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THE SCOTTISH GEOGRAPHICAL MAGAZINE.

THE COLORADO RIVER OF THE WEST.

By H. M. CADELL, B.Sc., F.R.S.E.

To trace back things to their first beginnings is at all times one of the most fascinating of mental pursuits. The historian diligently seeks to discover the origin of our present political and social systems, and the biologist is ever busy constructing long pedigrees for all the families of the organic world. A like fascination attaches to the study of the evolution of the land we live on, its history in the past, and the origin of its mountains, rivers, and geographical configuration. In this latter direction there is still a large and fruitful region to explore; but it is a region which may not be entered alone and unarmed, as it is beset on every side with difficulties, and is full of pitfalls into which the unwary may easily stumble. The geographer must here take for his companion the geologist, whose eye can pierce the solid rocks and, catlike, see what to others is veiled in deep darkness.

In the Old World, it is often an exceedingly hard task to trace out the geographies of the past, and to ascertain the laws by which the land has received its present forms and outlines. The data are too few—the countries which have been investigated are too complex in geological structure and too small in area, to permit of grand generalisations being easily arrived at. In America, however, there are vast regions where such difficulties are much less formidable, and of these the basin of the Colorado is a notable example. Its geological structure is of the simplest kind. The rocks lie in a series of great flat plateaux, uniformly upraised from the sea-bed in which they were formed, and they have, after long

ages of exposure, been eaten away and deeply dissected by streams and rivers, so that their anatomy can be studied with the greatest ease. There is probably no other part of the world so well fitted to impress on the mind the marvellous erosive power of running water. The Colorado, in flowing for ages over these tracts of horizontal strata, has excavated a series of gorges altogether unique in their depth and architectural magnificence. For hundreds of miles the river rushes along the bottom of a chasm thousands of feet deep, across a barren, rainless desert, shunned alike by the hunter, the miner, and the settler, and inhabited only by a few wandering tribes of Indians. The scenery of this region is wonderful beyond description. The rocks have generally brilliant red, yellow, or purple hues, and are carved by Nature's graving tools into endless varieties of architectural shapes and patterns.

The whole length of this "Great Walled River," from its sources amid the snow-clad peaks of the Rockies to its mouth in the Gulf of California, is 2000 miles, and its drainage system, which covers 255,049 square miles, is the second largest in the United States. The region has been thoroughly explored, and much advantage may result from the study of the valuable physical and geological data, and their bearing on more general problems of geographical evolution in other lands.

The basin is physically divisible into two portions. The upper part, to which we shall devote attention in the following pages, has a general height above sea-level of 4000 to 8000 feet. It is sharply separated from the lower region by a line of mural precipice, from whose brink the surface of the country suddenly drops from an elevation of 6000 feet to levels ranging between 1300 and 3000 feet above the sea. From the foot of this huge boundary-wall there stretches westwards and southwards along the lower reaches of the Colorado a vast and nameless desert, bristling with sharp rocks and terrible in its grim desolation.

GRAND CAÑON DISTRICT.—The plateau region east of this wild sierra country occupies the north-west corner of Arizona, and stretches northwards to the High Plateaux of Utah. It is known as the Grand Cañon District from the stupendous cañon or gorge of the Colorado which crosses it from east to west and divides it into two distinct areas. The length of the Grand Cañon District from NW. to SE. may be taken at about 180 miles, and its width from NE. to SW. at 125 miles. As there is no natural boundary on the south, the total area of the region may be placed anywhere between 13,000 and 16,000 square miles. The general character of the Grand Cañon District will best be understood by a glance at Figure 1, opposite plate. The Grand Cañon is the deepest and most magnificent of the series of gorges through which the Colorado rolls its waters. Its length from the great cliff at the Grand Wash to the mouth of the Little Colorado, measuring round all the windings, is about 220 miles, but the distance between these points is only 125 miles as the crow flies. Above the Little Colorado (Colorado Chiquito) the river has a

Figure 1.—View of Marble Cañon from the Vermilion Cliffs near the mouth of the Paria. In the distance, the Colorado River is seen to turn to the west, where its gorge divides the twin plateaus. On the right are seen the Eastern Kaibab Displacements, appearing as folds, and, farther in the distance, as faults, producing straight “cliffs of elevation.” The “cliffs of erosion,” near the brink of the Cañon, have all more or less indented sinuous outlines.

general south-westerly course. The part of the gorge between the Little Colorado and Paria tributaries is second only to the Grand Cañon in grandeur, and has been named by Powell the Marble Cañon, from the magnificent marble cliffs which form part of its walls. It is 66 miles in length, and ends at the foot of the Glen Cañon (Fig. 1).

The plateau region north of the Grand Cañon is drained by three principal streams. The most westerly is the Virgen River, which rises along the southern escarpment of the Markágunt Plateau, and flows south-westwards out of the plateaux, joining the Colorado in the desert, below the mouth of the Grand Cañon. The second drainage channel is the Kanab Creek, which flows due southwards from the plateaux, and enters the Grand Cañon by a magnificent side gorge in the middle of the Kanab division of the chasm. The third and most easterly tributary is the Paria River. It rises on the eastern side of the Paunságunt Plateau, and flows south-eastwards between the Paria and Kaiparowits Plateaux, entering the Colorado at the head of the Marble Cañon.

COLORADO PLATEAU.—The country draining into the Grand Cañon on the south has no marked physical divisions, but is a single nearly horizontal expanse 7000 to 7500 feet in altitude. It is known as the Colorado Plateau, and sweeps away southwards for fifty or sixty miles to the base of the volcanic range of the San Francisco Mountains. Low *mesas* gently rolling and clad with pine, piñon, and cedar, and shallow valleys yellow with sand or grey with sage, repeat themselves over the entire area. From such commanding points as afford an outlook over this region one solitary "butte" is always seen rising above the plain. Like Roraima, it is a pile of horizontal strata far removed from any rocks of the same family. Known as the Red Butte, it consists of Permian strata lying like a cameo on the flat Carboniferous beds of the plain, and owes its preservation to a hard cap of basalt poured out as lava when the region was entirely covered with Permian shales and sandstones. The erosion of ages has swept away all the surrounding unprotected beds of the same age, leaving this solitary outlier to tell its tale, as navvies leave pillars of soil in a cutting to show the amount of their excavation. An example of a solitary outlier of this kind is seen in the distance on the left side of Fig. 1.

