THE

AMERICAN JOURNAL OF SCIENCE.

[THIRD SERIES.]

ART. IX.—*Tertiary History of the Grand Cañon District;* by CLARENCE E. DUTTON, Captain of Ordnance, U. S. A., 4to, with folio atlas. U. S. Geological Survey, CLARENCE KING, Director. Washington, 1882.—With plate IV.*

THE features of the Grand Cañon of the Colorado and its varied illustrations of river erosion first began to be appreciated after the descriptions and views given in the Report of the Expedition under Lieutenant J. C. Ives in 1857–58, with which Professor J. S. NEWBERRY was associated as Geologist. Major POWELL's Reports and the photographs made by the Expedition under his direction added greatly to our knowledge and appreciation of the facts, making accepted truth of what had seemed to many to be almost beyond belief.

Captain DUTTON'S Report, just now published, still further illustrates the features of the region, portraying the magnificence of its various parts by remarkably effective views and word-pictures, besides describing its geological structure and history. In the course of the latter the author takes the reader on several excursions through the Grand Cañon among the castellated and cathedral-like peaks and ridges two to five thousands of feet in height which stand over its bottom and project from its deeply alcoved borders; and gives explanations along the way with regard to the peculiar features of the different rocks, the water-sculpturing process, the long and profound faults of the region, the many volcanic cones and outflows, and the era and extent of the great erosion.

These several topics are further discussed in separate chapters, treating of the physical history and evolution of the

* This notice has been prepared from advance sheets placed in the hands of the writer by the author.

various cañons of the district, their excavation, and the origin of special details.

In a previous Report on the High Plateau District of Utah, published in 1880, Captain Dutton had described with like fulness the country immediately north,* and the two Reports relate really to different parts of the same great plateau area. Between the parallels of 40° and 40° 30′, the Great Salt Lake comes to its southern end. Just east, in the same latitude, the Wasatch Mountains, rising in points to 13,000 feet, begin their north-and-south course. Farther eastward are spread out the tamer Uinta Mountains, a great plateau, 150 miles from east to west, and averaging 10,000 to 11,000 feet in height, yet reaching at one place a height of 13,694 feet. To the south, below the parallel of 40°, the Wasatch range falls off into the "High Plateaus" of Southern Utah, the Wasatch, Pavant, Awapa, Aquarius, Paunságunt and Markágunt plateaus, ranging from 10,000 to 11,600 feet in height, which are the subject of the former Report. These plateaus have together a length from north to south of 175 miles, with a breadth of 25 to 80 miles. Eocene beds, of lacustrine origin, are widely distributed over the summits with also extensive streams of trachytic and basaltic lavas of still later origin; and Cretaceous, Jurassic, Triassic, Permian and Carboniferous rocks come to view successively on descending into the intersecting gorges or valleys.

Passing south and southeast of the southernmost of these High Plateaus, the Markágunt and the Paunságunt, a series of great steps commences leading down, over successive cliffs and broad plateaus, from the Eocene table-land of the summit to, finally, the depths of the Grand Cañon—and with the account of this majestic "stairway" the new Report begins.

These successive steps to the cañon, along with the plateaus below them, cover a region on the north side of the river averaging 75 miles in breadth. The plateaus which this border area of the Grand Cañon include, beginning to the eastward, are the Kaiparowits, Paria, Kaibab, Kanab, Uinkaret, and Sheavwits plateaus.

The first step down from the Eocene of the summit is over Cretaceous rocks, for 4000 to 5000 feet—a vast series of sandstones and shales, of pale yellow and light brown to gray shades, rather brilliant in effect. The Kaiparowits plateau, the easternmost, is wholly Cretaceous at top, almost to the margin of the Colorado; and similar Cretaceous mesas cover nearly all northeastern Arizona and reach indefinitely eastward. The second step downward is over the Jura-Trias—first a descent of 300–500 feet over red shales with fossiliferous calcareous layers containing Jurassic fossils; then a great stratum of

* See for a notice, vol. xx, p. 63, 1880.

white sandstone, conspicuous for its cliffs and its massive architectural projections with few horizontal lines, a marked feature in the landscape along the Virgen. Below the "White Cliffs" come the "Vermilion Cliffs" of the Trias, mostly 1200 to over 2000 feet in height, generally thin-bedded, often presenting southward "a majestic front richly sculptured and blazing with gorgeous colors." The Paria plateau consists of the Trias at top. Below the Trias, and in some parts making the lower step of the great stairway, lies the Permian, consisting of evenly bedded sandy shales with thin layers of limestone, of deep and rich coloring—often chocolate, purple, red-brown between horizontal patches of violet, lavender and white.

