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THE YOSEMITE GLACIERS.

THERE have lately come to my knowledge some interesting, and I think, conclusive observations as to the former great extent of the glacier system of the Sierra Nevada Mountains, in the neighborhood of the Yosemite Valley. They seem to throw light upon the causes which formed the Valley, or rather, by way of exclusion, upon the forces which did not form it. Before giving these observations, which have recently been made by Mr. John Muir, a gentleman who has made the region of Yosemite his study for years, and who records thus his personal examinations, it may be well to say a few words on the physical configuration of the region, that the force of his remarks may be better appreciated.

In all this immense region, with a radius of fifteen miles at least, there are now no proper glaciers, though there are large accumulations of snow upon the higher crests, and in their valleys, whose melting in the summer gives rise to the magnificent catacacts of the Yosemite Valley. The rocks, as every traveller there knows, are smoothed and polished to the very edge of the Valley, showing the former existence of an immense sheet of ice. What ordinary travellers saw on a limited scale, Mr. Muir has examined on a very large scale, having traversed the upper Sierra in all directions, and ascertained the existence of a glacier system, frequently alluded to in the "Geology of California" published by the State, whose size and direction had previously been rather guessed at than determined. That there are no glaciers there, as in the Alps, and comparatively little snow remaining till summer, is accounted for by its rapid evaporation in the very dry air of these high ranges. Not only are grooved polishings found, but well-marked moraines in the higher part of the range; but they do not exist to any great extent in the Valley proper, though they are traced far down the three great canons at the eastern end, the Tenaya, Merced or Nevada; and Illilouette or South Canons. There is a well-marked median moraine from the union of the Nevada and Tenaya glaciers, on the north side of the Merced river, near the hotels—well rounded, and now overgrown with large trees. The markings indicate a former glacier extending from Mt. Dana and Mt. Lyell, 13,000 feet high, fifteen miles in length, and more than a mile thick to the edge of the Valley; these marks are plain on the Sentinel dome, 4,150 feet above the Valley, and there is in the cabinet of the Boston Society of Natural History, a slab from Tenaya Cañon polished by the ice, brought home by Mr. Waterston. This glacier filled the upper or little Yosemite Valley, a counterpart of the larger one, but 2,000 feet higher, communicating with it above the Nevada fall, the main stream of the Merced river flowing through both. Also, a glacier passed down the Illilouette Cañon from the Obelisk group to the edge of the great Valley. It has been generally assumed that the land at
the head of the Merced river was not high enough for the formation of a glacier into the Valley.

Now comes the question, which Mr. Muir discusses: Was the Valley once occupied by a glacier?

The following are Mr. Muir's observations, almost in his own words, in a recent letter:

"I have been over my glacial territory, and am surprised to find that it is so small and fragmentary. The work of ancient ice, which we proposed to christen 'glacial system of the Merced,' is only a few tiny topmost branches of one tree in a vast glacial forest. The Merced ice basin was bounded by the summits of the main range, and by the spurs which once reached to the summits, viz., the Hoffman and Obelisk ranges. In this basin not one island existed, for all of its highest peaks were overflowed by the ice, Mt. Starr King, South Dome, and all. Vast ice currents broke over into the Merced basin from the Tuolumne, and most of this Tuolumne ice had to cross the Tuolumne Cañon.

"It is only the vastness of the glacial pathways of this region, that prevents their being seen and comprehended at once. A scholar might be puzzled with the English alphabet, if it were written large enough, and if each letter were made up of smaller ones.

"The beds of these vast ice-rivers are veiled with forests, and a network of small water channels. Yosemite was completely overwhelmed with glaciers, and they did not come down gropingly to the main valley of the Merced by the narrow, angular, tortuous canons of Tenaya, Nevada and Illilouette, but they flowed grandly and directly above all of its highest domes, like a steady stream, while their lower currents went mazing down in the crooked and dome-blocked channels of cañons.

"Glaciers have made every mountain form of this whole region; even the summit mountains are only fragments of their pre-glacial selves. The summits enclosing the basins of the glaciers are steeper on the north than on the south side, on account of the greater depth and duration of the ice sheltered from the sun; and this difference in steepness between the north and south sides of summits is greater in the lower, as those of the Obelisk group. Such mountains as Starr King, Cloud's Rest, Cathedral Peak, etc., do not come under this general law, as their contours were determined by the ice which flowed about and above them; but even among these inter-basin mountains we frequently find a marked difference in steepness between their north and south sides, because many of the higher of these, and crests extending east and west, continued to shelter and to nourish fragmentary small glaciers long after the disappearance of the main stream to which they belonged.

