 1,500 feet below, is the Jurassic white sandstone. Most of the Jurassic (800 feet), the whole of the Trias, which here has unusual thickness (2,800 or 2,900 feet), and the whole of the Permian and Permo-Carboniferous (1,200 or 1,300 feet), overlie the continuation of the strata on which we stand. The total throw is not far from 6,500 feet. Still northward extends the fault, and still it rapidly increases. At length it reaches a maximum displacement of more than 12,000 feet on the west side of the Markáguñt. Continuing northward it gradually decreases, and finally disappears near the western flank of the Tushar Mountains. The entire length of this fault is more than 200 miles. It is throughout its whole extent a primary geological and topographical feature of the region it traverses.

With regard to the age of the fault we have some information. It is not probable that all its portions were sheared simultaneously, and it is quite certain that its development was very slow and gradual and progressed through a long stretch of geological time. Confining our attention to that portion extending along the western flank of the Uinkaret, we find that nearly the whole displacement took place after the eruption of the oldest basalts, for the fault dislocates the most ancient lava beds. Whether some small portion of it may or may not have existed before these eruptions we cannot positively say, but no evidence of such priority has been noted. On the other hand, all the younger lavas, and some, at least, of the middle-aged lavas flowed across the fault and have not since been cut by it. But some of the middle-aged lavas appear to have suffered some dislocation. Hence we infer (1), That the age of this part of the Hurricane fault is not older than the beginning of the Pliocene. (2), That the displacement went on in harmony and conjunction with the volcanic activity. (3), That for a long period, historically speaking, it has been quiescent, and no movement has within the historic epoch taken place. (4), That the beginning of the Hurricane fault is older than the beginning of the Toroweap fault. These conclusions are of great importance in unraveling the history of the Grand Cañon district, for they at once become links in a chain of reasoning which, though complex, is very systematic and self-consistent. The faults are evidences of vertical

THE HURRICANE FAULT—IN THE QUEANTOWEAR VALLEY

CHAPTER VI.

THE KAIBAB.

The Kaibab is the loftiest of the four plateaus through which the the Grand Cañon extends. It is from 1,500 to 2,000 feet higher than the Kanab Plateau on the west, and from 2,500 to 4,000 feet higher than the Marble Cañon platform on the east. Its superior altitude is due wholly to displacement and not to erosion, for the strata upon its summit are the same as those upon the surfaces of the others. The upheaval has produced a sharp fault upon the western flank and a great monoclinal flexure upon its eastern flank. Throughout its entire platform the upper Carboniferous forms the surface. The Kaibab begins at the base of the Vermilion Cliffs near the little village of Paria; its northern extremity terminating in a slender cusp. Steadily widening and increasing very slowly in altitude, it reaches southward nearly a hundred miles to the Colorado River, where it attains a breadth of about 35 miles. Its highest point is about 9,280 feet above the sea, but most of its surface is between the altitudes of 7,800 and 9,000 feet.

When viewed from a distance its summit, projected against the sky, looks remarkably smooth and level. The slow increase of altitude from north to south may be discerned, and yet, in the absence of positive knowledge, it would be doubted by the careful observer whether this might not be due to perspective, and not real. When we actually visit the plateau we find the summit, seeming so smooth when viewed from afar, to be really very rugged. It is scored with a minutely ramified system of ravines, varying much in depth, but averaging about 300 feet in the heart of the plateau, and much deeper at the flanks. The whole summit is magnificently forest-clad. In this respect it is in strong contrast to the other plateaus, excepting, however, in a much inferior way, the higher parts of the Uinkaret. The other plateaus are formidable deserts; the Kaibab is a paradise. The forests are due to the superior altitude of the plateau, for the higher the altitude the moister the climate. Through the southern portion of the Kaibab is cut the finest portion of the Grand Cañon. Vast and imposing as is the scenery at the foot of the Toroweap, the scenery of the Kaibab is much more impressive. I propose in the present chapter to describe in familiar language a journey from Kanab to the Kaibab, and to the brink of the chasm, where we may contemplate its sublimity. Its geological significance must be discussed in a future work.

When the order is given to the party encamped at the little village of Kanab to prepare for the Kaibab, it is obeyed with more than ordinary

alacrity. From the chief of the party down to the herders and cooks all look forward to delightful wanderings in a cooler atmosphere, in open forests of noble pines and spruces, in flowery parks and winding avenues of rich verdure; to scenery the grandest of earth, and to communion with Nature in her noblest and loveliest moods. As we descend

FIG. 12.—Section across the Kaibab. *a*, *a'*, two branches of the West Kaibab fault. *b*, *b'*, two branches of the East Kaibab monocline. The vertical scale is double the horizontal.

FIG. 11.—Section across the Kaibab. The vertical scale is double the horizontal. *a*, West Kaibab fault. *b*, East Kaibab monocline. Length of section about 22 miles.

the village street and take a well-known by-path upon its outskirts, even the poor animals know whither they are going; they have traveled this trail before and remember the long, green bunch-grass and tufted "gramma," the lupine and wild oats. They trot along with nimble steps, requiring neither spur to urge nor rein to guide them. Before us is the Permian terrace rising by the gentlest of slopes; through it the Kanab River has cut a wide shallow gap in which stand several pretty little buttes carved sumptuously in the characteristic style of the formation. Beyond it the Carboniferous platform extends southward without visi-

KANAB CAÑON.

dry. I have known the temperature of the air to be 110° at midday, falling to 54° at midnight, without any general atmospheric disturbance or change except that which is due to nocturnal radiation. Upon the open desert the air is almost always still both by day and night. Rarely do the high winds blow over it in summer, and even strong breezes are uncommon except in the vicinity of great cliffs. At night the stillness is profound, and unless there is water or green vegetation hard by even the chirping of insects is unheard. The only sound which breaks upon the ear is the howling of the wolves that prowl about the camp and follow the tracks of the animals.

The hours roll quickly past as we move onward in the darkness. At length when the stars betoken the approach of midnight we halt, strip off the packs and saddles, hobble the animals and turn them loose to browse upon the scanty herbage. As the sun rises we are once more on the road. For ten miles from Kanab the trail descends by a hardly perceptible grade. Thence it ascends gradually at a rate of about 150 feet to the mile. From the fifteenth to the twenty-third mile it lies in shallow ravines but at last emerges upon more open ground. As we look back towards the north one of the grand spectacles of the Plateau country is disclosed to us. It is a view of the great cliffs which bound the southern terraces of the High Plateaus rising one above another. Nearly 10,000 feet of strata are exposed edgewise and occupy a line of frontage from 50 to 60 miles in length. It includes the stratigraphic series from the base of the Permian to the summit of the Lower Eocene. The view of the terraces from the north, from the brink of the Marká-gunt or Pamságunt, is of a very different character from this. There we see only their sloping summits with now and then a fragment of a mural front swung into view obliquely by the meandering course of the line of escarpment. Here the general line of frontage faces us while the terrace platforms are invisible. The view is a distant one but it requires great distance to bring into the field of vision an exposure so vast. At their nearest points the Permian is 15 miles away, the Trias 20, the Jura 35, and the Eocene more than 50. It should be observed that we are looking across the broad depression or concavity before spoken of, and that there is a gentle slope downwards for 15 miles to the base of the Permian, which lies 1,900 feet below us. Notwithstanding the distance there is no difficulty in distinguishing the different formations, and there would have been none even if we had never before seen the terraces, provided we had become familiar with their several aspects elsewhere; so strongly individualized are their colors and their sculptural forms. The Cretaceous alone is obscure, for in the portions of the terraces now in sight it does not form cliffs but breaks down in long slopes covered with soil and débris. If we were a few miles further west the Cretaceous cliffs of the Paria amphitheater would be visible and be as easily determined as the others, but here the Kaibab hides them. Although nearly 10,000 feet of strata are disclosed the summit of the Eocene lies only

5,000 to 5,500 feet above the base of the Permian, for in the interval between the two exposures the northward dip of the whole mass has carried down the Eocene about 5,000 feet.

From every elevated point on the Kanab Plateau this magnificent display is in full view. All of the broader geological facts in the stratigraphy and structure of the terraces may be distinctly seen and interpreted. The increment in thickness of the Mesozoic strata towards the west is very plain. The effect of the great Sevier fault, which comes down from the High Plateaus cutting across the terrace platforms and disappearing at the Pipe Spring promontory of the Vermilion Cliffs is now visible. By a simple reconstruction, lifting up the thrown side of this fault and gradually depressing the westward extension of the strata until the Eocene is horizontal, we can restore mentally the whole mass to the attitude it held in Eocene time, and it will require but a slight effort of the imagination to detect the original configuration which determined the present positions of the drainage basins of the Virgin, Kanab, and Paria Rivers. With a measured base-line extending east and west upon this part of the Kanab Plateau and with a fine large theodolite it would be practicable to make all the measurements necessary for determining the masses and positions of the several stratigraphic members with a degree of accuracy not materially less than could be obtained by studying them upon their own ground.

A spectacle of this kind is most impressive to the geologist. It brings into one view the coördinated results of observations made laboriously by months of travel and inspection in a very broad and rugged field. The great distances through which the eye can reach, the aspect of cliffs towering above and beyond cliffs, the great cumulative altitude thus attained, the immensity of the masses revealed, the boldness of form, the distinctness of the lines of stratification, and especially the brilliant coloring, subdued indeed, but also refined by the haze, give to the scene a grandeur which has few parallels.

But we turn our backs upon it, and pursue our way, pausing anon to look at it with a reverent enthusiasm. The daylight discloses the western Kaibab wall upon our left, only five or six miles distant, and our course changes from southeast to south parallel to its front. Already we feel the influences of its long spurs sweeping outward and dying away in the desert platform, and the trail becomes more hilly. Once or twice it takes us down into ravines which are the continuations of the great chasms which cut it to its base and recede far into its mass, winding out of sight in profound depths. Vegetation has made its appearance all around us, not abundantly, indeed, but sufficiently to contrast with the desolation behind us. Upon the crest of the plateau we can see the giant pines and spruces, and we covet their luxurious shade. Nearer, on either hand, are piñons and cedars, mountain mahogany and mesquite, with many low forms of desert shrubbery. Many species of cactus are seen, the most abundant of which are the opuntias,

or prickly pears. Of these there are four or five very common species. A large caetus "orchard" in blossom is a very beautiful sight, displaying flowers which, for beauty of form and richness of color, are seldom surpassed by the choicer gems of the conservatory. Nor is it less attractive when in the fruit, for it yields a multitude of purple "pears," which are very juicy and refreshing, and by no means contemptible in flavor. There is another form of cactus not likely to be forgotten by anybody who has once seen it, and which is very common on the Kanab desert. It is a stout bush, with many branches, growing from 3 to 6 feet high. The trunk and branches have a hard, woody core, and are thickly fringed with rows of strong, sharp spines which present a very ferocious aspect. Altogether it is the most truculent-looking member of the vegetable kingdom I happen to be acquainted with. Very common, too, are the yuccas, or "Spanish bayonets," which resemble, on a small scale, the noted agave or century plant. Another common species, somewhat resembling the last, bears a cluster of melon-like seed cases of the size and form of cucumbers, which the Indians gather and dry for food.*

At length the trail leads down into "Stewart's Cañon," a rather broad cañon valley descending towards us from the south. Just where we enter it it turns sharply to the west forming an elbow, and, sinking thence ever deeper into the earth through a course of fifteen miles, it opens at last into the heart of Kanab Cañon at a depth of nearly 3,500 feet. Here at the elbow it is comparatively shallow. Before reaching the elbow it runs northward close to the base of the Kaibab wall, which rises more than 1,200 feet above its floor, while the opposite or western side is only about 400 feet high. The difference in the altitudes of the two sides is accounted for by the presence of the West Kaibab fault, which runs at the foot of the wall throwing down the western side more than 800 feet. The geological relations here are worthy of some study. The presence of the fault is detected in a moment. Upon the western side the familiar grey limestones of the Upper Aubrey series form the entire wall. Upon the eastern side the same beds are seen upon the summit more than 800 feet higher than on the western side. Beneath them is the hard crossbedded sandstone, and still lower down the brilliant red sandy shales of the Lower Aubrey. Here, too, is seen that curious phenomenon so often presented in connection with the faults of this region. As the thrown beds approach the fault-plane they are turned *down*.