The country north of the Grand Cañon is, unlike the Colorado Plateau, divisible into several distinct areas with well marked topographical boundaries. The Grand Cañon receives from this side the drainage of four plateaux—the Sheavwits, Uinkaret, Kanab, and Kaibab. East of these lies a fifth, the Paria Plateau, which drains into the Marble Cañon. Let us in imagination make a journey eastwards over this region.

SHEAVWITS PLATEAU.—This is the westmost of the four, and has for its western boundary the gigantic escarpment overlooking the Grand Wash, a broad and deep valley descending from the north, and entering

the Colorado at the mouth of the Grand Cañon. This strath is generally dry, but is occasionally flooded with deluges of mud during the winter rains. The plateau wall was produced by a great fault, on the east side of which the horizontal strata of the district were hoisted several thousand feet above those on the west. The displacement diminishes towards the north, and is not found forty miles north of the Colorado. The surface of the plateau, which is diversified by some volcanic masses and Permian outliers like the Red Butte, slopes gradually to the east and north-east for a distance of thirty miles, in correspondence with the inclination of the strata.

HURRICANE LEDGE.—The eastern limit of the Sheavwits Plateau is the Hurricane Ledge, one of the most striking topographical and geological features of the Grand Cañon district. It is a huge step, the result of a second fault, which, like the first, has lifted all the country to the east at a recent geological period. While the Grand Wash fault diminishes towards the north, the Hurricane fault continues to increase. At the Grand Cañon it has a displacement of 1800 feet. It runs straight north for thirty miles, and then begins to grow till it has displaced the region no less than 6000 feet at the place where it crosses the Virgen River. Above the Hurricane Ledge there are extensive grazing lands, and where there are springs the Mormon inhabitants have, by the help of irrigation, succeeded in raising the products of a temperate climate. In the region below, along the course of the Virgen and Santa Clara rivers, sub-tropical plants are cultivated, and for one standing on the ledge it is possible to throw a stone from the land of the potato and apple to that of the fig and sugar-cane.

The Hurricane Ledge presents an almost impassable barrier to the traveller across the plateaux. It may only be crossed where occasional narrow gullies have gashed its front, or where old volcanoes on the plateau above have poured over the brink streams of lava, and formed rugged slopes which may be climbed with difficulty.

UINKARET PLATEAU.—On gaining the top we reach the second terrace known as the Uinkaret Plateau. It is the narrowest of the four, but has strongly marked features. The Grand Cañon and Hurricane Ledge define it sharply on the south and west, while on the north the plateau terminates at the base of the Permian cliffs—the first step up to the High Plateaux of Utah. The eastern boundary is only partially supplied by the Toroweap Valley, which extends northwards from the Grand Cañon for some twenty-three miles, and then disappears, leaving no distinct dividing-line between this part of the Uinkaret and the Kanab Plateau on the east. The length of the Uinkaret Plateau may be roughly stated at 45 to 50 miles, and its width from 8 to 12 miles.

Like the Sheavwits Plateau, the Uinkaret has been the scene of repeated volcanic outbursts, and the billowy profiles and gloomy hues of

the basaltic cones and lava-flows, which cover a large area, form a sharp contrast to the rectilinear outlines and glowing tints of the surrounding region. The volcanic eruptions took place at two different times. The earlier series of eruptions was probably connected with the first throes of upheaval at the close of the Miocene period. After the successive and long-continued periods of uplift and denudation, during which the region received its present wondrous physiognomy, the volcanic fires again burst forth, and multitudes of little cinder cones and coulées of basaltic lava were formed on the plateau. The highest and most conspicuous part of the Uinkaret is Mount Trumbull, a broad, well defined, isolated mass, rising nearly 2000 feet above the plain at its base, and 3000 feet above the Toroweap Valley near its south-eastern flank. Two or three miles to the south-west lies Mount Logan, a tabular eminence of greater area but lower height than Mount Trumbull. Both these mountains are the denuded remains of the older volcanic series which were erupted when the surface of the region was still covered with Permian strata. From the top of Trumbull it is possible to make out over 120 distinct cinder cones of the later family, sprinkled like molehills over the plateau. Altogether some 170 such centres of eruption have been counted on the Uinkaret and its environs, the majority being thickly planted round the sides of Mount Trumbull. As a rule they are small, and rarely reach a height of 700 or 800 feet. The plateau is like the volcanic districts of Auvergne, or the Eifel and the Siebengebirge, where the extinct cones and craters have not yet been obliterated by the wasting hand of time, but impart to the whole landscape their characteristic type of scenery.

KANAB PLATEAU.—The Toroweap Valley runs along another line of fault, which, like those to the west, has lifted the region beyond, and given rise to a third great step upwards to the east. This line of cliff is 800 or 900 feet high at the foot of the Toroweap, but diminishes with the fault towards the north. The Kanab Plateau is the broadest of the four, but is the least pronounced in its features. It is a simple monotonous expanse of desert, with only one salient point of interest. This is the Kanab Cañon, a magnificent side gorge which runs through the centre of the plateau, and opens into the heart of the Grand Cañon.

KAIBAB PLATEAU.—We have now reached the highest and most interesting part of the Grand Cañon district. The Kaibab has an elevation of from 7500 to 9000 feet. The summit is comparatively flat, and terminates on the eastern and western sides in lofty battlements overlooking the barren wastes around. The plateau is an uplift between two great displacements throwing in opposite directions. These lines of dislocation converge towards the north and meet at the hamlet of Paria, thus giving the plateau a rudely triangular outline. The longest side of the plateau, extending from the Grand Cañon to the Vermilion Cliffs, is 90 miles in length. Its greatest breadth from east to west is 35 miles.