"In ascending any of the principal streams of this region, lakes in all stages of decay are found in great abundance, gradually becoming smaller and more recent until we reach the almost countless ones of the summits. Upon the main Merced and its branches there are not less than a hundred of these lakes, from a mile to a hundred yards in diameter, with many more of much smaller size. Both Yosemite and
Hetch-Hetchy valleys are lake basins filled with sand, and the matter of moraines abundantly and rapidly supplied by their swift descending rivers from upper moraines.

"The mountains above Yosemite have scarcely been touched by any other denudation than that of ice; perhaps all of the post-glacial denudation of every kind would not average an inch in thickness for the whole region. I am surprised to find that water has had so little to do with mountain structure in this region. None of the upper Merced streams give record of floods greater than those of to-day. A cross section of the glacial and water basin of the Nevada branch of the Merced, a few miles above the little Yosemite, shows glacial striæ, clear and unwashed, with undisturbed glacial drift nearly to the water channel of the river, whose perpendicular walls are about two feet deep; this stream even in flood was never more than five feet in depth, showing a water area, as compared with the ice stream, utterly insignificant."

With the light of Mr. Muir's observations, it seems to me that the formation of this valley could not have been due to the action of water or of ice.

The characteristic feature of this valley is the concentric structure of the granite, as seen in the "Domes" and "Arches." The views of Prof. Whitney, who has given this region more study than any other geologist, have already been given on page 33. That the peculiar appearance of these dome-like structures, very general in this portion of the Sierra, is not the result of ice or water action, is shown by the overlapping of these concentric granite plates overhanging the valley, and causing the enormous cavities or "Arches," left by the fall of the masses from the action of the frost and the elements, at the present time high above the reach of ice or water.

According to Mr. Muir, as taken from his published and unpublished letters to newspapers and friends, there were in the Merced basin,—bounded by the ridge extending from Mt. Lyell, northwesterly to the Cathedral Peak and to Mt. Hoffman; by a shorter parallel ridge about eight miles to the westward, running also northwesterly to Mt. Clark, of the Obelisk group; and a connecting ridge running a little east of north to Mt. Lyell, this last being the divide between the tributaries of the Merced river on the north, and the San Joaquin on the south, an area ten miles square on each side of the middle or Nevada Cañon of the Yosemite Valley—there were three great central glaciers, named respectively from the south northward: 1. The Nevada, coming down the cañon of that name, through the little or upper Yosemite Valley, in which now flows the main stream of the Merced with the Nevada and the Vernal falls, flowing in a generally west direction from the Lyell group, and about twelve miles long. 2. The Tenaya, in the cañon of that name, coming down by Cloud's Rest, and leaving as its most beautiful traces the Tenaya and Mirror lakes—flowing in a southwesterly direction from the Cathedral Peak and the neighboring summits, of about the same size at the Nevada glacier. 3. The Hoffman glacier, from the easterly slope of the mountain of that name, coming into the Valley by Indian Cañon, the
North Dome, and the Glacier Cañon. The marks left by these glaciers, miles in length and width, and thousands of feet in thickness, are now the polished surfaces, the smoothed domes, the extensive moraines, the beautiful lakes, and the green meadows—the strie and grooves are mostly obliterated by the frosts and the rains and the streams of centuries, except in a few protected, small, and hardly accessible places.

The fourth great ice stream which flowed to the Yosemite Valley, was the glacier which filled the basin of the Yosemite Creek on the north side of the Valley, from which now descends on the edge the beautiful Yosemite Fall, 2,600 feet high. This basin has been thoroughly examined by Mr. Muir, who estimates its glacier as having been fifteen miles long, five wide in the middle, and in many places 1,000 feet deep—uniting with the central glacier in the Valley by a mouth extending from the east side of El Capitan to Yosemite Point, east of the falls, a distance about four miles; on the north flowed by the great Tuolumne glacier from Mt. Dana and its range, the mightiest of these ice-rivers. It came from the western and southwestern slopes of Mt. Hoffman, and the main stream flowed nearly south; it had several branch basins among the higher spurs of this range, flowing to the east, now abounding in small clear lakes, set in the solid granite, without the usual terminal moraine dam. The north sides of these, and most of the spurs and ranges in this portion of the Sierra, as long since noticed by Prof. Whitney, are very steep compared with the southern, and as the spurs here mainly run east and west, their glaciers were deeper, more sheltered from the sun, and therefore longer lived than the main stream; the result is small glacier action, little detritus, and a quiet melting into clear lakes, with comparatively small borders of the meadows so characteristic of the disappearance of the lower glaciers. Though the declivity and rate of progress of some of the tributaries were great, the main stream, according to Mr. Muir, was rather level, and in one part of its course compelled to make a considerable ascent; to this fact of levelness, width at mouth, and overwhelming power of the concentrated central glaciers, he attributes in great measure the present height of the Yosemite Falls. The main stream of the Merced river, flowing through a narrow and deep cañon, has in its course the thundering Nevada and Vernal falls; while the wide and gently sloping Yosemite basin conducts its stream almost noiselessly and with comparative smoothness till it makes its final and only feathery plunge of half a mile vertical descent into the Valley.