The trail leads southward up Stewart's Cañon with an ascent that is barely perceptible. We become conscious of increasing altitude indirectly by the barometer and by the change in the vegetation. The desert shrubs have mostly disappeared and given place to the scrub-oaks and weeds which are the unfailing indications of a cooler and

* The Mormons find a singular use for this plant. The pounded root, macerated in water, yields a thick liquid which makes a very good substitute for soap.

FIG. 13.—A fault with the beds flexed downward on the sunken side

moister climate. But the most welcome sight is the close proximity of the yellow pines which stand upon the summit above and even upon the lower platform which looks down from the western side. As yet they do not grow in the valley bottom. We have not quite reached the Kaibab, though it is close at hand—nay, we pass right by its open gates which seem to invite us in with a welcome; for at intervals of a mile or two we perceive upon the left the openings of grand ravines leading up to its platform and the moment we enter any one of them we are within the precincts of the great plateau. Stewart's Cañon is the trunk valley which receives the drainage of a considerable section of the western side of the Kaibab. The large affluents all come from the east, and none of any importance from the west.

About five miles from the point where the trail enters the valley we reach the first water—a tiny stream coming down from one of the great ravines and sinking into the soil a few hundred yards beyond the mouth. Halting long enough to allow the animals to drink we move onward about two miles further up the valley and make camp. Here there comes out of the Kaibab wall, about 300 feet above us, a stream of water as large as a man's body, which cascades down the rocks into a pool covering half an acre. There is a phenomenon here worth noticing, for it is a prelude to some very singular facts of general prevalence throughout this wonderful plateau. Across the outlet of the pool a rude dam has been constructed of stones and mud, which may be easily torn open or replaced. When the dam is open a large stream equal to the influx pours out of it, but the whole outpour sinks within a quarter of a mile. When the dam is closed the water in the pool rises about 15 inches and there is no outflow. All the water which enters the pool then sinks along the newly submerged margin. A stream of that size anywhere else in the Plateau country would ordinarily run eight or ten miles, and in a moist country would run much further. The sudden sinking of

streams is by no means rare, but is generally exceptional. On the Kaibab it is the rule. Upon all its broad expanse there is nothing which can be properly called a brook or a living stream. About a dozen springs are known, but their waters in every instance sink in the earth within a few hundred yards of their sources. And the "Big Spring" in Stewart's Cañon yields several times as much water as all the others put together. With this foreknowledge the prospects of water supply upon the Kaibab might seem discouraging; but we shall not suffer for the want of it.

Although the sun is still high when the Big Spring is reached nothing will be gained by prolonging the day's march, and it is well to take a look at the surroundings. In some way, without knowing exactly when and where, we seem to have gotten into the Kaibab; for around us is the sylvan scenery and a rolling country traversed by many valleys and ravines. True they are not the finest types, but when we recall the desert we have just left this place looks like a paradise. The barometer shows a considerable altitude, 7,850 feet, and the air though warm is not oppressive. As we approached the plateau from the desert and saw its battlements towering grandly in the distance and becoming hourly more grand, its level parapet retreating into indefinite distance in either direction, it never occurred to us that we might be spared the arduous struggle of scaling the wall, or, as a still more arduous alternative, the forcing of a rough passage through some narrow ravine for many miles. Yet we have reached this spot by a route as easy as an old-fashioned turnpike. In truth, the configuration of the southern part of the Kaibab could not be discerned as we approached it from the north. But putting together the observations of the journey it now becomes apparent that the surface of the Kanab Plateau rises quite rapidly towards the south, while the Kaibab gains in altitude much more slowly. Opposite our last camp the difference in the altitudes of the two plateaus is about 2,300 feet. Here it has greatly diminished, and the passage from one to the other is now partly by a very gentle inclined plane and partly by a fault. Fifteen miles further south the fault vanishes or becomes insignificant, and the passage is by a long slope.*

Resuming in the morning the route up Stewart's Cañon, a half-hour's ride brings us to an abandoned saw-mill. Here the trail leaves the valley which we have followed for ten miles and turns up into a large ravine coming from the east or southeast. It is much narrower than Stewart's Cañon, with very abrupt and almost precipitous walls about 600 feet

*It may be remarked here that every fault in the district is accompanied with a corresponding break in the topography. A cliff or steep slope is produced by it. I do not recall an instance where the lifted beds are planed off by erosion, so as to make a continuous level with the thrown beds. The cliffs generated by displacement have a character of their own which the experienced observer distinguishes quickly and confidently from cliffs of erosion. These characteristic breaks in the topography often betray a fault in localities where it would otherwise have been passed over unnoticed and unsuspected.

high. The traveler in the Plateau province learns to dread the necessity which compels him to thread a deep gorge or cañon unless he knows beforehand that there is a practicable and easy trail through it. If it is dry it is almost certain to be obstructed by fallen fragments and thickly set with scrub, its bottom scoured into rough gullies by the sudden floods; and half the time it will be necessary to mount the steep talus and thread it. If it carries a living stream the way is still worse, for in addition to the foregoing difficulties there are dangerous quicksands, impenetrable thickets of willows and thorny bushes, and the stream meanders from wall to wall. Unless there is a good trail the traveler will usually prefer to mount the cliff if a break can be found in it and seek the mesa above, and thus by a single struggle get rid of the miseries below. Not so the ravines of the Kaibab. Like the paths trodden by the pilgrims in the Delectable Mountains, "their ways are pleasantness and all their paths are peace." The ravine we enter is but a fair specimen of a vast number of them which cover the whole broad surface of the plateau with an infinite network of ramifications. Its bottom is covered with a carpet of grass and flowers growing rankly in a smooth firm soil free from rocks and undergrowth. Here and there a clump of aspens or noble pines grow in the way, but offer no obstacles to progress. It is like riding through a well-kept park or an avenue shaded by ancient trees. And now the effect of the absence of streams becomes manifest. Not only are there no perennial brooks, but there are no indications that even in the time of heavy rains or of melting snow any notable amount of water ever runs in these channels. Yet the Kaibab is a moist region. In summer the rains are frequent and in winter the snow lies deep. Horses cannot winter there and the wild cattle and deer, late in October, abandon it and seek the lower regions around its flanks. In all other plateaus or mountain ranges of equal mass and altitude and with equal precipitation there are many goodly streams and even large creeks fed throughout the summer by numberless copious springs; and when the snows melt these streams become raging torrents. But so rare are the indications of running water on the Kaibab even in times of melting snow, or of vernal rains, that whenever we find a "wash" we look at it with surprise as if it were a strange phenomenon demanding special explanation. But the very absence of these traces of running water constitutes one of the greatest charms of the Kaibab, for every ravine is as smooth as a lawn and carpeted with a turf of mountain grass, richly decked with flowers of rare beauty and luxuriance.

The great trees grow chiefly upon the main platform above us. Except in the highest part of the plateau they are mostly the yellow pine (*Pinus ponderosa*), but large spruces are also common (*Abies grandis*. *A. Engelmanni*). Upon the flanks of the ravines they also grow, the pines upon the northern or sunny side, the spruces upon the opposite. In the valley bottom they grow scatteringly, and for the most part leave

it quite open. Contrasting finely with these are the aspens (*Populus tremuloides*) with their white trunks and pale green foliage. Throughout the greater part of the plateau these three genera comprise all the arboreal forms that occur. But upon its borders we also find cedars, mountain mahogany, and piñon (*Juniperus occidentalis*, *Cercocarpus ledifolius*, and *Pinus edulis*), the latter, though classed as a pine, differing greatly from the more typical forms of the genus.

The ravine, where we enter its mouth, is about 600 feet in depth. The ascent is by a very easy grade, averaging about 100 feet to the mile. As we progress it becomes shallower, but not so rapidly as the grade might indicate, for the plateau summit also rises though at a lower grade towards the east. The course is a crooked one, but none the less agreeable on that account. Every traveler on foot or horseback has probably observed how tiresome and monotonous the road becomes when he can see it stretching away before him for many miles, and how charming the diversity when it wanders hither and thither. It matters not if the successive vistas are as much alike as two turns of a kaleidoscope, there is always an impatience to see what is beyond the next turn. So it is here. The successive scenes are much alike, or change by insensible degrees, but the same general view is presented in ever varying detail, and its subject matter is always delightful.

It is difficult to say precisely wherein the charm of the sylvan scenery of the Kaibab consists. We, who through successive summers have wandered through its forests and parks, have come to regard it as the most enchanting region it has ever been our privilege to visit. Surely there is no lack of beautiful or grand forest scenery in America, and it is a matter of taste what species of trees are the most pleasing. Probably few people would select the conifers and poplars as the highest types of arboreal beauty. I suspect that the charm consists in influences far more subtle than these outward forms. The delicious climate, neither cold nor hot, neither wet nor excessively dry, but always exhilarating, is a fundamental condition by virtue of which the body and mind are brought into the most susceptible mood. The ease with which we move from place to place, the absence of all anxiety or care for the three great requisites of camp life, fuel, water, and grass, are accessory conditions. The contrast of the desert with its fatigue, its numberless discomforts and privations, is still another. But the scenery is also very beautiful in itself. The trees are large and noble in aspect and stand widely apart, except in the highest parts of the plateau where the spruces predominate. Instead of dense thickets where we are shut in by impenetrable foliage, we can look far beyond and see the tree trunks vanishing away like an infinite colonnade. The ground is unobstructed and inviting. There is a constant succession of parks and glades—dreamy avenues of grass and flowers winding between sylvan walls, or spreading out in broad open meadows. From

June until September there is a display of wild flowers which is quite beyond description. The valley sides and platforms above are resplendent with dense masses of scarlet, white, purple, and yellow. It is noteworthy that while the trees exhibit but few species, the humbler plants present a very great number, both of species and genera. In the upper regions of the High Plateaus, Mr. Lester F. Ward collected in a single season more than 600 species of plants, and the Kaibab, though offering a much smaller range of altitude and climate, would doubtless yield as rich a flora in proportion to the diversity of its conditions.