The surrounding region is a desolate expanse of flat crumbling rock, of a red or orange hue, unwatered save by scanty springs, and clad with nothing but sparse cactus or desert scrub. After toiling over this naked wilderness, and mounting the last great step, what a goal is reached in the oasis of the Kaibab! "Its broad surface is clothed with magnificent forest, opening in grassy parks, which during the summer are gay with flowers of rare beauty and luxuriance. It is a paradise to the explorer, who, weary of the desert, wanders with delight among its giant pines and spruces, and through its verdant but streamless valleys." The Kaibab is a moist region. In summer the rains are frequent, and in winter the snow lies deep, but there are no perennial streams such as are found in other mountainous regions of equal size and altitude. Every ravine is dry and carpeted with a turf of mountain grass, smooth as a lawn and richly bedecked with flowers. The trees, which are large and noble, stand well apart, except in the upper parts of the plateau, where the spruces predominate. The main genera are the yellow pine (*Pinus ponderosa*), the spruce (*Abies grandis* and *A. Engelmanni*), and the aspen (*Populus tremuloides*); but on the borders of the plateau, the cedar (*Juniperus occidentalis*), the mountain mahogany (*Cercocarpus ledifolius*), and the piñon (*Pinus edulis*) are also to be found.

In the centre of the Kaibab there is a small strath 10 miles long and about three in breadth, named the De Motte Park. It is smooth and treeless, but the ground surrounding it and rising rapidly to heights of 300 and 400 feet above its floor, is densely clad with forest. If the traveller loses his way among the hills, ravines, and forest glades of the Kaibab, which are all extremely like one another, he must go at once to the De Motte Park. The way may be long, but it is easy and sure. The main ravines all radiate from the summit overlooking the Park, and to find the way out of the labyrinth he has only to follow the course of one of them up to its head, and avoid deviating into any of the minor tributary branches. Pools of water are to be found at many parts of the Kaibab. They vary in depth from a yard or two to 100 feet, and have sometimes a diameter of over 100 yards. None of these are fed by running water, and their origin is somewhat obscure. The rains sink through the rock as easily as through sand, and supply the perennial springs that gush forth from the sides of the Grand Cañon thousands of feet below, and it is possible that these lagoons are the mouths of swallow-holes connected with the subterranean channels, and kept open by the solution of the limestone of the plateau.

From the summit of the Kaibab magnificent views are to be had of the wondrous region below. The panorama from Point Sublime is described in glowing language in the eighth chapter of Captain Dutton's *Tertiary History of the Grand Cañon District*,¹ a volume from which much of the information in these pages is drawn; and Mr. Holmes has, with

¹ Washington, 1882.

skilful hand, given us a vivid pictorial representation of the stupendous scene in the atlas accompanying the monograph (Plates xv., xvi., xvii.).¹

PARIA PLATEAU.—The eastern side of the Kaibab is formed by a great monoclinal bend downwards of the strata. The surface sinks rapidly nearly 4000 feet between the edge of the Kaibab and the brink of the Marble Cañon, where the bedding of the rocks is again nearly flat. The Paria Plateau is the northern part of the area between the Kaibab and the Marble Cañon. It is bounded on the north by the Paria River, and terminates on the south in the eastern extension of the richly coloured and ornate escarpment of the Vermilion Cliffs.

THE TERRACES.—All the great physical features imprinted by the *subterranean* forces on the Grand Cañon District cross it in an approximately north and south direction. There is, however, another and equally distinct system of cliff lines at right angles to the first. These are cliffs of erosion, which have not been elevated into their present forms, but are the result of the long-continued action of *subaërial* agencies. As we go northwards from the brink of the Grand Cañon, parallel to the ledges that separate the minor plateaux, the land begins after a while to rise in a series of terraces which form a great stair up to the High Plateaux of Utah.

For many miles round the Grand Cañon the country consists of sandstones and limestone beds of Carboniferous age. They appear at first quite horizontal, but on closer inspection are seen to slope very slightly towards the north. This inclination is not uniform, but varies from *nil* up to 2° or 3°, and may be averaged at 40' over the whole plateau. Small as it appears, its cumulative effect is great enough to depress the surface of the Carboniferous formation to sea-level beneath the Markágunt Plateau, and to raise it to a height of 8000 feet at the San Francisco Mountains, 130 to 180 miles further south. Had the beds been quite flat we should, in ascending from the edge of the Grand Cañon to the top of the Terraces, have to climb 10,000 feet, as this is the thickness of the formations beneath which the Carboniferous series is buried. The slight tilt which the area has received, however, saves us half this climb, for, on crossing the edges of the Terraces, we only gain 5000 or 6000 feet in height.

The lowest terrace, known as the Shinárumpt Cliffs, is formed by the outcrop of the Permian sandy shales and sandstones, scattered outliers of which have been already mentioned as occurring sporadically over the plateau. The hues of the Terraces are gorgeous in the extreme, and

¹ A reduced copy of one of Mr. Holmes' best drawings of the scenery of the Grand Cañon forms the frontispiece of Dr. A. Geikie's *Text-Book of Geology*. Copies of this and other publications of the United States Surveys may be seen in the Library of the Scottish Geographical Society, and in those of other scientific Societies in the country. The accompanying illustrations are from Powell's *Report*.

reach their climax of brilliancy in the Lower Triassic and Permian series. Dense rich reddish-brown bands and streaks of chocolate are interbedded with purple, violet, lavender, and white, while lower down there are layers of a peculiar Indian red, alternating with more sober greys.

THE VERMILION CLIFFS.—The Permian terrace is not always distinct, and sometimes runs under and forms part of the great Triassic escarpment of the Vermilion Cliffs. This huge mural precipice runs eastwards from the Hurricane Ledge to Paria, and, crossing the Colorado at the foot of the Glen Cañon, trends southwards under the name of the Echo Cliffs, which gird in the Grand Cañon District on the east. The Vermilion Cliffs increase in size and magnificence towards the valley of the Virgen, where they rise 2000 feet above the plain. The sandstone beds, which greatly predominate, are separated at places by thin bands of gypseous shale, and these, being partly soluble, are more easily eaten out by the weather. They thus produce lines of deep shade which cross the cliff faces, and throw into stronger relief the bright-coloured sandstone zones between. The shales retain a wonderful uniformity over wide areas, and individual beds may be traced along the cliffs with unchanged thickness and hue for many miles. Near the top of the Trias is a massive bed of sandstone everywhere distinct from the thinner bands below. It swells in thickness from 200 feet at Kanab to 1200 feet in the valley of the Virgen. It is gashed from top to bottom with straight vertical joints, and the weather, taking advantage of all such weak places, is ever at work widening the joint fissures into deep gullies and clefts. After long ages of such erosion the summit of the Vermilion Cliffs has become fretted and carved into domes, towers, and pinnacles of wondrous form and beauty.

