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[T H I R D S E R I E S .]

ART. XLII.—*The Outlet of Lake Bonneville*; by G. K. GILBERT.

SOME of the readers of the Journal will remember that the name "Lake Bonneville" has been applied to a great body of water which formerly covered the desert basins of Utah. Its most conspicuous vestiges are its shore lines, and from them it is known that the ancient water surface was more than ten times as great as that of Great Salt Lake, and the ancient water level was about one thousand feet above the modern.

It was early surmised that the ancient lake was freshened by overflow, but the point of discharge was for a long time undiscovered, and it may be said to be still in controversy. The present paper takes up the subject of the outlet where it was left nearly two years ago.

In this Journal for April, 1878, the writer maintained that the point of outflow was Red Rock Pass, Idaho, at the north end of Cache Valley; that the discharging stream descended through Marsh Valley and thence continuously to the Pacific Ocean; and that, flowing over soft material at first, it gradually excavated at the Pass a channel more than three hundred feet deep, and lowered the lake level by the same amount. In the June number of the Journal, Dr. A. C. Peale controverted my conclusion, declaring, first, that the original altitude of Red Rock Pass was considerably below the highest level of Lake Bonneville; second, that the ancient shore line exists in Marsh Valley at the north of the pass, just as in Cache Valley at the south; and finally, that the real point of discharge, when the water stood at the Bonneville level, was about forty-five miles north of Red Rock Pass.

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Dr. Peale treats, in the same article, a question of priority and other matters of purely personal interest, and his remarks thereon invite reply, but I have a strong distaste for personal controversy, and I am confident that the readers of the *Journal*—not even excepting Dr. Peale—will cheerfully excuse me if I refrain. I shall therefore confine myself to the question of outlet.

Within a few months I have revisited Marsh Valley and Red Rock Pass, and have examined the lower cañon of the Portneuf. My observations do not serve to diminish materially the disparity between Dr. Peale's conclusions and my own, but they throw light on some of our contradictions in matters of simple observation. These contradictions depend in part upon a misinterpretation of certain terraces, and will be better understood after a brief enumeration of the characters by which terraces of diverse origin may be distinguished.

The term *terrace* is applied in topography to a level surface, or one of very gentle slope, limited on one side by a surface which *descends* at a greater angle, and usually limited on the other by a surface which *ascends* at a greater angle. Where the limiting slope is steep it is called a *scarp*. A scarp may stand above a terrace, rising from its inner edge and facing toward it, or it may lie below it, falling from its outer edge and facing from it. Most terraces are margined by scarps on one edge or the other, and some on both.

Terraces are produced in at least five different ways, namely: by differential erosion, by streams, by waves, by differential deposition, and by displacement.

Terraces by Differential Erosion arise wherever a series of dissimilar strata lying nearly horizontal are subjected to rapid erosion. The soft strata are destroyed more rapidly than the hard, and the latter, where they overlie soft beds, are undermined so as to break off by vertical fracture. A stair-like system of terraces and scarps is thus formed, in which each terrace marks the outcrop of a soft rock and each scarp the outcrop of a hard one.

These terraces are distinguished from all others by the constant relation of form to stratigraphic structure.

A *Stream terrace* is produced whenever a stream, which has for a long time, flowed at one level, is induced by changed conditions to excavate a new channel at a lower level. While flowing at the upper level the water forms a broad flood plain. By the subsequent excavation this plain is in part destroyed, and what remains becomes a terrace. A scarp of even height separates the terrace from the new channel of the stream or from a new flood plain.

It is characteristic of stream terraces that they slope in the direction of the stream that carved them.

Wave terraces are found on the shores of all bodies of water. The action of waves, combined with that of currents, carves away the land on all salients. The direct action is confined to a few feet above and below the water-level, but whatever is undermined by the waves is thrown down by gravity and brought within their reach. The results of the erosion are, first, a broad terrace lying under shallow water and sloping gently from the shore; and, second, a sea-cliff or scarp springing from the water's edge.