At a distance of about eight miles from its mouth, the ravine we have chosen has become very shallow, with gently sloping sides. At length we leave it and ascend its right bank to the upper platform. The way here is as pleasant as before, for it is beneath the pines standing at intervals varying from 50 to 100 feet, and upon a soil that is smooth, firm, and free from undergrowth. All is open, and we may look far into the depths of the forest on either hand. We now perceive that the surface of the plateau undulates with rolling hills and gently depressed vales. These valleys are the ramifications of the drainage channels. They are innumerable and cover the entire surface of the plateau. The main channels all deepen as they approach the edges of the plateau and often attain considerable depth, becoming at the same time precipitous. The deepest are those which emerge near the elbow of Stewart's Cañon and north of that point. These attain depths exceeding a thousand feet. The ravines which descend towards the eastern flank of the plateau terminate in a different manner. In the interior parts of the plateau these drainage valleys are all shallow, rarely exceeding 300 or 400 feet in depth, and seldom abrupt.

After two or three miles upon the summit, the trail descends into another valley, whose course we follow upward for about seven miles. At the distance of about twenty miles from Stewart's Cañon, we find that we have gained about 1,200 feet of altitude, and that the vegetation has changed its aspect somewhat. The pines, though still abundant, are now in the minority, and the spruces and aspens greatly predominate. The spruces form dense thickets on either hand, which nothing but the direst necessity would ever induce us to enter. Of this genus there are several species, varying much in habit. The great firs (*Abies grandis*, *A. Engelmanni*) are exceedingly beautiful on account of their sumptuous foliage. But the most common species is a smaller one (*A. subalpina*), with a tall and straight trunk, its branches spreading only five or six feet. These trees cluster so thickly together that a passage through them is extremely difficult and sometimes impossible. But we are not constrained to attempt it, for they seldom grow in the valley bottoms. Again we leave the ravine, and winding about among the hills, passing from glade to glade, we at length find ourselves upon the summit of a long slope, which descends rapidly into a great park, the largest on the Kaibab. It has received the name of

DEMOTTE PARK.

DE MOTTE PARK.

Its length is about ten miles, its average width about two miles. It is a depressed area in the heart of the plateau and is on every side girt about by more elevated ground rising by strong slopes 300 or 400 feet above its floor. The borders and heights above are densely forest-clad, but not a tree stands within the park itself. Descending into its basin and proceeding southward about two and a half miles, we reach a little spring where we make camp. The distance from the Big Spring to Stewart's Cañon is about 26 miles by trail.

De Motte Park is eminently adapted to be the base of operations in a campaign of geological investigation upon the southern part of the Kaibab. It is a central locality from which we may radiate in any direction to the bounds of the plateau. Here the great bulk of the supplies may be deposited, and from the supply camp we make journeys with light packs for one, two, or three days, as it may suit our convenience, and to it we may return to fit out for another short trip. The circumstances which make the park so advantageous in this respect are worth reciting.

Notwithstanding the open character of the forest there are two difficulties in the way of travel on the Kaibab. The first has already been mentioned, scarcity of water. We know of about a dozen small springs, some of them conveniently located for the purposes of the explorer, others not. There is, however, another source of water supply which will be described presently. The second difficulty is the danger of getting lost and bewildered in the forest. This may seem to be a singular source of danger for an explorer, who of all men is bound to know his exact whereabouts at every step. But if he were to visit the Kaibab with that easy confidence and without a guide he would probably learn a severe lesson in less than a fortnight. The young Mormon herders who range over this region, and who follow a trail with the keen instincts of Indians, and with more than an Indian's intelligence, dread the mazes of the forest until they come to know them. Even the Indians who live and hunt there during the summer and autumn have sad tales about comrades lost when the snows came early and buried the trails so that they could not be followed. The bewildering character arises from the monotony of the scenery. There are hundreds of hills and gulches, but they all look alike. There are no landmarks except trees, which are worse than none at all. If you enter a ravine for the second time at a point other than that at which you first entered it you would probably fail to recognize it. As with the faces of the Chinese, no conscientious white man would be willing to swear that he had ever seen any particular one before. Yet the riddle of the Kaibab is soon solved, and, once read, all danger is over. If the traveler is lost there is an infallible clew. He must go at once to De Motte Park. But how shall he find the way? If he has reason to

suppose that he is within a dozen miles of it he has only to enter a main ravine and follow it to its head. This, however, does not apply to the portions of the plateau which lie more than five miles north of the park. The way may be long, but is easy and sure. A few ravines fade out before reaching the near neighborhood of the park. In that event take the nearest one on the right or left. All of them head upon the summit which looks down into the park. It is necessary, however, to keep to the *main* ravine and avoid its minor tributaries, and there is a criterion by which it may be distinguished. At the confluence of a lateral ravine the grade of the main ravine is always the less of the two.

Although this may seem to be nothing more than a trival bit of woodcraft, it really illustrates an important fact—the drainage system of a large portion of the Kaibab. The study of this drainage system will shed some light upon the geological history not only of the plateau itself, but of the region adjoining, and of the Grand Cañon.

The thought which must be predominant in the mind of one who for the first time enters the Kaibab is of the Grand Cañon. The fame of its grandeur is world-wide, and the desire to see it as it is grows stronger the nearer he approaches to it. This longing must be at least tempered if not wholly satisfied before the mind is in the humor to contemplate anything else. Our first expedition, then, shall be to the brink of the great abyss.

As the sun is rising and before his beams have penetrated to the bottom of the park we are on the way. On either hand is the forest, covering the slopes and the heights above, but ending suddenly at the foot of every incline. Before us to the southward stretches the open field with hardly an undulation. Six or seven miles away we can see the sylvan walls approach each other, leaving a narrow gateway between the tall spruces where the surface of the ground for a moment is sharply projected against the sky. The scene is, on the whole, a very attractive one. There is a great wealth of vegetation, somber indeed, and monotonous, but the darkness of the tone is suggestive of depth and richness of color. The only alleviating contrast is between the smooth expanse of the park and the myriads of sharp spikes which terminate the tree tops. The spirit of the scene is a calm, serene, and gente one, touched with a tinge of solemnity and melancholy.

About a mile from camp we came upon an object worthy of attention. It is rather a deep depression in the earth about 200 feet across and very nearly circular. Within it is a large pool of water. Its depth below the valley floor may be about 40 feet, and the depth of the water 5 or 6 feet in the middle. It is a fair specimen of a frequent occurrence upon the Kaibab. I have never seen them elsewhere, and the explanation is difficult. The interest lies in the mystery of their origin. In every day's ride we usually find three or four of them and sometimes more. Some of them contain water, but the majority do not. Some hold water throughout the year, some only in the early summer or until

autumn. They vary in size and depth very considerably. Some are as narrow as 20 feet; some are 300 to 400 feet across. The depths vary from a yard or two to a hundred feet. The form is crater-like—always approximately circular. They do not appear to occur under any special set of conditions. They are found as often upon the platforms as in the valleys and are not uncommon upon the slopes of the ravines. In a few instances traces may be seen of rain gullies or washes leading into them, but not often, and none have ever been noted leading out of them. Whatever running water may enter them sinks within their basins; but it is certain that many of them rarely receive any running water. In the cases of those which do the wonder is that they do not soon fill up with sand and silt, for the water generated by heavy rain storms or by melting snows, when sufficient in volume to run in a stream, is always thick with mud. The scarcity of running water on the Kaibab has been mentioned. Yet the precipitation is comparatively great and the evaporation small. It is apparent that all the water which falls upon its vast expanse, with the exception of a slight percentage evaporated, must sink into the earth, where it is doubtless gathered in subterranean drainage channels which open in the profound depths of the great amphitheaters of the Grand Cañon. In those depths are large creeks of perennial water issuing from the openings of those underground passages. This implies a system of subterranean rivulets, but it is not more wonderful than the endless caverns in the limestones of Kentucky and Indiana, and it is probably not upon so large a scale nor so greatly ramified. It also argues a high degree of permeability both in the upper strata and in the overmantling soil. The water sifts through them as easily as through sand, and rarely gathers into streams even in the most copious showers or most rapid melting of the snow. Whether these "lagoons" and "sink-holes," as we termed them, are the openings of pipes leading down into the subterranean rivers and kept open by a gradual solution of the limestone, it is difficult to say. There are some difficulties in the way of this theory.

Moving rapidly southward, at length we reach the Sylvan Gate at the lower end. Passing through we immediately find ourselves at the head of a second park very similar to De Motte's, but smaller, having a length of nearly three miles. It is named Little De Motte Park, and the Sylvan Gate occupies a divide between the two. It contains a large lagoon holding stagnant water. There is a chain of these parks reaching from the northern end of De Motte's southward, a distance of 25 miles, separated only by necks of forest.

Our first objective point is a spring situated in one of the large ravines which head in the heights overlooking these two parks. Without some foreknowledge of the way to reach it, or without a guide, it would be impossible to find it, and the same is true of any other spring on the summit, but with this foreknowledge we seek the southwestern border of Little De Motte and enter the timber. During half an hour there is

a miserable struggle with fallen trees and thick set branches of spruce and aspen, but at length the heights are gained, and we descend into a shallow ravine where the way is once more open. The winding glade with smooth bottom richly carpeted with long green grass, aglow with myriads of beautiful blossoms is before us, and the tall trees are on either hand. Soon it leads into a larger one, and this into another, until at last the main ravine is reached. Very sweet and touching now are the influences of nature. The balmy air, the dark and somber spruces, the pale green aspens, the golden shafts of sunlight shot through their foliage, the velvet sward—surely this is the home of the woodland nymphs, and at every turn of the way we can fancy we are about to see them flying at our approach, or peeping at us from the flowery banks.

By half-past ten the spring is reached. Next to the Big Spring, in Stewart's Cañon, it is the largest on the summit of the plateau. Here, too, is the only semblance of running water, for the stream flows a little more than half a mile before it sinks. The water is cold and delicious. It has a faint whitish cast like that which would be produced by putting a drop or two of milk into a bucket of pure water. I presume it is caused by a fine precipitate of lime. We called it the "Milk Spring." Pansing here for a hasty lunch, and to fill the kegs (for to-night we may make a "dry" camp), we push on. We climb out of the ravine, and in fact we only came here to obtain water, as it is the only place near to the point of destination at which water can be procured. The route now becomes more rugged, leading across ravines and over intervening ridges, crossing the grain of the country, so to speak. But it is not difficult, for the pines have taken place of the spruces, and where the pines predominate the forest is very open. For eight miles from the Milk Spring we continue to cross hills and valleys, then follow a low swale shaded by giant pines with trunks three to four feet in thickness. The banks are a parterre of flowers. On yonder hillside, beneath one of these kingly trees, is a spot which seems to glow with an unwonted wealth of floral beauty. It is scarcely a hundred yards distant; let us pluck a bouquet from it. We ride up the slope.