In the neighbourhood of the Virgen, the Vermilion Cliffs send off buttes resembling vast bergs detached from the parent ice-sheet, only here it is the parent mass which has retired, and the bergs which have withstood the powers of the air. Architecturally the buttes may be likened to colossal temples and cathedrals flanked with massive buttresses and crowned with domes and spires, which shoot high into the air and mingle with the clouds. They are carved and fretted into the most ornate and ever-changing forms, but are all built on the same plan, cut from the same block, and girded with the same bright belts of colour.

THE WHITE CLIFFS.—Each formation in the Grand Cañon region has its own style of architecture. When we reach the terrace above by one of the few passes through the Vermilion Cliffs, we are confronted by another line of precipices of a totally different character. The Jurassic series, which follows the Trias in palæontological succession, is here represented by bright red fossiliferous shales resting on a very massive bed of white sandstone, nearly 1000 feet in thickness. The shales are from 300 to 500 feet thick, and yield typical Jurassic fossils, but it is the great sandstone bed that first strikes the eye and draws the attention of the

explorer. The white cliff-faces are, on near inspection, seen to be etched with myriads of gracefully curved and diagonal lines of "false-bedding." The harder laminae project in little ridges from 6 to 15 inches beyond the softer ones, and the entire surface comes to have the appearance of a huge piece of petrified filagree work. But in the distance all minor features fade away, and the cliffs rear their pallid battlements aloft, unmarred from base to summit by vertical or horizontal shadows. Unlike the ornate Vermilion Cliffs below, the Jurassic escarpment is as bald and severe as a row of military barracks. Their appearance is not even relieved by a fringe of sloping talus, like the long smooth bank that sweeps round the base of Salisbury Crags at Edinburgh, and adds so much to their impressiveness and massive strength. The White Cliffs are, however, not altogether devoid of scenic interest, as their edges are sinuous and often furrowed by gullies, or occasionally carved into dome-shaped buttes and stacks of fantastic form.

From the top of the White Cliffs the country slopes upwards to the Markágunt and Paunságunt Plateaux. The outcropping edges of the Cretaceous sandstones and shales do not here give rise to very prominent terraces; but in the Paria district the ledges rise quickly tier above tier, and form an imposing stairway 4000 feet in height. The Cretaceous rocks show none of the orange, purple, and chocolate hues so common to the other formations of the district, but the pale yellows and light brown tints of the sandstones, intercalated with the blue or dark iron-greys of the shales, give an altogether peculiar colour-effect to this formation.

THE PINK CLIFFS.—We have now reached the highest of the terraces. The Eocene escarpment of the Pink Cliffs crowns the Cretaceous slope, and completes the list of formations in this region. It is not a deep-sea formation, but is a series of deposits formed in a lake, brackish at first, but afterwards quite fresh. These beds bespeak a great change in the geological and physical history of this part of the earth's crust. They tell of upheaval of the land and disappearance of the sea over large areas, and the beginning of the present history of a great continent. The cliffs are carved into rows of square obelisks and pilasters of uniform size and pattern, and produce the effect of a huge colonnade from which the entablature has been removed or fallen in ruins. There are limestones at the top, and thick beds of marl below, mixed with sandstone and conglomeratic layers. At the top there is a snow-white band over an orange yellow zone, but the main mass of the cliffs has a pale red tint, which, as the sun sinks towards the horizon, deepens into a rich rose colour, seen in no other rocks, and beautiful beyond description.

THE GRAND CAÑON.—Such are the main orographic and structural features of the plateau region through which the Colorado has cut its gorge. The wonders of the great chasm itself may perhaps be best described by first giving a short account of Powell's memorable pioneering

voyage through the cañons in 1869.¹ Major J. W. Powell, his brother, and eight men formed the party who, on the 24th of May 1869, started in four stout boats from Green River City on the Union Pacific Railway. The voyage down the Green River was exciting and perilous in the extreme, and many hairbreadth escapes were made long before the Grand Cañon was reached. The boats were often overturned among the rapids, and one was dashed to pieces at the Disaster Falls, a very bad part of the gorge through the Uinta Mountains, where Ashley, a previous explorer, had been wrecked, and several of his men drowned. The adventures had occasionally a certain smack of grim humour about them. On one occasion Powell and one of his men began the ascent of the cañon wall just below the mouth of the Yampa, a tributary of the Green River above its junction with the Uinta. After ascending five or six hundred feet they came to a sheer precipice, up which they managed to climb till the top was nearly reached. "Here," says Powell, "by making a spring I gain a foothold in a little crevice, and grasp an angle of the rock overhead. I find I can get up no further, and cannot step back, for I dare not let go with my hand,² and cannot reach foothold below. I call to Bradley for help. He finds a way by which he can get to the top of the rock over my head, but cannot reach me. Then he looks around for some stick or limb of a tree, but finds none. Then he suggests that he had better help me with the barometer case; but I fear I cannot hold on to it. The moment is critical. Standing on my toes, my muscles begin to tremble. It is sixty or eighty feet to the foot of the precipice. If I lose my hold I shall fall to the bottom, and then perhaps roll over the bench, and tumble still further down the cliff. At this instant it occurs to Bradley to take off his drawers, which he does, and swings them down to me. I hug close to the rock, and let go with my hand, seize the dangling legs, and, with his assistance, I am enabled to gain the top."

On they sped, past the mouths of the Uinta and Grand, camping at the river's brink at night, and naming the precipices and the unknown cañons they sailed through by day. Higher and still higher towered the walls on either side, and when, on the 12th of August, the foot of the Marble Cañon was reached, they found themselves sailing in the bottom of a chasm three-quarters of a mile beneath the level of the surrounding country. The Great Unknown now lay before them, and no voyager had ever solved the problem of that awful gulf. "Stories were related of parties entering the gorge in boats, and being carried down with fearful velocity into whirlpools, where all were overwhelmed in the abyss of waters; others of underground passages for the great river, into which boats had passed never to be seen again. It was currently believed that

¹ For full information, see Professor J. W. Powell's *Report on the Exploration of the Colorado River of the West and its Tributaries*. Washington, 1875.