It is one of the chief characteristics of a wave terrace that its upper edge, where it joins the scarp, follows a water line. In the case of Lake Bonneville the water has long since disappeared from the terraces, but the horizontality remains as a conspicuous feature—subject only to slight modification by orographic displacement.

Delta terraces are produced by differential deposition. Where a stream enters a lake or other body of deep water, the chief part of the detritus it transports is deposited at its mouth. The effect of this is to extend its bed on the side toward the deep water. As the mouth protrudes a deposition takes place along the bed, so as to maintain a constant declivity of channel, and soon the bed is so raised that the water finds a lower way at one side and leaves it. By a repetition of this process the mouth of the stream is shifted from point to point, and the delta is made to encroach on the lake along its whole face. The form eventually produced is that of a terrace sloping gently down to the shore and there limited by a submerged scarp. The declivity of the scarp depends on the coarseness of the material deposited. The declivity of the terrace is identical with that of the stream which formed it. The contour separating the terrace from the scarp is a curve convex toward the lake.

A chief characteristic of a delta terrace is that its lower edge, where it joins the scarp, follows a water line and is horizontal. In the delta terraces of Lake Bonneville the horizontality remains though the water has disappeared.

Terraces by displacement are usually produced by faulting. A fault traversing a surface of gentle slope drops down the portion at one side or lifts the portion at the other, and separates the two by a scarp. The scarp is the only feature added to the topography, but by its addition the raised portion of the slope becomes a terrace.

Whatever is characteristic of the terrace by displacement pertains to the scarp. A *fault scarp* usually holds an even height for long distances. It maintains an even, often a

straight, course across the country, ascending and descending slopes without change of direction. It is only by accident that it is ever horizontal.

Wave terraces and delta terraces are associated phenomena of shore lines. They agree in the essential character of horizontality, and by that are distinguished from all other terraces. They have no such relation to rock structure as have terraces by differential erosion. Their scarps are not of even height like those of stream terraces. Their course across the country has the sinuosity of a contour, and not the directness of a line of orographic displacement.

Returning now to the consideration of the outlet of Lake Bonneville, let us glance a moment at the general features of the vicinity. Cache Valley and Marsh Valley are parts of the same trough-like depression, separating two mountain ranges. The general trend of the trough and of the ranges is a little west of north. Marsh Valley lies to the north of Cache Valley. It is thirty-five miles long and has a maximum width of fourteen miles. Cache Valley is fifty-five miles in length and eighteen in width. At the north end of Marsh Valley the trough is ended by the junction or close approximation of the bordering ranges. At the south end of Cache Valley it is interrupted by a low cross range. At Red Rock Pass, where the two valleys adjoin, the trough is restricted by spurs from the two ranges, and a few protruding crags show that there is a low cross ridge of limestone buried by more recent deposits. On the west side of Cache Valley there is a low interval in the bounding range—so low that the Bonneville flood overtopped it and made Cache Valley a bay of the great lake. At this point Bear River has cut a narrow gorge, through which the drainage of the entire valley finds its way to the basin of Great Salt Lake. Bear River and several other streams enter Cache Valley from the east by cañons traversing the bounding range. In like manner the Portneuf cuts through the eastern range to enter Marsh Valley, and then passes from it at its extreme northwestern angle by a deep-cut valley of erosion, opening to the great plain of the Snake River.

According to Dr. Peale, the Bonneville flood filled Cache and Marsh Valleys to the same level. Red Rock Pass was only a point of stricture of the lake, and the outlet was at the north. He mentions terraces in Marsh Valley and gives their altitudes, impliedly regarding them as shore terraces. According to my own observations, Cache Valley was occupied by Lake Bonneville, and Marsh Valley was not so occupied, but was traversed from south to north by the stream which overflowed at the north end of Cache Valley. There are no shore terraces nor

other lake phenomena of the Bonneville epoch in Marsh Valley.