The earth suddenly sinks at our feet to illimitable depths. In an instant, in the twinkling of an eye, the awful scene is before us.

CHAPTER VII.

POINT SUBLIME.

Wherever we reach the Grand Cañon in the Kaibab it bursts upon the vision in a moment. Seldom is any warning given that we are near the brink. At the Toroweap it is quite otherwise. There we are notified that we are near it a day before we reach it. As the final march to that portion of the chasm is made the scene gradually develops, growing by insensible degrees more grand until at last we stand upon the brink of the inner gorge, where all is before us. In the Kaibab the forest reaches to the sharp edge of the cliff and the pine trees shed their cones into the fathomless depths below.

If the approach is made at random, with no idea of reaching any particular point by a known route, the probabilities are that it is first seen from the rim of one of the vast amphitheaters which set back from the main chasm far into the mass of the plateau. It is such a point to which the reader has been brought in the preceding chapter. Of course there are degrees in the magnitude and power of the pictures presented, but the smallest and least powerful is tremendous and too great for comprehension. The scenery of the amphitheaters far surpasses in grandeur and nobility anything else of the kind in any other region, but it is mere by-play in comparison with the panorama displayed in the heart of the cañon. The supreme views are to be obtained at the extremities of the long promontories, which jut out between these recesses far into the gulf. Towards such a point we now direct our steps. The one we have chosen is on the whole the most commanding in the Kaibab front, though there are several others which might be regarded as very nearly equal to it, or as even more imposing in some respects. We named it *Point Sublime*.

The route is of the same character as that we have already traversed—open pine forest, with smooth and gently rolling ground. The distance from the point where we first touched the rim of the amphitheater is about five miles. Nothing is seen of the chasm until about a mile from the end we come once more upon the brink. Reaching the extreme verge the packs are cast off and sitting upon the edge we contemplate the most sublime and awe-inspiring spectacle in the world.

The Grand Cañon of the Colorado is a great innovation in modern ideas of scenery, and in our conceptions of the grandeur, beauty, and power of nature. As with all great innovations it is not to be comprehended in a day or a week, nor even in a month. It must be dwelt upon and studied, and the study must comprise the slow acquisition of

14.—A lateral amphitheater of the second order.

the meaning and spirit of that marvelous scenery which characterizes the Plateau country, and of which the great chasm is the superlative manifestation. The study and slow mastery of the influences of that class of scenery and its full appreciation is a special culture, requiring time, patience, and long familiarity for its consummation. The lover of nature, whose perceptions have been trained in the Alps, in Italy, Germany, or New England, in the Appalachians or Cordilleras, in Scotland or Colorado, would enter this strange region with a shock, and dwell there for a time with a sense of oppression, and perhaps with horror.

THE PANORAMA FROM POINT SUBLIME—LOOKING EAST.

Whatsoever things he had learned to regard as beautiful and noble he would seldom or never see, and whatsoever he might see would appear to him as anything but beautiful and noble. Whatsoever might be bold and striking would at first seem only grotesque. The colors would be the very ones he had learned to shun as tawdry and bizarre. The tones and shades modest and tender, subdued yet rich, in which his fancy had always taken special delight, would be the ones which are conspicuously absent. But time would bring a gradual change. Some day he would suddenly become conscious that outlines which at first seemed harsh and trivial have grace and meaning; that forms which seemed grotesque are full of dignity; that magnitudes which had added enormity to coarseness have become replete with strength and even majesty; that colors which had been esteemed unrefined, immodest, and glaring, are as expressive, tender, changeful, and capacious of effects as any others. Great innovations, whether in art or literature, in science or in nature, seldom take the world by storm. They must be understood before they can be estimated, and must be cultivated before they can be understood.

It is so with the Grand Cañon. The observer who visits its commanding points with the expectation of experiencing forthwith a rapturous exaltation, an ecstasy arising from the realization of a degree of grandeur and sublimity never felt before, is doomed to disappointment. Supposing him to be but little familiar with plateau scenery, he will be simply bewildered. Must he therefore pronounce it a failure, an overpraised thing? Must he entertain a just resentment towards those who may have raised his expectations too high? The answer is that subjects which disclose their full power, meaning, and beauty as soon as they are presented to the mind have very little of those qualities to disclose. Moreover a visitor to the chasm or to any other famous scene must necessarily come there (for so is the human mind constituted) with a picture of it created by his own imagination. He reaches the spot, the conjured picture vanishes in an instant, and the place of it must be filled anew. Surely no imagination can construct out of its own material any picture having the remotest resemblance to the Grand Cañon. In truth the first step in attempting a description is to beg the reader to dismiss from his mind, so far as practicable, any preconceived notion of it.

Those who have long and carefully studied the Grand Cañon of the Colorado do not hesitate for a moment to pronounce it by far the most sublime of all earthly spectacles. If its sublimity consisted only in its dimensions, it could be sufficiently set forth in a single sentence. It is more than 200 miles long, from 5 to 12 miles wide, and from 5,000 to 6,000 feet deep. There are in the world valleys which are longer and a few which are deeper. There are valleys flanked by summits loftier than the palisades of the Kaibab. Still the Grand Cañon is the sublimest thing on earth. It is so not alone by virtue of its magnitudes, but by virtue of the whole—its *ensemble*.

The common notion of a cañon is that of a deep, narrow gash in the earth, with nearly vertical walls like a great and neatly cut trench. There are hundreds of chasms in the Plateau country which answer very well to this notion. Many of them are sunk to frightful depths and are fifty to a hundred miles in length. Some are exceedingly narrow, as the cañons of the forks of the Virgen, where the overhanging walls shut out the sky. Some are intricately sculptured, and illuminated with brilliant colors; others are picturesque by reason of their bold and striking sculpture. A few of them are most solemn and impressive by reason of their profundity and the majesty of their walls. But as a rule the common cañons are neither grand nor even attractive. Upon first acquaintance they are curious and awaken interest as a new sensation, but they soon grow tiresome for want of diversity, and become at last mere bores. The impressions they produce are very transient, because of their great simplicity and the limited range of ideas they present. But there are some which are highly diversified, presenting many attractive features. These seldom grow stale or wearisome, and their presence is generally greeted with pleasure.

It is perhaps in some respects unfortunate that the stupendous pathway of the Colorado River through the Kaibabs was ever called a cañon, for the name identifies it with the baser conception. But the name presents as wide a range of signification as the word house. The log cabin of the rancher, the painted and vine-clad cottage of the mechanic, the home of the millionaire, the places where parliaments assemble, and the grandest temples of worship, are all houses. Yet the contrast between Saint Mary's and the rude dwelling of the frontiersman is not greater than that between the chasm of the Colorado and the trenches in the rocks which answer to the ordinary conception of a cañon. And as a great cathedral is an immense development of the rudimentary idea involved in the four walls and roof of a cabin, so is the chasm an expansion of the simple type of drainage channels peculiar to the Plateau country. To the conception of its vast proportions must be added some notion of its intricate plan, the nobility of its architecture, its colossal buttresses, its wealth of ornamentation, the splendor of its colors, and its wonderful atmosphere. All of these attributes combine with infinite complexity to produce a whole which at first bewilders and at length overpowers.

From the end of Point Sublime, the distance across the chasm to the nearest point in the summit of the opposite wall, is about 7 miles. This, however does not fairly express the width of the chasm, for both walls are recessed by wide amphitheaters, setting far back into the platform of the country and the promontories are comparatively narrow strips between them. A more correct statement of the general width would be from 11 to 12 miles. This must dispose at once of the idea that the chasm is a narrow gorge of immense depth and simple form. It is somewhat unfortunate that there is a prevalent idea that in some way an

THE PANORAMA FROM POINT SUBLIME—LOOKING SOUTH.

essential part of the grandeur of the Grand Cañon is the narrowness of its defiles. Much color has been given to this notion by the first illustrations of the cañon from the pencil of Egloffstein in the celebrated report of Lieutenant Ives. Never was a great subject more artistically misrepresented or more charmingly belittled. Nowhere in the Kaibab section is any such extreme narrowness observable, and even in the Uinkaret section the width of the great inner gorge is a little greater than the depth. In truth a little reflection will show that such a character would be inconsistent with the highest and strongest effects. For it is obvious that some notable width is necessary to enable the eye to see the full extent of the walls. In a chasm one mile deep, and only a thousand feet wide, this would be quite impossible. If we compare the Marble Cañon or the gorge at the Toroweap with wider sections it will at once be seen that the wider ones are much stronger. If we compare one of the longer alcoves having a width of 3 or 4 miles with the view across the main chasm the advantage will be very decidedly with the latter. It is evident that for the display of wall surface of given dimensions a certain amount of distance is necessary. We may be too near or too far for the right appreciation of its magnitude and proportions. The distance must bear some ratio to the magnitude. But at what precise limit this distance must in the present case be fixed is not easy to determine. It can hardly be doubted that if the cañon were materially narrower it would suffer a loss of grandeur and effect.

The length of cañon revealed clearly and in detail at Point Sublime is about 25 miles in each direction. Towards the northwest the vista terminates behind the projecting mass of Powell's Plateau. But again to the westward may be seen the crests of the upper walls reaching through the Kanab and Uinkaret Plateaus, and finally disappearing in the haze about 75 miles away.

The space under immediate view from our stand-point, 50 miles long and 10 to 12 wide, is thronged with a great multitude of objects so vast in size, so bold and majestic in form, so infinite in their details, that as the truth gradually reveals itself to the perceptions it arouses the strongest emotions. Unquestionably the overruling feature is the colossal wall on the opposite side of the gulf. Can mortal fancy create a picture of a mural front a mile in height, 7 to 10 miles distant, and receding into space indefinitely in either direction? As the mind strives to realize its proportions its spirit is broken and its imagination completely crushed. If the wall were simple in its character, if it were only blank and sheer, some rest might be found in contemplating it; but it is full of diversity and eloquent with grand suggestions. It is deeply recessed by alcoves and amphitheaters receding far into the plateau beyond, and usually disclosing only the portals by which they open into the main chasm. Between them the promontories jut out, ending in magnificent gables with sharp mitered angles. Thus the wall rambles in and out, turning numberless corners. Many of the angles are acute and descend as sharp

spurs like the forward edge of a plowshare. Only those alcoves which are directly opposite to us can be seen in their full length and depth. Yet so excessive, nay so prodigious, is the effect of foreshortening, that it is impossible to realize their full extensions. We have already noted this effect in the Vermilion Cliffs, but here it is much more exaggerated. At many points the profile of the façade is thrown into view by the change of trend, and its complex character is fully revealed. Like that of the Vermilion Cliffs, it is a series of many ledges and slopes, like a molded plinth, in which every stratum is disclosed as a line or a course of masonry. The Red Wall limestone is the most conspicuous member, presenting its vertical face eight hundred to a thousand feet high, and everywhere unbroken. The thinner beds more often appear in the slopes as a succession of ledges projecting through the scanty talus which never conceals them.