Below all these, lies the Carboniferous. It is the floor of all the plateaus above enumerated except the two eastern, the Paria and Kaiparowits; and covers also a wide region south of the Colorado at the same level.

The thickness of rock passed over in descending from the top of the Eocene of the High Plateaus to the Carboniferous is 5000 to 6000 feet. But the Eocene thickens toward the Uinta Mountains to 4000 and 5000 feet, making the whole thickness of the formations overlying the Carboniferous about 10,000 feet. The Carboniferous has a small dip to the northward. The overlying beds partake of this dip in some degree, especially at their free southern borders. The beds thin somewhat to the eastward and most markedly so the Triassic in contrast with the Tertiary which thicken in that direction.

The Grand Cañon, 5000 to 6000 feet in depth, is cut out of the Carboniferous and lower formations, the Carboniferous making 4000 to 4500 feet of the whole, and the Archæan, with in some parts Silurian and Devonian strata, constituting the rest. The higher beds of the Carboniferous for 700 to 750 feet are of limestone; next below are red and gray sandstones and shales for 1000 to 1500 feet; and again below, for 1800 feet, mostly limestones, with other sandstones underneath.

The channel of the cañon has (1) an upper portion or story which is 4 to 5 miles wide, and about 2000 feet deep, and (2) an inner chasm cut through the floor of the upper to a depth of 3000 feet or more. The lofty walls of the upper portion, set back 2 to 3 miles from the profounder chasm and stretching along interminably (more than 100 miles), up and down the stream from east to west, are wonderful in architectural features, and add immensely to the grandeur of the landscapes. The so-called inner chasm is not a narrow cleft with perpendicular walls, and a slender strip of water half hid away in the dark depths. It has nowhere a width less than its depth and

is generally of much greater width; and over part of the broad area are crowds of mountain towers and temples, 3000 to 5500 feet in height, with combinations of amphitheatres, alcoves, buttresses and towers along the sides; and all is open to the sunlight.

The scenic effects of the out-cropping formations depend greatly on the horizontal bedding; but also largely on the unequal spacing of the beds, the variations in hardness tending to make cliffs to alternate with taluses, at longer or shorter intervals; and on the diversities in shade and brilliancy of coloring. The architectural forms, though on a mountain scale, are literally architectural, and different in type for the different formations. We quote a few paragraphs from the descriptive part of the Report.

"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 structure 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 influence of the scenery. Of these and many 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. 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. Northwestward of the southern 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 every where 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 1200 feet in the valley of the Virgen. 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 every where 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 Pepis 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 Virgen. At length they reach the sublime. The altitudes increase until they approach 2000 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.

"As we moved northward from Short Creek, we had frequent opportunities to admire these cliffs and buttes." * * *

"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—that of the temples and towers of the Virgen. At our feet the surface drops down by cliff and talus 1200 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 farther foreground of the picture stretches the inner cañon of the Virgen, 900 feet in depth and here of considerable width. Its bottom is for the most part unseen, but in one place it 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 4000 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 is all before us; yet it is only the central object of a mighty throng of structures wrought up to the same exalted style, and filling up the entire panorama. Directly in front of us a complex mass of white towers, springing from a central pile, mounts upward to the clouds. Out of their midst, and high over all, rises the dome-like mass of the temple which dominates the entire landscape. It is almost pure white, with brilliant streaks of carmine descending its vertical walls. 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, 1400 feet high, descends vertically from the eaves of the temples, and is succeeded by a steep slope of ever-widening base-courses leading down to the esplanade below. The curtain wall is decorated with a lavish display of vertical mouldings, and the ridges, eaves, and mitred angles are fretted with serrated cusps. This ornamentation is suggestive rather than precise, but it is none the less effective. It is neither repetitive, nor 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."

The illustrations of the report, both in the text and atlas, are admirable, and more than sustain the author's descriptions. Those from the drawings of Mr. Holmes are like photographs in accuracy of detail and aerial effect. Plate IV is a reduced copy of a plate in the text, representing "Vishnu's Temple," one of the architectural masses in the Cañon south of the Kaibab plateau, *having a height from its base of* 5500 *feet.* For others, and a continuation of the descriptions of this region of nature's architectural marvels, the reader is referred to the report itself.