² Powell had gone through the Civil War, and had lost his right arm in the battle of Shiloh.

the river was lost under the rocks for several hundred miles. There were other accounts of great falls whose roaring music could be heard on the distant mountain summits. There were many stories current of parties wandering on the brink of the cañon, vainly endeavouring to reach the waters below, and perishing with thirst at last in sight of the river which was roaring its mockery into dying ears."

The gorge had increased in depth from 200 feet at the head of the Marble Cañon to 3500 feet at the beginning of the Grand Cañon. The path had always been found roughest where the rocks were hardest, but now the river entered a gorge of metamorphic rocks harder than any that had before been met with. A roar of waters was heard ahead where the river dashed over a set of falls with a descent of 75 or 80 feet in a third of a mile. Granite crags rose dark and grim on either side, and as no footing was to be had along the water's edge whereby a "portage" might have been effected, no alternative was left but to shoot the rapids, and brave the dangers of the river or perish in the attempt. Their skill and pluck were rewarded. The rapids were safely passed, and the three boats shot into smooth water below the falls. The bottom of the gorge was dark and narrow. Black granite walls rose 1000 feet above the river, and above the granite the flaring red carboniferous strata, with their characteristic ledges, screees, and corners, towered high into the air, and spread out over the surface of the plateau more than a mile above the river's brink. Other falls were reached, and the boats became unmanageable. One was overturned, and the crew thrown into the raging river. The water-tight compartments, with which she was fitted in bow and stern, kept her up, however, as they had often done before, and her occupants, clinging to the sides, were rescued by their comrades in the other boats.

The granite and metamorphic rocks cropped out only in the part of the cañon opposite the Kaibab Plateau, and when, on the 21st of August, the party crossed the line of the West Kaibab displacement, the dreaded crags disappeared, and they were swept into quiet waters. Since starting, they had passed more than 600 rapids and falls, and were now in a pitiful plight indeed. The little canvas they had for camping under at night was rotten and useless; the rubber ponchos had all been lost, and more than half of the explorers were without hats to ward off the sun's rays when the thermometer stood above 110°. They had not a blanket a piece, and, worst of all, rations were nearly exhausted, and could not last much more than a week. As the barometers were all so much injured as to be useless, the reckoning in altitude was lost, and it was impossible to know how much descent still lay before them.

At several parts of the cañon they were surprised to find ruins of stone and lime buildings, pieces of pottery, flint chips, and other relics of a race more civilised than the Indians who now inhabit the plains above. These may have been the homes of the aborigines who, tradition says, were driven by the Spanish invaders from Arizona and New Mexico, and sought safe retreats in the then unknown lands of the cañons.

Between the Kaibab and the Hurricane Ledge the walls of the cañon are of the soft Carboniferous strata of the plateau, and the rapids are consequently less numerous and steep than in those parts where granite predominates. On reaching the Uinkaret division of the gorge the remains of the old volcanoes were seen crowning the cañon walls. At some places floods of lava had been poured over the brink, and had once filled the chasm to a height of 1200 or 1500 feet. But the river had cleared out its course again, and was once more grinding down into the old sandstones and limestones below. On the 27th of August the boats reached the line of the Hurricane Ledge, and here fresh troubles began. The river turned southwards, and the dreaded granite hove once more in sight. The falls ahead roared louder than any that had yet been passed, and the stoutest hearts began to quail. One of the crew wrecked at the Disaster Falls had left the party at the Uinta River, and gone home, satisfied with the perils he had already encountered, and now three others refused to enter what seemed the very jaws of death, preferring to climb the cañon wall, brave the desert and the Indians, and find their way to the nearest Mormon settlement, seventy-five miles off. One of the boats was so battered that Powell, with his brother and their four remaining comrades, determined to leave her behind, and explore the rest of the cañon in the two others, or perish in the attempt. The three deserters helped their companions to lift the boats over a rock 25 or 30 feet high, and after a sad good-bye, began their ascent into the plateau above, and were soon lost to sight. The falls proved dangerous, but not so bad as they appeared from above. The boats were dashed about, and Powell's was upset, but no lives were lost, and on the evening of the 28th of August they left the granite behind, and breathed freely once more. Next day they passed the Grand Wash, and, with feelings better imagined than described, emerged from the portals of the Grand Cañon.

Inquiries were made about the three men who left above the granite falls, and their sad story was soon learned. The poor fellows arrived almost starved at an Indian village, and were kindly treated and put on their homeward way. They were, however, afterwards followed up and murdered by the Indians, who mistook them for a party of miners who had lately killed a squaw, and would not believe their story of a voyage down the dreadful cañon.¹

DIMENSIONS AND FORM OF THE GRAND CAÑON.—The distance from the Little Colorado to the Grand Wash is $217\frac{1}{2}$ miles following the

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¹ In the *Bulletin* of the American Geographical Society, June 30, 1887, an article, entitled "The Great Walled River," gives an account of a second and better equipped expedition, under Powell, down the Colorado in 1871 and 1872. None of his original comrades accompanied him again. With three boats and ten men he sailed down as far as Kanab Cañon, where the height of the water, and the news of an ambuscade of Indians further down the river, led him to discontinue the voyage.

Figure 2.—View of the inner gorge of the Grand Cañon of the Colorado, looking east from Toroweap.

windings of the river. At the confluence of the two Colorados the Grand Cañon has a depth of 3600 feet. Three or four miles west of this point the land rises quickly to the summit of the Kaibab, and the gorge deepens in consequence to about 6000 feet. The Kaibab division—about 60 miles in length—is the most sublime part of the Grand Cañon. It is 1000 feet deeper, more diversified, and better adorned with magnificent features than any other portion of the chasm. The side walls are suddenly lowered by each of the great faults which cross the plateau, but the declivity of the river-bed soon repairs the lost altitude. At the Grand Wash the river issues from a gateway 5000 feet in height, and the walls on either side sink to mere banks a few hundred feet above the water's edge.

The absolute height of the river-bed falls from 2640 feet at the Little Colorado to 1000 feet at the Grand Wash, so that the average slope of the bottom of the Grand Cañon is 7.56 feet per mile. This inclination is far from uniform, as Powell found to his cost, and varies from 12.07 feet among the hard granite crags beneath the Kaibab to 5.01 in the softer sedimentary division of the Kanab. In the Marble Cañon the average fall is 7.82 feet per mile, and the whole fall, from the head of the Marble Cañon to the foot of the Grand, is 2190 feet for a distance of 283½ miles. The total fall between Green River Station and the Grand Wash is 5000 feet.