In revisiting Marsh Valley I traversed it from end to end and made careful search for ancient shore terraces. The most favorable position from which to detect such vestiges is one which brings the eye in the same horizontal plane with them. The apparent distortion which arises from perspective is thus avoided, and all the little modifications of surface wrought by the waves, being brought into one straight line across the landscape, appeal to the eye by their *ensemble*. The most favorable light for the observation is one which throws the scarps into shadow or deep shade, and thus contrasts them with the adjoining terrace faces. In examining Marsh Valley I gave particular attention to the selection of stations and of light, and I considered my inspection of no part of the margin complete until I had viewed it from the proper height and in a favorable light. I ascended to a level corresponding to that of the Bonneville beach at ten different points, and the series of views thus obtained omitted no portion of the valley. I saw stream terraces and displacement terraces of considerable magnitude and a few inconspicuous terraces due to unequal erosion, but no wave terrace and no delta terrace.

If Marsh Valley had really been filled by the lake, as Cache Valley was, there could be no difficulty in finding evidence of the fact. The water would have been eight or ten miles broad and 400 feet deep, and the waves raised by the wind on a bay of such dimensions would leave most conspicuous monuments of their force. Arms of Lake Bonneville two or three miles in width and less than 100 feet in depth have elsewhere been traced out by means of their distinct and well-characterized shore lines, and this under conditions of slope, etc., similar to those existing in Marsh Valley.

But if Marsh Valley contained no lake, of what nature are the terraces adduced by Dr. Peale in support of his conclusions? The question is easier proposed than answered, but I think a partial explanation can be given.

The first locality he mentions is "two miles north of Red Rock Pass, on the east side of the valley." At this place there is a conspicuous stream terrace at about the right altitude to personate a delta terrace of the Bonneville series. Its surface is part of an alluvial cone formed by Marsh Creek before the Bonneville epoch, and its scarp is one wall of the channel worn by the outflowing river during that epoch. The river pared away the margin of the sloping plain spread by the creek and left the remainder as a terrace. The edge of this terrace is, at its highest point, 50 feet higher than the nearest trace of the Bonneville beach, two miles away; and it descends northward

until it passes below the level. On top of the terrace and about half a mile back (east) from its edge, there is a second scarp from 10 to 20 feet in height, and due to displacement. This fades out to the northward and at the same time descends with the general slope. Dr. Peale's observation probably refers to one or the other of these scarps, and in either case fails to take account of the lack of horizontality.

His second locality is "six miles west of Red Rock Pass." The only terraces I found at that point are stream terraces, sloping so conspicuously to the N.E. and N.W. that it is hard to believe they were mistaken for beaches. A few miles beyond there is a fault scarp with a much stronger semblance, and where this crosses the old freight road which ascends to Malade Pass it has very nearly the altitude appropriate for the Bonneville Beach. Its true character, however, cannot be mistaken when it is critically examined.

His third locality, "twenty-six miles from Red Rock Pass on the west side of the valley," was not identified.

Passing now from the subject of the general position of the outlet to the question of its precise location at the time of the commencement of the outflow, I find myself able to make a concession to Dr. Peale. I at first supposed that the divide originally lay between Red Rock and Hunt's Butte, just as it lies to-day, and I so described it. A careful reëxamination of the locality has convinced me that I was in error, and has led me to assign it a position two miles north of Red Rock. Dr. Peale placed it about forty-five miles north of Red Rock, so that my new determination is nearer to his than my old was.

With the aid of the accompanying map I hope to make the chief topographic features of the locality, and the history of the outflow, clear to the reader.