Looking into the Yosemite glacier basin from any of its surrounding domes, you see many small patches of dark forests, apparently in close contact with bare rock, which mark the places of the fragmentary moraines of the basin, as later eroding agents have not had time to form a soil thick enough for the general growth seen in the Valley itself. Wherever, says Mr. Muir, a deep tributary was laid against a narrow ridge, sheltered from the sun by surrounding rocks, there are invariably found one or more small terminal moraines; melted off from the main trunk, with an independent and longer duration, their
moraines are left entire, because the water basins above them do not furnish streams large enough to wash them away, as is the case in the moraines of the canons and deeper water-courses. In the basins of exposed tributaries there are no terminal moraines, as their glaciers disappeared with the main stream. He says, "Medial and lateral moraines are common upon all the outside slopes, some of them nearly perfect in form; but down in the main basin there is not left one unaltered moraine of any kind, immense floods having washed down and levelled them into border meadows for the present stream, and into sandy flower-beds and fields for forests."

Between the three upper tributaries of the Yosemite basin glacier, he found well-defined medial moraines, these having been preserved from levelling floods by their position on the higher slopes, with only small water collections behind them. Down at their junction, where they were swept round by the main stream, is a large level field of moraine matter, which, like all the drift fields of this basin, is covered with a dense forest of pines and firs, the summit forests being composed almost entirely of a thickly-growing and pitch-covered pine. The domes of this upper basin present the same concentric structure and perpendicular cleavage already alluded to in the North and the Half-Dome of the Valley. Next west of the Yosemite basin, on the north side of the Valley, is the Ribbon stream basin, in which now runs the stream flowing into the Valley west of El Capitan by the Virgin's Tears Fall, dried up so early in the summer that it is rarely seen by travellers. This basin, Mr. Muir found, was occupied by a glacier, flowing nearly south, about four miles long and three wide, joining the central glacier west of El Capitan. He spent two days in this basin, whose glacier was one of the smallest which entered the Valley, the most of whose ice was derived from a south-west spur of the Hoffman group. The slope of its bed is steep and regular, and its ice must have moved with considerable velocity; exposed to the southern sun, it must have disappeared among the first, leaving a comparatively long period for the obliteration of the striated surfaces by the storms and the various disintegrating agencies of the weather; as in the Yosemite basin, the unprotected rock is disintegrated four inches deep, and no ice marks could we expect to find except upon hard quartz, or under a protecting boulder. Though he has not yet found the glacial stria, the fact of its existence is fully proved by the moraines, and meadows, and valley grooves, characteristic of glacial action here; its smooth and lake-like basin has fine forests of firs, growing upon moraines levelled by overflowing waters.

Next west of this, on the north side, he explored the Cascade basin, and in it he soon found a large patch of the old glacier bed, polished and striated, with the direction of the flow clearly indicated as south 40 deg. west. At the head of the Cascade meadows he discovered a well-defined terminal moraine, and the ends of both ridges which formed the banks of the ice are broken and precipitous, indicating great pressure. Following up one of the tributaries some miles, he found, throughout the entire length, many polished surfaces, moraines,
and striæ, giving as clear and unmistakable evidence of glacial action as can be found anywhere in the Alps.

Still farther to the west is the Tamarack basin, which had its glacier opening into the cañon of the Merced below the Yosemite Valley, and still others for more than twenty miles west of the Valley proper, which he intends to explore hereafter.