The following are some points in the geological history of the region which the report brings out:

While Silurian and Devonian rocks (the latter paleontologically identified in the Kanab Cañon by Mr. Walcott) occasionally occur, the Carboniferous, for the most part, rests directly on the Archæan. Between the Carboniferous and the underlying Paleozoic beds there is always unconformability, both through the greater or less dip of the latter and the erosion of the surface; and the same is true through the Sierra country of central and western Arizona, and of Nevada and western Utah. But from the bottom of the Carboniferous to the top of the Cretaceous the beds are one continuous conformable series. The beds of this long range appear to have been deposited horizontally; the thick lower limestone of the Carboniferous was probably made in moderately deep water, and the rest of the formations—mostly sandstones and shales—near mean-tide level, as proved by ripple-marks and other evidences. From this fact is drawn the important conclusion that a gradual subsidence was taking place as the depositions went forward; and since the Cretaceous contains lignitic or coal-bearing beds throughout, and at short intervals alternating in the upper part with brackish-water instead of marine beds, it is inferred that there were alternations of emergence and submergence going on during its progress also, ending finally in

widely-extended estuary and terrestrial conditions. The Cretaceous seas probably stretched across from the Gulf of Mexico to the Pacific, with interruptions only of narrow emerged areas—that of the Great Basin being one of these, and another in Arizona. Between these two areas, or along the parallels of 34° and 37°, "we can now travel from the Mississippi to the Pacific without being at any time more than fifty miles distant from some known mass of Cretaceous beds;" and "every indication we now have raises a presumption in favor of a complete connection." The distance is nearly 2,000 miles.

"At the close of the Cretaceous, important vertical movements were inaugurated, and around the borders of the Plateau province some important flexures were generated." This epoch, the close of the "Lignitic" or "Laramie" formation, was that, it is supposed, of the making of the Wasatch Mountains. A great area, from the Aquarius plateau to the Colorado, must have been denuded at this time of the Cretaceous, so that the Tertiary over it was laid down on the Jurassic beds; and similar facts occur at other points indicating that "the Cretaceous closed amid important disturbances. Still the deposition of strata was not ended." The depositions of Eocene beds went forward in *fresh* waters until 1200 to 5,000 feet of strata were added to the series, the facts showing that a single lake extended from the Uinta Mountains southward over the Plateau region; that the elevation was sufficient, and sufficiently persistent to make great lake-basins; and evincing, also, since the beds are successively of shallow water origin, that, as before, a subsidence was going on over the Eocene lake region to as great a depth as the thickness of the beds. The earlier subsidence had been greatest in the line of the Wasatch Mountains; the later was most so farther to the northeastward, in the region of the Uinta Mountains, where Eocene beds have a thickness of 5,000 feet and the great Eocene lake made its final disappearance, only the lower Eocene occurring over the Plateau District.

The Miocene depositions followed, but it is difficult to find "in this district any epoch separating the later Eocene from the Miocene; and of the Pliocene nothing is known from any beds or fossils. Both eras were no doubt eras of gradual emergence; at the close of the Miocene an uplift took place of probably 2,000 to 3,000 feet, and at or near the close of the Pliocene a greater upheaval of 3,000 to 4,000 feet."

The making of the great north-and-south faults of the plateau region—first described by Powell—some of which extend northward over the region of the "High Plateaus" far toward the Wasatch Mountains, began, according to the author, at the close of the Miocene, and went on for some of them during the