Numerous detached masses are also seen flanking the ends of the long promontories. These buttes are of gigantic proportions, and yet so overwhelming is the effect of the wall against which they are projected that they seem insignificant in mass, and the observer is often deluded by them, failing to perceive that they are really detached from the wall and perhaps separated from it by an interval of a mile or two.

At the foot of this palisade is a platform through which meanders the inner gorge in whose dark and somber depths flows the river. Only in one place can the water surface be seen. In its windings the abyss, which holds it extends for a short distance towards us and the line of vision enters the gorge lengthwise. Above and below this short reach the gorge swings its course in other directions and reveals only a dark, narrow opening, while its nearer wall hides its depths. This inner chasm is 1,000 to 1,200 feet deep. Its upper 200 feet is a vertical ledge of sandstone of a dark rich brownish color. Beneath it lies the granite of a dark iron-gray shade, verging towards black, and lending a gloomy aspect to the lowest deeps. Perhaps a half mile of the river is disclosed. A pale, dirty red, without glimmer or sheen, a motionless surface, a small featureless spot, inclosed in the dark shade of the granite, is all of it that is here visible. Yet we know it is a large river, a hundred and fifty yards wide, with a headlong torrent foaming and plunging over rocky rapids.

A little, and only a little, less impressive than the great wall across the chasm are the buttes upon this side. And such buttes! All others in the West, saving only the peerless Temples of the Virgen, are mere trifles in comparison with those of the Grand Cañon. In nobility of form, beauty of decoration, and splendor of color, the Temples of the Virgen must, on the whole, be awarded the palm; but those of the Grand Cañon, while barely inferior to them in those respects, surpass them in magnitude and fully equal them in majesty. But while the Valley of the Virgen presents a few of these superlative creations, the Grand Cañon presents them by dozens. In this relation the comparison would be analogous

THE PANORAMA FROM POINT SUBLIME—LOOKING WEST.

to one between a fine cathedral town and a metropolis like London or Paris. In truth, there is only a very limited ground of comparison between the two localities, for in style and effects their respective structures differ as decidedly as the works of any two well developed and strongly contrasted styles of human architecture.

Whatsoever is forcible, characteristic, and picturesque in the rock-forms of the Plateau country is concentrated and intensified to the uttermost in the buttes. Wherever we find them, whether fringing the long escarpments of terraces or planted upon broad mesas, whether in cañons or upon expansive plains, they are always bold and striking in outline and ornate in architecture. Upon their flanks and entablatures the decoration peculiar to the formation out of which they have been carved is most strongly portrayed and the profiles are most sharply cut. They command the attention with special force and quicken the imagination

FIG. 15.—Pinnacles on the brink.

with a singular power. The secret of their impressiveness is doubtless obscure. Why one form should be beautiful and another unattractive; why one should be powerful, animated, and suggestive, while another is meaningless, are questions for the psychologist rather than the geologist. Sufficient here is the fact. Yet there are some elements of impressiveness which are too patent to escape recognition. In nearly all buttes there is a certain *definiteness* of form which is peculiarly emphatic, and this is seen in their profiles. Their ground-plans are almost always indefinite and capricious, but the profiles are rarely so. These are usually composed of lines which have an approximate and sometimes

a sensibly perfect geometrical definition. They are usually few and simple in their ultimate analysis, though by combination they give rise to much variety. The ledges are vertical, the summits are horizontal, and the taluses are segments of hyperbolas of long curvature and concave upwards. These lines greatly preponderate in all cases, and though others sometimes intrude they seldom blemish greatly the effects produced by the normal ones. All this is in striking contrast with the ever-varying, indefinite profiles displayed in mountains and hills or on the slopes of valleys. The profiles generated by the combinations of these geometrical lines persist along an indefinite extent of front. Such variations as occur arise not from changes in the nature of the lines, but in the modes of combination and proportions. These are never great in any front of moderate extent, but are just sufficient to relieve it from a certain monotony which would otherwise prevail. The same type and general form is persistent. Like the key-note of a song, the mind carries it in its consciousness wherever the harmony wanders.

The horizontal lines or courses are equally strong. These are the edges of the strata, and the deeply eroded seams where the superposed beds touch each other. Here the uniformity as we pass from place to place is conspicuous. The Carboniferous strata are quite the same in every section, showing no perceptible variation in thickness through great distances and only a slight dip.

It is readily apparent, therefore, that the effect of these profiles and horizontal courses so persistent in their character is highly architectural. The relation is more than a mere analogy or suggestion; it is a vivid resemblance. Its failure or discordance is only in the ground plan, though it is not uncommon to find a resemblance, even in this respect, among the Permian buttes. Among the buttes of the Grand Cañon there are few striking instances of definiteness in ground plan. The finest butte of the chasm is situated near the upper end of the Kaibab division; but it is not visible from Point Sublime. It is more than 5,000 feet high, and has a surprising resemblance to an Oriental pagoda. We named it Vishnu's Temple.

On either side of the promontory on which we stand is a side gorge sinking nearly 4,000 feet below us. The two unite in front of the point, and, ever deepening, their trunk opens into the lowest abyss in the granite at the river. Across either branch is a long rambling mass, one on the right of us the other on the left. We named them the Cloisters. They are excellent types of a whole class of buttes which stand in close proximity to each other upon the north side of the chasm throughout the entire extent of the Kaibab division. A far better conception of their forms and features can be gained by an examination of Mr. Holmes's panoramic picture than by reading a whole volume of verbal description. The whole prospect, indeed, is filled with a great throng of similar objects, which, as much by their multitude as by their colossal size, confuse the senses; but these, on account of their proximity, may be most

VISHNU'S TEMPLE—HEAD OF THE GRAND CAÑON.

satisfactorily studied. The infinity of sharply defined detail is amazing. The eye is instantly caught and the attention firmly held by its systematic character. The parallelism of the lines of bedding is most forcibly displayed in all the windings of the facades, and these lines are crossed by the vertical scorings of numberless water-ways. Here, too, are distinctly seen those details which constitute the peculiar style of decoration prevailing throughout all the buttes and amphitheaters of the Kaibab. The course of the walls is never for a moment straight, but extends as a series of cusps and re-entrant curves. Elsewhere the reverse is more frequently seen; the projections of the wall are rounded and are convex towards the front, while the re-entrant portions are cusp-like recesses. This latter style of decoration is common in the Permian buttes and is not rare in the Jurassic. It produces the effect of a thickly set row of pilasters. In the Grand Cañon the reversal of this mode produces the effect of panels and niches. In the western Cloister may be seen a succession of these niches, and though they are mere details among myriads, they are really vast in dimensions. Those seen in the Red Wall limestone are over 700 feet high, and are overhung by arched lintels with spandrels.

As we contemplate these objects we find it quite impossible to realize their magnitude. Not only are we deceived, but we are conscious that we are deceived, and yet we cannot conquer the deception. We cannot long study our surroundings without becoming aware of an enormous disparity in the effects produced upon the senses by objects which are immediate and equivalent ones which are more remote. The depth of the gulf which separates us from the Cloisters cannot be realized. We crane over the brink, and about 700 feet below is a talus, which ends at the summit of the cross-bedded sandstone. We may see the bottom of the gorge, which is about 3,800 feet beneath us, and yet the talus seems at least half way down. Looking across the side gorge the cross-bedded sandstone is seen as a mere band at the summit of the Cloister, forming but a very small portion of its vertical extent, and whatever the reason may conclude, it is useless to attempt to persuade the imagination that the two edges of the sandstone lie in the same horizontal plane. The eastern Cloister is nearer than the western, its distance being about a mile and a half. It seems incredible that it can be so much as one-third that distance. Its altitude is from 3,500 to 4,000 feet, but any attempt to estimate the altitude by means of visual impressions is felt at once to be hopeless. There is no stadium. Dimensions mean nothing to the senses, and all that we are conscious of in this respect is a troubled sense of immensity.

Beyond the eastern Cloister, five or six miles distant, rises a gigantic mass which we named Shiva's Temple. It is the grandest of all the buttes, and the most majestic in aspect, though not the most ornate. Its mass is as great as the mountainous part of Mount Washington. That summit looks down 6,000 feet into the dark depths of the inner

abyss, over a succession of ledges as impracticable as the face of Bunker Hill Monument. All around it are side gorges sunk to a depth nearly as profound as that of the main channel. It stands in the midst of a great throng of cloister-like buttes, with the same noble profiles and strong lineaments as those immediately before us, with a plexus of awful chasms between them. In such a stupendous scene of wreck it seemed as if the fabled "Destroyer" might find an abode not wholly uncongenial.

In all the vast space beneath and around us there is very little upon which the mind can linger restfully. It is completely filled with objects of gigantic size and amazing form, and as the mind wanders over them it is hopelessly bewildered and lost. It is useless to select special points of contemplation. The instant the attention lays hold of them it is drawn to something else, and if it seeks to recur to them it cannot find them. Everything is superlative, transcending the power of the intelligence to comprehend it. There is no central point or object around which the other elements are grouped and to which they are tributary. The grandest objects are merged in a congregation of others equally grand. Hundreds of these mighty structures, miles in length, and thousands of feet in height, rear their majestic heads out of the abyss, displaying their richly-molded plinths and friezes, thrusting out their gables, wing-walls, buttresses, and pilasters, and recessed with alcoves and panels. If any one of these stupendous creations had been planted upon the plains of Central Europe it would have influenced modern art as profoundly as Fusiyama has influenced the decorative art of Japan. Yet here they are all swallowed up in the confusion of multitude. It is not alone the magnitude of the individual objects that makes this spectacle so portentous, but it is still more the extravagant profusion with which they are arrayed along the whole visible extent of the broad chasm.

The color effects are rich and wonderful. They are due to the inherent colors of the rocks, modified by the atmosphere. Like any other great series of strata in the Plateau Province, the Carboniferous has its own range of characteristic colors, which might serve to distinguish it even if we had no other criterion. The summit strata are pale gray, with a, faint yellowish cast. Beneath them the cross-bedded sandstone appears showing a mottled surface of pale pinkish hue. Underneath this member are nearly 1,000 feet of the lower Aubrey sandstones, displaying an intensely brilliant red, which is somewhat masked by the talus shot down from the grey, cherty limestones at the summit. Beneath the lower Aubrey is the face of the Red Wall limestone, from 2,000 to 3,000 feet high. It has a strong red color, but a very peculiar one. Most of the red strata of the west have the brownish or vermilion tones, but these are rather purplish-red, as if the pigment had been treated to a dash of blue. It is not quite certain that this may not arise in part from the intervention of the blue haze, and probably it is rendered more conspicuous by this cause; but, on the whole, the purplish cast seems to be inherent. This is the dominant color-mass of the cañon, for the ex-

panse of rock surface displayed is more than half in the Red Wall group. It is less brilliant than the fiery red of the Aubrey sandstones, but is still quite strong and rich. Beneath are the deep browns of the lower Carboniferous. The dark iron-black of the hornblendic schists revealed in the lower gorge makes but little impression upon the boundless expanse of bright colors above.