On the south side of the Valley was also a glacier of immense extent and thickness, coming down from the Obelisk or Mt. Clark group, overtopping Mt. Starr King, the main stream flowing in a westerly and northerly direction — entering the Valley of the Illilouette or South Cañon, one of its great sheets scoring and polishing the Sentinel Dome and Glacier Point. Farther to the west, on the south side, was also the Pohono glacier, in the basin where now flows the stream of that name, pouring into the Valley under the name of the "Bridal Veil" Fall, nine hundred feet in height.

While the Sentinel Rock and the Cathedral Rocks on the south side were fashioned by glaciers, so the Washington Column, North Dome, and the Three Brothers mark the action of the ice stream on the north side; the depressions between these peaks being so many glacier grooves or valleys, modifications, doubtless, of previously existing cañons or gorges.

Judging from what has already been discovered, it is altogether probable that future investigation will demonstrate the former existence of an immense glacier in this portion of the Sierra Nevada, larger even than Mr. Muir supposes, extending quite to the foot hills of the range, — causing by its gradual decay and tremendous force the present configuration of the country, with its streams, fertile meadows, and forests, — covering the Mariposa region, and carrying in its detritus the auriferous sand, so profitably worked in the beds of its rivers — extending over the present valleys of the Merced and Tuolumne rivers, even into the plains of the San Joaquin river and the Stockton valley.

Mr. Muir's researches have, I think, shown that all of the higher basins were filled with ice, with a sheet so deep and universal, that only a few of the highest crests of the Sierra were large enough to separate it into individual glaciers — many of the highest and the great domes having been flowed over and polished and rounded, like the boulders in a river. The enormous thickness and weight of this universal glacier will explain the marks of pressure above alluded to in the Cascade glacier; this, with the glaciers filling the valley, was but an insignificant fragment of the great whole. Glaciers poured into the valley by all its deeply covered cañons, and the great depression of the valley, we now behold with wonder and admiration, was hardly more than a deep rut in the grand pathway of this magnificent ice stream, so high did its thickness rise above the walls of the valley. All the rocks, and mountains, and domes, and meadows of the upper Merced, we can now readily believe, received their peculiar forms and distribution through the agency of ice, and not of water; and that the domes and cañons and walls of the great valley itself have been fashioned by the same ice-action — the ice stream
finding the valley previously existing, modifying, but not producing it, through the grand combination of its forces acting in a long-continued, uniform direction upon granite of the peculiar concentric structure above alluded to.

Among the most characteristic proofs of the existence of former glaciers here, are the innumerable lakes and meadows of the Sierra. The glacier receives boulders, and transports sand and dust from its polishing of the surrounding rocks, and on retreating builds up a terminal moraine, which forms a dam for the waters which are derived from the melting ice, at the same time by its irresistible grinding hollowing out a lake basin more or less deep. Gradually retiring, and finding a long period of rest under protecting rocks, it forms another moraine and dam like the first, but higher up, scooping out another basin and forming another lake. If the glacier then formed disappears, two lakes are thus formed, one above the other, as are frequently found; if there are more numerous periods of rest, there will be a chain of lakes in proportion to this number.

At first pure, and filled with floating ice, in course of time the streams from the higher crests and the melting snows carry their detritus to these rock-rimmed lakes; then the lake becomes fringed with a border of yellowish and brown sedges, deriving their lowly sustenance chiefly from their water-absorbing leaves; then, as the soil increases in thickness, come other rush-like plants and mosses in the swampy edges, exactly defining the limits of the water; then the grasses, and the flowers, and the shrubs, and the forests, as the meadow becomes more solid and extended. In the spring of the year, these high meadows are flooded with water from the ridges on each side, and are at all times to be traversed cautiously by the traveller, a wandering from the path being attended with the danger of sinking inextricably into the springy treacherous peat-like bog.

With these facts before us, it seems to me evident that the formation of the Yosemite Valley is not due to water. The erosive action of water, the tremendous power of which the Niagara gorge amply proves, is well seen in the Sierras, but not remarkably in this portion of it; its action does not produce such vertical walls as those of this valley, nor such perpendicular surfaces in granite as the sides of El Capitan, more than three thousand feet high, meeting each other almost at a right angle, and with faces turned down the valley in a direction opposite to that in which water must have acted. There is no source for water of depth sufficient to have filled this valley; and the Half-Dome rises two thousand feet above the top of the valley, and the same above the action of water had it filled the whole valley — this is five miles in length, one-half to a mile wide, with very irregular sides, and a narrow outlet at its western extremity.