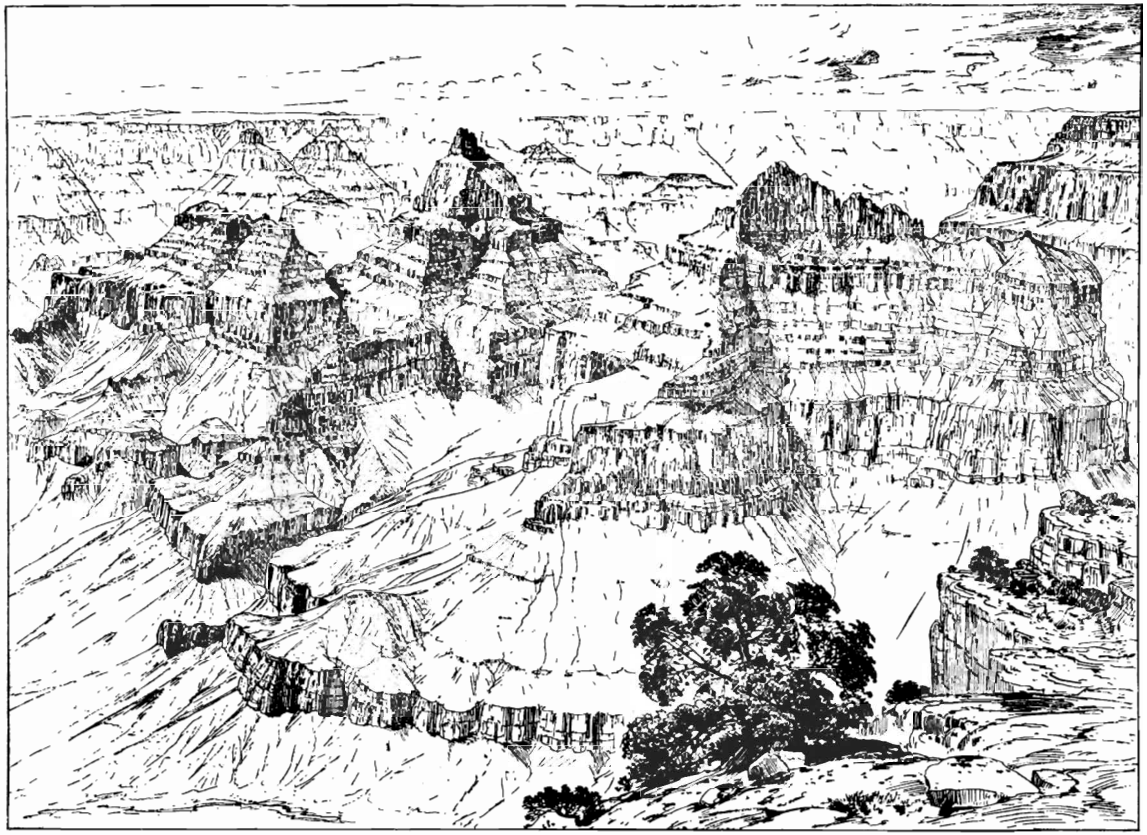
Pliocene. Among them the largest is the Hurricane fault, following the west side of the Uinkaret plateau, along which the displacement in the south wall of the Grand Cañon is 1500 feet; and farther north, near the Virgen River, 6,600, it making the Hurricane bluff 1200 to 1600 feet—ten miles farther north probably over 12,000 feet, the Eocene being on one side and the Carboniferous on the other—that is, if, as is probable, the Permian and Mesozoic beds, which there are now absent, were once in the series as they are elsewhere; and, farther north, it extends into Utah, along the west side of the Markágunt plateau and the southwest flank of the Tushar range, where it finally ends its course of 200 miles beneath great lava floods. Another is the Kaibab fault which outlines the Kaibab plateau on the west, and extends to the northward about as far as the Hurricane fault. The Kaibab fault is referred to the Pliocene and the Hurricane to later Pliocene.

The numerous volcanic cones and wide spread streams of lavas add greatly to the geological interest of the region. They cover much of the Uinkaret plateau, and descend from it for 1500 to 2000 feet into the upper portions of the Grand Cañon, and thus prove that the eruptions took place after the great faulting and after a large part of the erosion. But beyond this, some of the streams make a further plunge to the depths of the cañon; and in places over the bottom also there are cones and widely spread sheets of lavas. The Miocene, or its close, was the era of the earlier volcanic out-flows; but a large part were of Pliocene date; and some are of quite recent time, their scoriaceous lavas looking as if of recent ejection, perhaps dating but a few centuries back.

In the history of the erosion, Captain Dutton observes that the first channeling along the line of the Grand Cañon occurred in the early Tertiary or at the close of the Cretaceous. The removal of Cretaceous beds that once covered the borders of the Colorado Cañon south of the Aquarius plateau, leaving a surface of Jurassic beds, was part of the earlier erosion. The emergence was small in the Eocene, the climate moist, and, during its latter part "the degrading forces no doubt made progress in removing the Mesozoic deposits that originally covered the region;" and this work went on through the Miocene, completing nearly the denudation of the Tertiary, Cretaceous and Jura-Trias; that is, sweeping off large parts of these upper formations down to the Permian. The cutting of the Grand Cañon through the Carboniferous is stated to have gone on after the uplift closing the Miocene; at this time "the outer chasm of the Grand Cañon was cut" through the Permian and the upper part of the Carboniferous, and although it must at first have been narrow, it finally reached a width of some miles.

Then after another rise, "most probably near the close of the Pliocene," "the faults increased their displacement, the volcanic vents reopened," and the Colorado River resumed the operation of sinking its channel; and, as time went forward it made the inner chasm with all its grand features. The erosion made quite rapid progress owing to the high pitch given the surface by the new elevation; it has now almost ceased, the river having nearly reached a level of slight change by erosion or what is here called its base-level,—a base-level nearly for the stream at the present state of elevation of the land and ordinary annual floods. Captain Dutton observed that the Glacier period intervened between the Pliocene and the present time—a rainy rather than an icy era for that district—increasing the depth of the Cañon and making some new channels; but, he adds—limiting the effects more than some others might do, in view of the fact that the head waters of the Colorado drain the wide mountain region of the Rocky mountain summit for a breadth from north to south of more than 300 miles,—"The Glacial period appears to have been of too brief duration to have achieved any very great results in this district."

J. D. D.



VISHNU'S TEMPLE. COLORADO CAÑON.