The Grand Cañon is not a simple chasm like a great crack with straight sides, but is divided into two distinct parts. There is first an outer valley, from 5 to 6 miles broad, between vertical walls of cliff 2000 feet in height. This great esplanade is rough indeed, but relatively flat when compared with its lofty walls. The inner or second part of the cañon runs like a trench along the middle of this floor. It is 3000 feet deep, and from 3500 to 4000 feet in breadth, measuring from brink to brink between the nearly perpendicular walls. Fig. 2 conveys an idea of the appearance of the inner cañon opposite the Kanab Plateau.

GEOLOGY OF THE GRAND CAÑON.—The walls of the outer cañon are of limestone and brilliant red sandstone. They constitute the Aubrey division of the Carboniferous formation of this region, and, although innocent of coal seams, are believed to be the equivalents in age of the coal measures of Pennsylvania and Britain. The strata of the inner gorge are known as the Red Wall group, and consist of red and brown sandstones and massive beds of purplish limestone. These strata rest unconformably on the upturned edges of an enormous mass of older stratified rocks, which form the lower part of the cañon wall for some miles below the mouth of the Little Colorado. The latter are conspicuous in the distance by their regular bedding and chocolate and magenta tints. They are believed from fossil evidence to be of Silurian age. There is, however, a still older group of rocks on which the Silurian beds in turn repose unconformably. In cutting through the granite the river has dissected the region to the bone, and exposed the whole anatomy of the

plateau. The Archæan crystalline schists, which may be popularly described as granite, are the primeval foundation on which the stratified formations have been reared. They formed the framework and superstructure of the land in the dim mists of geological antiquity. Volcanoes burst through and poured their floods of lava over that ancient land-surface, and some of the lavas may still be seen in section high up in the cañon wall. Worn down and afterwards submerged, the Archæan rocks became buried beneath many thousands of feet of sediment in the seas of Siluria. The sea-bed was in course of time again upheaved, and the deposits were crumpled from below and attacked by the watery elements above. The Silurian fragment in the Grand Cañon is part of a formation 10,000 feet in thickness, the greater part of which has been completely denuded away. A long-continued submergence now set in. While coal forests grew rank and dense on the neighbouring land, a constant shower of sediment was rained on this part of the ocean floor. Deposition went on throughout the Secondary ages, and was not arrested till the final upheaval began at the beginning of the Tertiary Period.

At the close of the Cretaceous Period the region south of the Uintas was cut off from the sea and converted into a great fresh-water lake, in which Eocene strata were laid down. This movement of upheaval affected the entire western part of the continent. Several lakes were formed; but the Plateau Lake was the largest, and sediment accumulated in it to a thickness of from 1200 to over 5000 feet. In course of time it began to dry up, and shrank slowly away from the south, finally disappearing at what is now the base of the Uintas, at the close of Eocene time.

THE LIFE-HISTORY OF A RIVER.—Rivers are born with the land, and their first courses are shaped by the prevailing slopes. While the land remains above sea-level its drainage areas are being constantly worn away, and this process will only be arrested when the rivers reach their "base-level of erosion"—the slope at which their transporting power ceases, and they begin to deposit their load. Most of the British rivers have reached this stage in their history, and meander along nearly level straths with velocity scarcely sufficient to carry seaward aught but the finest sediment. They cannot therefore deepen their beds any further: all they can do is to widen the straths, and spread abroad the alluvium from their swift mountain tributaries. In such a climate as ours the valleys all come to have a shape like a roofing tile, because the rain and frost eat back the sides of the channel as fast as the river scoops its way downwards. Were the climate dry, atmospheric erosion would be less active. The river would work by undermining, and the cliffs would consequently be kept vertical like those below the Falls of Niagara. With a high inclination the river would rush on at a correspondingly high velocity, and erode very actively. It would work downwards and produce a gorge, until the base-level was reached, and then it would have leisure to cut into the cliffs, and widen its channel into a strath.

EFFECT OF A DRY CLIMATE.—Such are the conditions under which the Colorado is at work. It is fed by the melting snows of the Rocky Mountains, and flows for many hundreds of miles through a dry region, where scarcely any addition is made to its volume. Between the junction of the Grand and Green and the lower end of the Grand Cañon—a distance of 500 miles—the Colorado has only two tributaries of importance. These are the San Juan and the Little Colorado. Professor A. H. Thompson gauged the Grand and Green in 1877, and found the minimum flow of the Colorado at the confluence to be 9260 cubic feet per second. The greater part of the water that the river receives from its tributaries, and from the springs which issue from the bottom of the cañon walls, is probably needed to compensate for the loss by evaporation. The dryness is extreme and the heat intense in the plateau region. From June to September the midday temperature is seldom below 90°, and often exceeds 110° F.; while the relative humidity is from 0.3 to 0.4 of saturation. The excessive aridity and heat sometimes give rise to the curious meteorological phenomenon of rain-streaks—showers which fall a certain distance, but are evaporated in mid-air before reaching the earth. The average rainfall is unknown, but Dutton thinks that 4 inches per annum is probably as large a precipitation as we are at present justified in assuming for the district draining laterally into the Marble and Glen Cañons.

In such an arid region atmospheric erosion is very small. The cliffs of the plateaux retain the vertical profiles they received when sawn into by running water during a moister age. The sharpness of the cliffs and the remarkable absence of tributary streams are the two most striking evidences of a long-continued rainless climate. The latter feature is very conspicuous in the valley of the Nile, which, in this respect, is the Old-World counterpart of the Colorado. The sources of the Nile are in far-off moist regions. It receives little or no water on its way, and but for the fact that it has nearly reached its base-level of erosion, the lower Nile Valley would be a typical cliff-walled cañon.