The total effect of the entire color-mass is bright and glowing. There is nothing gloomy or dark in the picture except the opening of the inner gorge, which is too small a feature to influence materially the prevailing tone. Although the colors are bright when contrasted with normal landscapes, they are decidedly less intense than the flaming hues of the Trias or the dense cloying colors of the Permian; nor have they the refinement of those revealed in the Eocene. The intense luster which gleams from the rocks of the Plateau country is by no means lost here but is merely subdued and kept under some restraint. It is toned down and softened without being deprived of its character. Enough of it is left to produce color effects not far below those that are yielded by the Jura-Trias.

But though the inherent colors are less intense than some others, yet under the quickening influence of the atmosphere they produce effects to which all others are far inferior. And here language fails and description becomes impossible. Not only are their qualities exceedingly subtle, but they have little counterpart in common experience. If such are presented elsewhere they are presented so feebly and obscurely that only the most discriminating and closest observers of nature ever seize them, and they so imperfectly that their ideas of them are vague and but half real. There are no concrete notions founded in experience upon which a conception of these color effects and optical delusions can be constructed and made intelligible. A perpetual glamour envelops the landscape. Things are not what they seem, and the perceptions cannot tell us what they are. It is not probable that these effects are different in kind in the Grand Cañon from what they are in other portions of the Plateau country. But the difference in degree is immense, and being greatly magnified and intensified many characteristics become palpable which elsewhere elude the closest observation.

In truth, the tone and temper of the landscape are constantly varying, and the changes in its aspect are very great. It is never the same, even from day to day, or even from hour to hour. In the early morning its mood and subjective influences are usually calmer and more full of repose than at other times, but as the sun rises higher the whole scene is so changed that we cannot recall our first impressions. Every passing cloud, every change in the position of the sun recasts the whole. At sunset the pageant closes amid splendors that seem more than earthly. The direction of the full sunlight, the massing of the shadows, the manner in which the side-lights are thrown in from the clouds determine these modulations, and the sensitiveness of the picture to the slightest variations in these conditions is very wonderful.

The shadows thrown by the bold abrupt forms are exceedingly dark. It is almost impossible at the distance of a very few miles to distinguish even broad details in these shadows. They are like remnants of midnight unconquered by the blaze of noonday. The want of half tones and gradations in the light and shade, which has already been noted in the Vermilion Cliffs, is apparent here, and is far more conspicuous. Our thoughts in this connection may suggest to us a still more extreme case of a similar phenomenon presented by the half-illuminated moon when viewed through a large telescope. The portions which catch the sunlight shine with great luster but the shadows of mountains and cliffs are black and impenetrable. But there is one feature in the cañon which is certainly extraordinary. It is the appearance of the atmosphere against the background of shadow. It has a metallic luster which must be seen to be appreciated. The great wall across the chasm presents at noonday, under a cloudless sky, a singularly weird and unearthly aspect. The color is for the most part gone. In place of it comes this metallic glare of the haze. The southern wall is never so poorly lighted as at noon. Since its face consists of a series of promontories projecting towards the north, these projections catch the sunlight on their eastern sides in the forenoon, and upon their western sides in the afternoon; but near meridian the rays fall upon a few points only, and even upon these with very great obliquity. Thus at the hours of greatest general illumination the wall is most obscure and the abnormal effects are then presented most forcibly. They give rise to strange delusions. The rocks then look nearly black, or very dark grey and covered with feebly shining spots. The haze is strongly luminous, and so dense as to obscure the details already enfeebled by shade as if a leaden or mercurial vapor intervened. The shadows antagonize the perspective, and everything seems awry. The lines of stratification, dimly seen in one place and wholly effaced in another, are strangely belied and the strata are given apparent attitudes which are sometimes grotesque and sometimes impossible.

Those who are familiar with western scenery have, no doubt, been impressed with the peculiar character of its haze, or atmosphere in the artistic sense of the word, and have noted its more prominent qualities. When the air is free from common smoke it has a pale blue color which is quite unlike the neutral gray of the east. It is always apparently more dense when we look towards the sun than when we look away from it, and this difference in the two directions, respectively, is a maximum near sunrise and sunset. This property is universal, but its peculiarities in the Plateau Province become conspicuous when the strong rich colors of the rocks are seen through it. The very air is then visible. We see it, palpably, as a tenuous fluid and the rocks beyond it do not appear to be colored blue as they do in other regions but reveal themselves clothed in colors of their own. The Grand Cañon is ever full of this haze. It fills it to the brim. Its apparent density, as elsewhere, is varied according to the direction in which it is viewed and the position of

the sun; but it seems also to be denser and more concentrated than elsewhere. This is really a delusion arising from the fact that the enormous magnitude of the chasm and of its component masses dwarfs the distances; we are really looking through miles of atmosphere under the impression that they are only so many furlongs. This apparent concentration of haze, however, greatly intensifies all the beautiful or mysterious optical effects which are dependent upon the intervention of the atmosphere.

Whenever the brink of the chasm is reached the chances are that the sun is high and these abnormal effects in full force. The cañon is asleep. Or it is under a spell of enchantment which gives its bewildering mazes an aspect still more bewildering. Throughout the long summer forenoon the charm which binds it grows in potency. At midday the clouds begin to gather, first in fleecy flecks, then in cumuli and throw their shadows into the gulf. At once the scene changes. The slumber of the chasm is disturbed. The temples and cloisters seem to raise themselves half awake to greet the passing shadow. Their wilted, drooping, flattened faces expand into relief. The long promontories reach out from the distant wall as if to catch a moment's refreshment from the shade. The colors begin to glow; the haze loses its opaque density and becomes more tenuous. The shadows pass, and the chasm relapses into its dull sleep again. Thus through the midday hours it lies in fitful slumber, overcome by the blinding glare and withering heat, yet responsive to every fluctuation of light and shadow like a delicate organism.

As the sun moves far into the west the scene again changes, slowly and imperceptibly at first, but afterwards more rapidly. In the hot summer afternoons the sky is full of cloud-play and the deep flushes with ready answers. The banks of snowy clouds pour a flood of light sidewise into the shadows and light up the gloom of the amphitheaters and alcoves, weakening the glow of the haze and rendering visible the details of the wall faces. At length as the sun draws near the horizon the great drama of the day begins.

Throughout the afternoon the prospect has been gradually growing clearer. The haze has relaxed its steely glare and has changed to a veil of transparent blue. Slowly the myriads of details have come out and the walls are flecked with lines of minute tracery, forming a diaper of light and shade. Stronger and sharper becomes the relief of each projection. The promontories come forth from the opposite wall. The sinuous lines of stratification which once seemed meaningless, distorted, and even chaotic, now range themselves into a true perspective of graceful curves, threading the scallop edges of the strata. The colossal buttes expand in every dimension. Their long narrow wings, which once were folded together and flattened against each other, open out, disclosing between them vast alcoves illumined with Rembrandt lights tinged with the pale refined blue of the ever-present haze. A thousand forms, hitherto unseen or obscure, start up within the abyss, and stand forth in

strength and animation. All things seem to grow in beauty, power, and dimensions. What was grand before has become majestic, the majestic becomes sublime, and, ever expanding and developing, the sublime passes beyond the reach of our faculties and becomes transcendent. The colors have come back. Inherently rich and strong, though not superlative under ordinary lights, they now begin to display an adventitious brilliancy. The western sky is all aflame. The scattered banks of cloud and wavy cirrus have caught the waning splendor, and shine with orange and crimson. Broad slant beams of yellow light, shot through the glory-rifts, fall on turret and tower, on pinnacled crest, and winding ledge, suffusing them with a radiance less fulsome, but akin to that which flames in the western clouds. The summit band is brilliant yellow; the next below is pale rose. But the grand expanse within is a deep, luminous, resplendent red. The climax has now come. The blaze of sunlight poured over an illimitable surface of glowing red is flung back into the gulf, and, commingling with the blue haze, turns it into a sea of purple of most imperial hue—so rich, so strong, so pure that it makes the heart ache and the throat tighten. However vast the magnitudes, however majestic the forms, or sumptuous the decoration, it is in these kingly colors that the highest glory of the Grand Cañon is revealed.

At length the sun sinks and the colors cease to burn. The abyss lapses back into repose. But its glory mounts upward and diffuses itself in the sky above. Long streamers of rosy light, rayed out from the west, cross the firmament and converge again in the east ending in a pale rosy arch, which rises like a low aurora just above the eastern horizon. Below it is the dead gray shadow of the world. Higher and higher climbs the arch followed by the darkening pall of gray, and as it ascends it fades and disappears, leaving no color except the after-glow of the western clouds, and the lusterless red of the chasm below. Within the abyss the darkness gathers. Gradually the shades deepen and ascend, hiding the opposite wall and enveloping the great temples. For a few moments the summits of these majestic piles seem to float upon a sea of blackness, then vanish in the darkness, and, wrapped in the impenetrable mantle of the night, they await the glory of the coming dawn.

CHAPTER VIII.

THE EXCAVATION OF THE CHASM.

The excavation of the Grand Cañon and the sculpture of its walls and buttes are the results of two processes acting in concert—*corrasion* and *weathering*. In discussing them it is necessary to take into the account the peculiar conditions under which they have operated; conditions which have no parallel in any other part of the world.

In common parlance it is customary to say, for brevity's sake, that the rivers have cut their cañons; but the expression states only a part of the truth. The river has in reality cut only a narrow trench no wider than the river's water surface. It has been the vehicle which has carried away to another part of the world the materials which have been torn from the strata by corrasion and weathering. Opening laterally into the main chasm are many amphitheaters excavated back into the platform of the country. At the bottom of each of them is a stream-bed over which in some cases a perennial river flows, while in other cases the flows are spasmodic. Like the trunk river these streams have corraded their channels to depths varying somewhat among themselves, but generally a little less than the depth of the central chasm. These tributaries often fork, and the forks are in the foregoing respects quite homologous to the main amphitheaters. Down the faces of the walls and down the steep slopes of the taluses run thousands of rain gullies. When the rain comes freely it gathers into rills which cascade down the wall clefts and rush headlong through the troughs in the talus carrying an abundance of sand and grit. These waters scour out their little channels in much the same way as their united waters cut down their beds in the amphitheaters of the second and first orders, and in the main chasm itself. But the work of flowing water, whether in the main channel or in an amphitheater, or in a gully or cranny of the cliff, is limited to two functions. The first is the cutting of a channel no wider than the surface of the stream; the second is the transportation of the débris. Corrasion alone then could never have made the Grand Cañon what it is. Another process, acting conjointly with corrasion and dependent upon it, has effected by far the greater part of the excavation. This other process is weathering. In order to comprehend their combined action it is necessary to study their action in detail, and to study also the special conditions under which they have operated here. We shall find the subject a very complicated one.

CORRASION.