At the point of greatest orographic constriction, that is, where the mountains bordering the general trough, approach nearest to each other, there is evidence of a connecting ridge of limestone. This ridge is so low that only a few peaks of its serrated crest project through the superficial deposits. To it belong Red Rock (R), Hunt's Butte (H) and the hills marked L, L, L. Just north of the ridge Marsh Creek issues from the mountains at the east. It flows southwestward for three miles, makes a sharp turn about Hunt's Butte, and then flows northward to Marsh Valley, occupying the old river bed all the way from Hunt's Butte. It is the largest stream of the vicinity of the pass, and has thrown so much debris into the river bed that it has determined the modern divide at the point of its accession. It is contained by high banks all the way from its mountain cañon to Hunt's Butte and has no freedom to shift its course over its own alluvion until it enters the river bed. Before the Bonneville epoch,—before the river bed was cut, the creek had dug no deep channel outside the mountain cañon and was free to roam at will. It distributed its debris equally in all directions, building a fan-shaped alluvial plain (A) with its apex at the mouth of the cañon. All parts of this plain radiated with equal slope from its apex, and its surface was part of a low-crowned cone. In brief it was an *alluvial cone*. It extended westward until it met the foot-slopes of a spur of the western range and that point of meeting (x), which was about two miles north of Red Rock, was the divide between Cache and Marsh Valleys. When the brimming waters of Lake Bonneville were discharged across it, a river channel was slowly excavated, and the margin of the alluvial cone was cut away. The edge of the surviving slope is fifty feet higher than the Bonneville beach at Hunt's Butte and therefore fifty feet higher than the original divide. As the channel of outflow deepened by wear, the lake level was lowered and its shore retreated southward. The head of the outflowing stream fol-

lowed the retreating shore until, at the Provo stage of Lake Bonneville—the lowest stage of outflow,—the point of outlet was at the edge of what is called Round Valley Marsh (*y*), nine miles south of Red Rock. When the lake dried away, the divide was left at that place, but Marsh Creek has resumed control of it by constructing an alluvial cone in the old river bed at Hunt's Butte (*a*) and building it higher than the level of the last discharge.

The Bonneville water line, so far as it survives, is represented by the heavy lines B, B. Its restored continuation and the restored banks of the outflowing river are represented by heavy broken lines. The margins of the water at its lowest, or Provo stage, when the point of outlet was at *y*, is shown by lighter broken lines.

While Marsh Creek was building its ancient alluvial cone, it ran in turn over all parts of it. At times it passed south of the divide and flowed to the Great Basin. At other times it passed north of the divide and flowed to the Portneuf river. When the outflow of the lake was initiated and the water level began to be lowered by the deepening of the channel of outflow it chanced that the creek was running over the southern part of its cone, and discharging into the lake at Hunt's Butte. The lowering of its point of discharge caused the creek to cut away its bed instead of building it up and it ceased to shift its channel. As the river bed grew deeper, so did the channel of the creek, and the latter now flows several hundred feet below the top of its old cone. When, by the building of its new cone in the abandoned river bed, the creek recovered possession of the divide, it resumed its ancient practice of discharging alternately to the north and to the south. To-day it is a tributary of the Portneuf. The next freshet may clog its channel with debris and divert it to the drainage of Bear river.

After the publication of my former article, I learned that the outlet had been independently discovered by my friend, Mr. Gilbert Thompson, and I am glad of this opportunity to give him credit. Mr. Thompson is not a professed geologist, but he is an expert topographer, and his close study of the natural forms, which it is his work to delineate, has more than once led to observations valuable to the geologists with whom he has been associated. I quote the following from his letter dated April 10, 1878:

"Thanks for your brochure, 'the Ancient Outlet of Great Salt Lake.' The past season I was along the northern limits of the ancient lake, between 111° and $112^{\circ} 22' 30''$ and was absolutely ignorant of your examination in 1876 and its results. . . . I was very much interested in the general subject of its limits and also of its outlet. . . . Toward

the last of the season, as I surveyed from the north the road through Red Rock Pass, after noting the remarkable topographical features of Marsh Creek, and keeping a close run of the profile as given by the aneroid, I was delighted at Red Rock to see unmistakable evidences of the ancient outlet of Great Salt Lake. . . . Thus you may have the gratification of knowing of an independent and entirely unbiased verification of your determination of this point; and it is nowhere else in the limits I have mentioned."