EROSIVE POWER OF RIVERS.—The lapidary's wheel is powerless to cut hard gems without a coating of still harder diamond dust strewn on it; and in like manner a river is powerless to erode its channel without a load of hard sediment to cut with. The sandblast is a powerful grinder, and can achieve great things when continuously and well directed. In the hydraulic mines of California, the water discharged against the gravel banks has been known to cut in a single year (equal to 100 days of uninterrupted work) channels from 10 to 20 feet deep in the hard basaltic pavement over which it flows. The course of the Colorado is steep and its flow is rapid. It receives large quantities of sand and gravel from its tributaries, and from the cliffs and gullies at its sides. The rocks crumble gradually down as the calcareous or gypseous matter which holds the particles together is dissolved away. When rain falls,

the loose disintegrated materials are washed down the long screes and side gullies, and are poured in torrents of thick mud into the central chasm. During such spasmodic floods the water often carries along more than twice its volume of solid matter. It is a common experience of explorers, in filling a camp-kettle from one of these burns during a spate, to find, after letting it stand all night, an inch of doubtful water on the top, over 7 or 8 inches of viscous red clay and 3 or 4 of sand and grit at the bottom. These mud torrents are not confined to the winter months, as local showers fall during summer with considerable frequency. The blocks which fall from the cliffs are soon ground up and carried off in particles by the river. Dutton estimates that, when exposed to the full force of the current, the largest masses can scarcely last more than three or four years. At the mouth of each lateral gorge a cone of alluvium is shot into the Colorado, and forms a barrier over which the water dashes in short and violent rapids. The rapids due to the unequal hardness of the rocky channel are long, and, with some notable exceptions, less violent than those over the piles of alluvial boulders.

THE HISTORY OF THE COLORADO AND ITS LESSONS.—The history of the Colorado, from its first beginnings in the far-off Miocene Period to its wonderful achievements in our own day, has been deciphered with great skill by the experienced officers of the United States Geological Survey. The sumptuous monographs descriptive of the regions explored are a mine of wealth to the geographers and geologists of the Old World. A careful study of these works will amply repay the trouble, and will throw much light on problems which, in the more complicated lands of the Old World, are dark and difficult to understand. Had the cradle of Geology been in the Far West, the science would doubtless have grown stronger and reached a riper manhood than it has yet attained. The history of the rocks is there so simple that a child could read, and rival theories with their accompanying *odium geologicum* are out of the question. But great discoveries are only received when the spirit of the age is ready to accept them, and Hero of Alexandria lay for nineteen centuries in his grave before any practical use was made of his invention—the steam-engine. It is only lately that we have reached the stage when the wonders of the West can be rightly appreciated, and men and money found to thoroughly explore and explain its vast unpeopled tracts. The story of the Cañons would not have been believed 100 years ago when Geology had its first beginnings; and there are still some geological sceptics who scoff at the denudation theory, and ascribe the cañons to convulsions of mother earth, supposing them to be great cracks in the crust, like those produced by the sun on the mud of a dry pond. Let us lay aside prejudice, and, looking the facts straight in the face, decide impartially which explanation is the true one.

We must return from the digression we have made, and again resume the thread of the geological history of the plateau region, which was left off

at the close of the Eocene Period. The great fresh-water lakes gradually dried up, and the denudation of the surrounding region went on apace. Let us imagine what would take place if the whole region of the Canadian Lakes were to be progressively upheaved several thousand feet. The declivity of the St. Lawrence would increase, and it would scoop out its bed at a correspondingly quicker rate. In course of time it would so deepen its channel that it would drain in succession Ontario, Erie, Huron, and Superior, and become a great river with many branches spreading over the beds of the dried-up lakes. The sediment in the lake bottoms would in time be washed or worn away, and the river would work its way downwards through the underlying rock, till it reached its base-level of erosion. It would then work laterally like a scythe, and broaden its gorge into a strath, till the whole drainage area became reduced to a comparatively level plain. Between the main groups of tributaries, patches of high ground, with perhaps some of the old lake deposits still lying on them, might be left remaining as plateaux, from whose nature the existence of former lakes could be ascertained. Such seems to be the general sequence of events in the history of the Colorado: first, great lakes; then, a St. Lawrence; and lastly, a great river rising in the interior of a continent, and flowing in a deep gorge of its own making, through straths excavated at a former stage in its history.

It is usual to suppose mountains to be the most permanent of the landmarks of the globe. But this is not always the case, as rivers may, under certain conditions, retain their positions even more permanently for long geological periods. This is a most striking and important feature in the history of the Colorado. Fill up all the gorges and restore the breached barriers, and the melted snows of the Rockies will not seek to clear the old channels out again, but will find their way seawards by quite a different route. The upper reaches of the Colorado are especially instructive in this respect. The Uinta Mountains in Utah branch off from the Wasatch range in an easterly direction, and extend right across the course of the Green River. Towards the east the Uintas diminish in height, and become lost in a series of low ridges and hills. The river does not, as might perhaps be expected, bend to the left and make a circuit round the eastern end of the barrier. Instead of this, it runs right through the ridge at the bottom of a cañon nearly 3000 feet deep, and emerges on the south, to be joined by the White River and the Uinta in a comparatively level country. Very little examination is needed to dissipate any idea that the cañon through the Uintas is a crack rent open by convulsions of the crust, and afterwards taken advantage of by the river in its southward course. The true explanation is, that the river was first on the ground, and had the prescriptive right of way. In a sawmill, it is the log and not the cutting edge that moves forward; so here the river has remained stationary, while the land has been pushed slowly up against its cutting edge, and grooved with a gigantic saw-draught equal in depth to the amount of lift. The ridge of the Uintas rises to a height

of 3000 feet above the river, but this distance by no means represents the whole amount of cutting the river has performed. While it has been at work deepening its channel, the atmospheric forces have been wearing down the country on either side. The Uintas rose as a huge wrinkle on this part of the earth's crust, and could the crown of the arch be restored by building up the lost pieces, it would rise to a height of 24,000 feet above its abutments. We must not suppose it ever actually reached this altitude, as the wearing down probably kept pace with the upheaval. There has been a race on the downward path between the river-bed and the surface of the country; and the river, by concentrating its energies along one line, has won by 3000 feet. The total length of the racecourse was 24,000 feet, so that the present cañons through the Uintas only represent an eighth of the whole cutting the river has made since the great wrinkle rose athwart its path.

The same process of upheaval has gone on along the lower reaches of the river; and the fact that it has not altered its course shows how very slowly such movements of elevation take place.