Mr. G. K. Gilbert has embodied in his admirable monograph on the Henry Mountains, a chapter on Land Sculpture, which sets forth in most logical and condensed form the mechanical principles which enter into the problems of erosion. In his analysis may be found a discussion of the conditions under which the sculpturing forces and processes achieve such peculiar results as we observe in the Plateau country.

The perusal of that chapter will give to the geologist's comprehension of the subject a most delightful definiteness and precision, and the reader, however learned he may be, will take great satisfaction in finding a subject so complex made so intelligible. The principles laid down by Mr. Gilbert will be adopted here and applied. For that purpose I quote from the chapter referred to such statements as are of immediate service.

The mechanical wear of streams is performed by the aid of hard mineral fragments carried along by the current. The effective force is that of the current; the tools are mud, sand, and bowlders. The most important of them is sand; it is chiefly by the impact and friction of grains of sand that the rocky beds of streams are disintegrated.

Where a stream has all the load of a given degree of comminution which it is capable of carrying, the entire energy of the descending water and load is consumed in the translation of the water and load, and there is none applied to corrasion. If it has an excess of load, its velocity is thereby diminished so as to lessen its competence and a portion is dropped. If it has less than a full load, it is in condition to receive more, and it corrades its bottom. A fully-loaded stream is on the verge between corrasion and deposition. * * * The work of transportation may thus monopolize a stream to the exclusion of corrasion, or the two works may be carried forward at the same time.

The rapidity of mechanical corrasion depends on the hardness, size, and number of the transient fragments, on the hardness of the rock-bed, and on the velocity of the stream. * * * The element of velocity is of double importance, since it determines not only the speed, but, to a great extent, the size of the pestles which grind the rocks. The co-efficients upon which it [velocity] in turn depends, namely, declivity and quantity of water, have the same importance in corrasion that they have in transportation.

Let us suppose that a stream endowed with a constant volume of water is at some point continuously supplied with as great a load as it is capable of carrying. For so great a distance as its velocity remains the same, it will neither corrade nor deposit, but will leave the declivity of its bed unchanged. But if in its progress it reaches a place where a less declivity of bed gives a diminished velocity, its capacity for transportation will become less than the load, and a part of the load will be deposited. Or if in its progress it reaches a place where a greater declivity of bed gives an increased velocity, the capacity for transportation will become greater than the load and there will be corrasion of the bed. In this way a stream which has a supply of *débris* equal to its capacity tends to build up the gentler slopes of its bed and to cut away the steeper. It tends to establish a single uniform grade.

Let us now suppose that the stream, after having obliterated all of the inequalities of the grade of its bed, loses nearly the whole of its load. Its velocity is at once accelerated and vertical corrasion begins through its whole length. Since the stream has the same declivity, and consequently the same velocity, at all points, its capacity for corrasion is everywhere the same. Its rate of corrasion, however, will depend upon the character of its bed. Where the rock is hard, corrasion will be less rapid than where

VIEW FROM THE EASTERN BRINK OF THE KAIBAB—OVERLOOKING THE MARBLE CAÑON PLATFORM.

it is soft, and there will result inequalities of grade. But so soon as there is inequality of grade there is inequality of velocity and inequality of capacity for corrosion; and where hard rocks have produced declivities, there the capacity for corrosion will be increased. The differentiation will proceed until the capacity for corrosion is everywhere proportional to the resistance to be encountered; that is, until there is equilibrium of action.

In general we may say that a stream tends to equalize its work in all parts of its course. Its power inheres in its fall, and each foot of fall has the same power. When its work is to corrade and the resistance unequal, it concentrates its energy where the resistance is great by crowding many feet of descent into a small space, and diffuses it where the resistance is small by using but a small fall in a long distance. When its work is to transport, the resistance is constant and the fall is evenly distributed by a uniform grade. When its work includes both transportation and corrosion, as in the usual case, its grades are somewhat unequal and the inequality is greatest when the load is least.

The foregoing analysis is applicable to the Colorado. It is, in respect to corrosion, an exceptional river. Nearly all the large rivers of the world along their lower and middle courses have either reached, or closely approximated to, that condition of equilibrium which Mr. Gilbert speaks of, in which the transporting power is nearly adjusted without excess to the load to be carried. They have little or no surplus energy to spare for corrosion, and therefore neither corrade nor deposit. But the Colorado is corradng rapidly, and has doubtless done so with little interruption throughout the entire period of its existence. The cause may be discerned in one important fact already brought out. The region it traverses has been throughout Tertiary time steadily rising, and the total elevation has been enormous. This progressive elevation has antagonized the tendency of the river to reach that adjustment of its energy to the work of transportation alone, and has kept alive its corrosive power. There have been probably some limited periods in the history of the river in which, for the time being, it had sunk its channel until it reached a "base-level"—a grade below which it could not corrade. But this state of affairs was afterwards subverted by a further elevation which increased the declivities of the channel, restoring the corrosive power. The last great upheaval, exceeding in amount 3,000 feet, was of comparatively recent occurrence, and the river has not yet reached the new equilibrium of action and the new adjustment of its energy to the work of simple transportation.

The reader who for the first time is brought to consider the enormous depth of the gash which the Colorado has cut would naturally turn to the rivers with which he is familiar to inquire whether they disclosed evidence of similar and commensurate action. He would rarely find any such evidence. It is only by examining the physical conditions of the Colorado and comparing them with other rivers in the light of such principles as Mr. Gilbert has laid down that the facts become intelligible. The first and most important factor to be considered is its declivity. The fall of the Colorado and its principal fork, the Green River, from Green River Station, on the Pacific Railway, to the end of the Grand Cañon, a

distance, as the river runs, of about 1,050 miles, is about 5,150 feet, or very nearly five feet to the mile. The fall through the Grand Cañon is on an average 7.56 feet to the mile. Taking the several divisions of the Grand Cañon, the declivity may thus be tabulated:

Declivity of the Colorado in the Grand Cañon.

Subdivisions.	Distance in miles.	Fall in feet.	Fall in feet per mile.
From Little Colorado to Kaibab division	9.6	60	6.25
Kaibab division	58	700	12.07
Kanab division	47.6	240	5.01
Uinkaret division	19.2	100	5.21
Sheavwits division	84	540	6.43
Totals.....	218.4	1,640	7.56

The Marble Cañon, with a length of 65.2 miles, has a descent of 510 feet, or an average fall of 7.82 feet per mile. When compared with the declivities in the middle and lower courses of other large rivers, that of the Colorado in the cañons is seen to be very excessive. It falls about as many feet as the others fall in inches. The flow of other large rivers which are usually considered swift is calm and easy in comparison with the rush of the waters of the Colorado.

There is another factor which would be fatal to corrasion in other rivers, but which in this one greatly augments its corrosive power. Not only are few rivers so swift, but fewer still are so continuously turbid and so heavily charged with sediment. Rarely is the river clear, even in the droughts of midsummer. Immense quantities of sand and clay are swept along at all parts of the year. Ordinary rivers, and even most of the exceptional ones, would be gorged with such quantities of sand, and instead of corrasion would have their energies fully taxed in carrying the load which the Colorado bears easily. This sand is the tool which it employs for its work, and it uses it with great effect. Though the river is heavily loaded, it is still underloaded, and has great power to corrade.*

To show how efficient the corrosive action may become under extremely favorable circumstances, we may cite the case of some of the great hydraulic mines in California. In these mines powerful streams of water are discharged against the gravel banks, and the spent water is gathered into a brook which finds its way over the "bed-rock" into a tunnel, and finally escapes into some deep natural gorge below the level of the workings. As the water flows away it carries with it all the debris washed from the banks, whether coarse or fine. In the well-known Bloomfield mine I saw a gash in the solid basaltic bed-rock 12 feet in depth, which I was assured had been cut by the escaping water and gravel in a period of about sixteen months. The actual running

* The details of corrasion in the cañon will be much more fully discussed in the monograph on the Grand Cañon District.

time of the water, however, had been equivalent to about 145 days of twenty-four hours each. This case is indeed a most extreme one, and no natural river can show any such rapid corrasion of any considerable length of its bed. It is not cited to support an inference of phenomenal rapidity in the corrasion of the Grand Cañon, but rather to illustrate the efficiency of corrasive action when all the attendant conditions are extremely favorable and no countervailing condition is present. But although the Colorado is far from being such an extreme case as the one just mentioned, it is still a very strong one. Yet there are some stretches in the river where the corrasion must be proceeding at a very rapid rate—at a rate not very many times slower than in the Bloomfield mine. These portions are in the hardest rocks, and they illustrate well the law which Mr. Gilbert has so clearly enunciated (p. 157, line 44).

The course of the Colorado in the Grand Cañon is a succession of headlong rapids or cataracts and of smooth but swiftly-flowing reaches. In the Kaibab division the rapids are very numerous, very long, and very frequent, while the still reaches are short. In the Kanab division the rapids are fewer and less formidable, while the still reaches are longer. In the Sheavwits, the condition is intermediate between those of the Kaibab and Kanab divisions. The rapids, however, are of two kinds, and are the results of two wholly independent causes. (1.) When the stream lies in the hard rocks, the declivity is much greater, and the rapid is then due to the greater slope of the bed. (2.) At the opening of every side-gorge, a pile of large boulders and rubble is pushed out into the stream. Most of the side-gorges are dry throughout the greater part of the year. But when the rains do come, their effects are prodigious.* In the vast amphitheaters the water is quickly shot down into the channel and rushes with frightful velocity along the bed, which has a slope of 200 feet or more to the mile. Nothing which is loose and which lies in the way of it can resist its terrible rush. Boulders of many tons' weight are swept along like chaff, and go thundering down the side-gorges into the main river. When the torrents reach the river the large fragments are dropped; for the maximum slope of the main stream (reckoned throughout any stretch exceeding four or five miles) never exceeds 25 feet to the mile; and the water, though great in volume at flood-time, has much less velocity than the torrents of the side-chasms. The river has, however, abundant power to sweep along fragments of considerable size, which are ground up as they move onward. The coarse material, the large boulders and rubble washed out of a lateral chasm, form a dam where the river becomes a cataract. They are also strung out for considerable distances below the dam, and thus the tendency is to build up and increase the grade of the river

* It is well to remember here the grand scale on which these lateral features of the chasm are laid out. The watersheds of these amphitheaters cover each from 10 to 50 square miles! And when a heavy rain comes, whatever water is not soaked up by the rocks and soil is in the bottom of the amphitheater in less than ten minutes!!

just beyond the rapid. But this tendency is quickly checked and brought to a stop by the increased power of the current due to the increased slope. The body of fragments brought into the river laterally is vast in amount. But on the whole it is insufficient at the present epoch to prevent the river from corradng its channel, though corrasion is greatly retarded by it. There are many stretches where there is an equilibrium between the tendency to cut deeper and the tendency to build up the bottom by the accumulation of *débris*; where the whole energy of the river is consumed in dissipating the fragments brought into it. But there are other portions where the river bed is in the bare rock of Palæozoic and Archæan strata, and wherever it is so corrasion is proceeding rapidly.