It should be remembered that the material to be worn by water here is granite, comparatively indestructible by agents which might readily wear away and undermine the shales and limestone at Niagara. The granite behind the Vernal fall is hardly at all worn by water, and even most of this possible erosion may be more reasonably attributed to ice. The insignificance of the water area compared to
THE WONDERS OF THE YOSEMITE VALLEY.

the ice area in the canons here has been shown by Mr. Muir in the Nevada glacier basin, and the fact that floods have never risen, and do not now rise high enough to change perceptibly the proportion of these areas. Floods now arise from rains and melting snows in all probability as great as ever occurred from the melting of the glaciers, and yet their action upon the walls of the canons and the contour of the valley is not perceptible. Such a flood occurred in the latter part of December of last year 1871, as witnessed by Mr. Muir, and described in a letter from him, in which he writes that more than one hundred cataracts were then pouring into the valley, and forty in sight at one time, each one with more water than flows over the Nevada or Vernal falls in midsummer. We cannot believe, therefore that any causes now in action there, have had much to do with the formation of the canons and the valley.

Has ice, then, made this valley? After Mr. Muir's observations, there can be no doubt that ice once filled this valley, and overwhelmed it at least one thousand feet deep, making a total thickness, supposing the valley to have antedated the glacial period, of more than three thousand feet of ice. From the sketch as given by him, it will be seen that, while the upper layers of the ice stream moved with irresistible force and considerable velocity, as shown by the polishings and the inclination of the surfaces, the comparatively insignificant portion of the glacier in the valley, from the narrowness of the canon of exit on the west, could not have moved much, but must have slowly wasted away, remaining long after the main glacier had disappeared, leaving a lake of gradually decreasing depth, and at last a wide valley, with the narrow and shallow Merced river in it, fed by the snows of the upper ridges.

Was the valley formed by ice? The Hetch-Hetchy valley, an almost exact counterpart of the Yosemite, but smaller, and about sixteen miles farther north, through which flows the Tuolumne river, as the Merced flows through the Yosemite, throws light on this question. The Tuolumne glacier, the largest in this region, flowed across this valley and across a canon three thousand feet deep, on its way to join the great glacier of the Merced basin below Yosemite; the course of the former across the latter is shown by the grooving of the rocks, and yet the Hetch-Hetchy valley and its canon above show groovings in their own axis, about east to west, the great glacier moving more nearly south-west. The united Tuolumne and Merced glaciers, below Yosemite, moved very nearly west, across the numerous angles of the crooked canon of the Merced. These two valleys and their canons, though half a mile deep, and each with their local glaciers, were so small in comparison to the great ice sheet, that this flowed over them without being influenced by them; the form of the valleys and canons was doubtless modified by the ice, which, had it produced them, would have greatly multiplied them, and have made these singular depressions the rule, and not the exception; and moreover the valleys would have borne in size a closer relation and proportion to the immense force that was at work over them.

There seems no hypothesis left except the one given by Prof. Whitney,
in the Geology of California, a hypothesis which his and all subsequent investigations seem to me to strengthen, viz.: that during or after the upheaval of the Sierra, there was a subsidence, the bottom of these valleys sinking down to an unknown depth, the debris going to fill the abyss. During the glacial period they were filled with ice, which, gradually melting, formed great lakes, imprisoned by moraines at the lower part; these have gradually been washed away by the floods, and scattered over the plains of the Merced, Tuolumne and San Joaquin meadows; now only a small stream flowing along the bottom, which is slowly filling up, the small and comparatively undisturbed last terminal moraine extending across the valley about opposite El Capitan, the force of the diminished flood being enough to cut a passage for the Merced river without disturbing the glacial deposits above its highest level.

Evidence of tremendous volcanic agency is not wanting in this region. Some of the high peaks are found capped with lava; Mt. Dana, perhaps the highest, has its granite nucleus flanked with metamorphic slates. This agency is even now active, as is shown by the hot springs and geysers which abound, and by the many severe shocks of earthquakes near the coast, of the extent and severity of the last of which, a few years ago, not the half of the truth has ever reached the public. On page 88 will be found a description of the earthquake of 1872.

The general absence of debris on the sides—the splitting of the Half Dome, with its perpendicular face of nearly half a mile above the edge of the valley and facing it—such immense vertical masses as El Capitan—can hardly be explained by any theory except that of subsidence. This is an exceptional theory, perhaps, but the phenomena are also exceptional.