During the moist Miocene Age, the plateau region was rapidly eaten away. The river, which carried off the Eocene lake deposits and the Secondary formations south of the terraces, at last reached its base-level of erosion. The Carboniferous rocks were probably protected by being below sea-level, and the river, after removing the Secondary strata, could not do more than partially smooth down the Permian beds which lay below. A time of elevation now began, and volcanic action accompanied the lift. The older basalts of Mounts Trumbull and Logan were poured out, and covered up the patches of Permian strata in the vicinity. The Colorado received fresh impetus, and began working its way downwards to a new base-level. The outer cañon was cut, and its floor is the base-level the river arrived at. The climate of the Pliocene period, succeeding the Miocene, was arid, and the river was not much aided in its work of erosion by side tributaries. Some which existed in the plateau region dried up, and left their side gorges opening high up in the cañon wall; and, of those which remained, most had their sources in the far-off highlands round the watershed.

After a period of rest, during which the river had time to widen the outer cañon for some miles, another upheaval began. The first lift had been one of 2000 to 3000 feet. This time it was greater, and amounted to 3000 to 4000 feet. The river began to excavate the inner cañon, and is still cutting downwards towards a new base-level. This upheaval was, like the first, accompanied by volcanic outbursts. The younger volcanoes of the Uinkarets emitted ashes and floods of lava, which gushed over the cliffs into the outer cañon, and, flowing across the great esplanade, rushed headlong into the inner chasm, which was not then so deep as it is at present, and formed a temporary barrier to the progress of the river. The great faults also belong to this series of movements. They cut sharply through the earlier volcanic rocks, but the more recent lavas cross

the lines of dislocation without the least sign of displacement. The movement must therefore have ceased several thousand years ago, before the last of the eruptions began. The old upheavals were paroxysmal, and interrupted by periods of rest, and it is possible that the earthquakes lately reported from Arizona may be connected with a new series of movements about to arouse the region from the centuries of repose it has lately enjoyed.

Since the dry climate began, the erosion of the plains bordering the Grand Cañon has almost ceased, as there is but little atmospheric waste and no running water to carry off the disintegrated materials. The erosion of the region is now almost entirely along the sides of the river. There is evidence indeed of a change of climate and a greater precipitation during the last stage in the evolution of the region. Many of the lateral cañons are slowly filling up with alluvium, which a perennial stream might easily remove, and there must therefore have been a time when the stream was strong enough not only to carry away the sediment, but to scoop out the rock below. This period corresponds to the Ice Age, which was here not icy but rainy. The ravines we have spoken of as radiating from the summit of the Kaibab, and affording to the lost traveller a clue to the labyrinth, were probably excavated by the running streams during this time of increased precipitation. The change in climate was only temporary, however, and all it effected was probably an increase in the volume of the streams, by which their transporting and eroding power was for a time enlarged.

In conclusion it may be well briefly to recapitulate the main lessons in geographical evolution which the Colorado is fitted to teach :—

1. **EROSIVE POWER OF RUNNING WATER.**—The geological structure of the plateaux shows that the present gorges in which the Colorado flows for long distances are entirely the work of running water laden with sediment, and are not fissures produced by terrestrial convulsions. Their present depth, which sometimes exceeds 6000 feet, only represents a small fraction of the whole cutting the river has performed since its birth.

2. **PERMANENCE OF RIVERS.**—The Colorado has continued to flow along its course since the end of the Eocene Period, when the great denudation of this part of America began. Mountains have been upheaved and worn away since that date, and volcanoes have lived and died within its basin, but it has outlived them all.

3. **SLOWNESS OF GREAT UPHEAVALS.**—The fact that the river has cut its way through the Uinta Mountains, which rose as a great barrier across its path, shows that the upheaval was so slow that the erosive action of the river could keep pace with the rising of the land. Had the upheaval been rapid, the river would have been deflected and turned into an altogether different channel.

4. EFFECT OF A DRY CLIMATE.—Tributary streams disappear and atmospheric erosion diminishes. Cliffs retain the sharp profiles they received when cut during a moister climate by running water, and rivers traversing arid regions tend to produce gorges and valleys with perpendicular sides, till, like the Nile, they reach a permanent base-level of erosion.

THE AUSTRALIAN ALPS.¹

TOPOGRAPHY AND OROGRAPHY.—Off the south-east coast of Australia, between Cape Howe and Sydney, the contour of the sea-bed shows an abrupt descent to a depth of 2170 to 2750 fathoms. This huge gully marks the western border of the vast subsidence area of the Central and Eastern Pacific, an area which is almost entirely girdled by a gigantic belt of active volcanoes. But here, in the western part of the Pacific, between New Zealand and the coast of Australia, and generally parallel to the latter between the points indicated, there exists this deep gully, which has in its rim neither active volcanoes nor important breaches. From this fact it may be inferred that this Australian depression is older in date than the broad subsidence area of the Pacific. The western wall of the depression curves steeply up to the surface of the ocean, and then towers up still higher in the mountain-system of the Australian Alps, which in general lie parallel to the coast, and are crumpled and folded along the line of their main axis. The Alps of south-east Australia belong therefore to an early geological period. And, indeed, they consist of granite and Silurian rocks, the latter much folded and metamorphosed, although in parts rich in fossils. In places, too, patches of Old Devonian limestone occur, as well as volcanic rocks, diorite and basalt, these last forming plateaux, as in the Bogong High Plains. The volcanic outbreaks to which these rocks owe their birth are assigned to the Devonian period. Scarcely any formations of younger date are to be met with in this region, with the exception of the Tertiary alluvial deposits which fill the beds of ancient valleys and lakes. But in no case do these Tertiary formations share in the plications of the older rocks; they lie either horizontal or with a very gentle inclination. The Silurian strata, on the other hand, are almost uniformly very steep or vertical. On the west and north the Australian Alps are skirted by the great Tertiary plain which now forms the basin of the river Murray. The elevation of the Alps seems to have taken place at a period earlier than the origination of the submarine gully which yawns at their eastern foot, and to be coëval with the subsidence of the Murray Plain.

The Australian Alps constitute a system of mountain-ranges lying in the south-east corner of Australia, and stretching from west to east, and

¹ Based on Dr. R. von Lendenfeld's study in *Petermann's Mitteilungen: Ergänzungsheft No. 87: Forschungsreisen in den Australischen Alpen*.