WEATHERING.

The work of corrasion is limited to the cutting of narrow gashes in the strata, and the grinding up of the fragments brought into the river channels. The widening of these cuts into the present configuration of the chasm is the work of weathering. The common notion is that "solid rock" is but little affected by any natural agents such as water and air, and though it is acknowledged that water and carbonic acid exert a certain nominal solvent and chemical action upon rock material, yet these are usually esteemed so feeble that even the enormous periods of time which the geologist invokes seem quite insufficient to warrant us in ascribing to them any very important effects. Our observation upon the works of human construction which have been exposed for many centuries to the action of the elements confirms this notion. The structures of Egypt, Greece, and Italy have been thus exposed for periods which are nearly or even exactly known. They bear evidence that this action is a real one, and that their final dissipation would, in the event of indefinite exposure, be a mere question of time. But they also indicate that so far as their own materials are concerned the process is exceedingly slow. Their rate of decay by solution, if applied as a factor to the recession of the walls of the Grand Cañon, would give a period of time so vast that the mind would promptly reject it because of its very enormity. But we shall find that the recession of those walls goes on, slowly indeed, but at a rate very much greater than would be inferred from an inspection and comparison of the works of human antiquity.

It is at once obvious that the building-stones are not a fair eriterion. They are selected for their durability, and of all rocks they represent those which offer the greatest possible resistance to weathering. Taking the common rocks only—those of frequent and world-wide occurrence—there is reason to believe that their rates of decay under equal conditions vary among themselves enormously. Leaving out of the account the unconsolidated or loosely consolidated strata, it cannot be doubted

THE MARBLE CAÑON.

that some indurated rocks decay fifty times faster than others, the conditions being identical as to climate and exposure. We have, it is true, no experimental or laboratory data upon which this assertion can be based, but it is, I am confident, quite defensible, and will appear to be so when we examine the results of weathering in the rocks in place. For there is another consideration which is not apparent in the decay of building-stones. The strata are disintegrated by a process which includes something far more efficient than mere solution or chemical decomposition.

At the base of every cliff in the Plateau country we find a large talus consisting of fragments fallen from the rock faces above. The fragments vary in size from boulders of many tons' weight down to the finest gravel, sand, and clay. Here is proof at once that the decay of cliffs goes on chiefly through the breaking off of fragments. It soon appears that the amount of material removed from the wall in solution is but a very trifling fraction of the quantity which has spalled off from the face of the wall. As the large fragments fall off from the vertical front they are dashed to pieces below. In this fragmental condition they expose a much greater surface to weathering and are dissipated with correspondingly increased rapidity. And now we come to the key of the problem. The explanation of those persistent profiles of the Grand Cañon is found when we analyze the formation and decay of talus. It is one of the most charming studies in the whole range of physical geology.

In the Carboniferous strata of the Grand Cañon we have a mass of rocks widely varying in lithological characters, but which on the average are just about as obdurate to weathering as the average of rocks found in other regions. So far as can be seen or inferred, in this respect they differ not at all from the strata of other regions. Some of them weather easily, some are very obdurate. Perhaps the only qualification to this comparative statement is that there are no extremely perishable strata in the whole series. The softest beds are still firm and perfectly indurated. The degrees of obduracy, however, appear to vary greatly in the series.

The upper stratum in the cañon wall is a cherty limestone, which is harder* than the average, though not extreme in that respect. It forms usually a precipitous face, though it is frequently breached and broken down. It is out of this series that the rows of pinnacles in the crest of the cañon are carved.† Beneath it is another series of limestones of less than average hardness. They are sometimes a little cherty

* In speaking here of relative hardness and softness, I wish to be understood as meaning the resistance which the rock opposes to destruction by direct weathering, and not hardness in the mineralogical sense, nor the resistance which the rocks might offer to the tools of the stone-cutter.

† The cherty limestones are full of silicious nodules. They occur in vast numbers and show a tendency to arrange themselves in bands parallel with the bedding. The inclosing matrix, though mainly calcareous, has much disseminated silica in the cherty form. In the weathering the nodules are dissolved out of the matrix and fall down the cliffs.

but far less so than the overlying beds. They break down always into a steep slope, covered with a talus partly of their own *débris* and partly of the cherty nodules weathered out from above. Beneath the limestones lies the cross-bedded sandstone, one of the most conspicuous members of the cañon. Of all the strata it is the hardest; in truth, is about as adamantinite as any rock to be found in the world. It forms everywhere the vertical frieze of the upper wall and is very seldom broken down into a slope. Underneath it comes the great series of Lower Aubrey sandstones, a thousand feet thick, made up of very many individual beds. They are similar in character, and all of them weather rapidly. We have, then, in the Upper and Lower Aubrey Groups, which form the outer chasm wall at the Toroweap (and which are almost exactly the same elsewhere throughout the Grand Cañon), four groups of strata which are alternately hard and soft (Fig. 16), (1) a hard cherty limestone, (2) a softer limestone, (3) an extremely hard sandstone, (4) a great thickness of much softer sandstones.

FIG. 16.—Development of cliff profiles by recession in the upper wall of the chasm.

It has already been explained that the attack of erosion is made chiefly upon the scarp walls and steep slopes of a country and only feebly upon level surfaces. Imagine, now, a cut made by a corradng stream into such a series of strata as that which has just been described. It will soon appear that it is quite immaterial whether the cut be made very gradually or instantly,—by a miracle, as we may suppose. Weathering at once attacks the face of the wall. The softer beds yielding much more rapidly, gradually undermine the harder ones above, and the latter cleave off by their joints and great fragments fall down. If we suppose the corraded cut to have been made instantly and the river to be flowing in it, the fragments would at first fall into the stream and be devoured by corrasion as fast as they fall. But after a time the widening of the cut so produced would leave a platform on the margin of the stream where the fragments would begin to form a talus. As the recession by waste goes on, the talus grows larger and larger, and gradually mounts up on the breast of the lower wall. Now the effect of a talus is to protect the beds upon whose edges it lies, and to retard their rate of decay by virtue

of that protection. At first, then, the talus causes the lowest beds to lag behind in the recession. As it mounts up the wall, higher and higher beds gain protection, and they, too, begin to lag behind, until at last the talus mounts up very nearly to the base of the extremely hard, cross-bedded sandstone. Thus the entire lower series of soft strata becomes converted into a slope covered with talus, and at this stage all the beds above stand as a single vertical face. But immediately a second cliff and talus begin to form above the hard sandstone; for since the lower soft beds are protected and their rate of recession reduced by the talus, the upper soft beds, being naked, must recede at a more rapid rate, until they, too, become a slope and receive the protection of a talus from the hard limestone at the summit.

It appears, then, that the recession of the hard beds is accelerated by undermining, while the recession of the soft beds is retarded by the protection of the talus. The result is the final establishment of a definite profile, which thereafter remains very nearly constant as the cliff continues to recede. *Thus the talus is the regulator of the cliff profile.* There are many minor features which may be explained satisfactorily, and one of them is the curvature of the Lower Aubrey profile.

Throughout the greater part of the chasm the slope of the Lower Aubrey is a very graceful curve, but in the Kaibab division it is usually straight and descends at an inclination of about 30 degrees, the angle of repose, or very nearly so, for the débris which occurs here. Taking first the Toroweap section, we remark that at the base of the main palisade is the broad esplanade or plain which forms the floor of the upper chasm. It is from a mile to three miles in width. In a great talus the fragments are slowly and continually creeping down by the action of rain and frost. The plain at the base acts as a check to the descent. Nowhere except, perhaps, at a notable distance away from the base or in the very lowest part of the stratigraphic series are the beds wholly buried in talus. Considerable areas of rock surface project through the covering. The tendency of the descent of talus under the conditions here considered is to give more protection to the lower beds than to the higher. The check given to the descent of the talus by the level plain is felt more strongly at the base of the slope than higher up. Moreover, the finer débris is more readily washed down a slope of given declivity than the coarse, and thus the débris at the base of the talus is finer than that above; and fine débris is a more efficient protection than coarse. In consequence of this greater protection, the recession of the lower beds is less rapid than that of the higher ones, and in general terms the protection of any given bed in the slope is inversely proportional to the square or some other complex function of its height above the base. The curved profile at once follows, and it is demonstrably of the hyperbolic class.

In the Kaibab the case is different. Here the mighty plinth of the Red Wall limestone cuts off the foot of the Lower Aubrey slope, giving

a free discharge to the fragments into the depth below. There is no check to the descent of the talus; the amount of protection given by it to all the beds of the Lower Aubrey is very nearly uniform, and the slope becomes straight. But whenever, as sometimes happens, the top of the Red Wall precipice stands at an unusual distance from the Lower Aubrey, the curvature of the profile of the latter appears, and its emphasis is proportional to the distance which separates the vertical planes of the Red Wall and of the cross-bedded sandstone.

Many details of repetitive or systematic sculpture are presented in the great chasm, and they may be explained as readily as the profiles. Only one other feature can be alluded to here, and the allusion will be brief. It concerns the plan or horizontal projections of the component features of the Kaibab division, the blocking out of the cloister buttes and the temples, and their reduction to their present forms. In a general way it is apparent that these have been originated by the profound corrasion of short lateral tributaries of the Colorado and the subsequent widening of the cuts into the present amphitheaters and alcoves; the buttes and temples being the residual masses between them. But the contours of the latter are striking and peculiar in the extreme. They are explained by observing that wherever recession of the cliffs takes place it proceeds with great uniformity along the entire front. It starts along the line of a stream which is tortuous, but as it proceeds it carries back the cliff in a succession of curves, and in process of time minor inequalities are obliterated. Each larger bend of the stream gives rise to its own curve in the trend of the wall, and where successive curves intersect they form very sharp cusps. Everything here depends upon uniformity in the rate of the recession of all parts of the cliff. Where the outward spreading circles of erosion from two distinct alcoves or amphitheaters meet by recession in opposite directions, a butte is cut off and a saddle or "col" is formed. The cusps between two intersecting circles are exceedingly sharp and well formed, and three circles generally give rise to a fine gable.

The peculiar cliff-forms of the Plateau country would hardly be possible in any other, for no other presents those conditions which are necessary for them. These conditions may be summarized as follows: (1.) The great elevation of the region. (2.) The horizontality of the strata. (3.) A series of strata containing very massive beds which differ greatly among themselves in respect to hardness, but each member being very homogeneous in all its horizontal extent; in a word, heterogeneity in vertical range and homogeneity in horizontal range. (4.) An arid climate. The great elevation is essential to high reliefs in the topography. Only in a high country can the streams corrade deeply, and it is by corrasion of streams that the features are originated and blocked out. The effect of horizontality of the strata is self-evident. With regard to vertical heterogeneity, it is apparent that it is essential to give diversity to profiles. If the rocks were homogeneous in vertical

(NOTE) THE COLORING OF THE MAPS AND LITHOLOGICAL (ROCK)
 SYMBOLS ARE GIVEN IN THE WESTERN GEOLOGICAL SURVEY