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Studies in the Sierra. No. 1-Mountain Sculpture.

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In the beginning of the long glacial winter, the lofty Sierra seems to have consisted of one vast undulated wave, in which a thousand separate mountains, with their domes and spires, their innumerable canions and lake basins, lay concealed. In the development of these, the Master Builder chose for a tool, not the earthquake nor lightning to rend and split asunder, not the stormy torrent nor eroding rain, but the tender snow-flowers, noiselessly falling through unnumbered seasons, the offspring of the sun and sea. If we should attempt to restore the range to its pre-glacial unsculptured condition, its network of profound canions would have to be filled up, together with all its lake and meadow basins; and every rock and peak, however lofty, would have to be buried again beneath the fragments which the glaciers have broken off and carried away. Careful study of the phenomena presented warrants the belief that the unglaciated condition of the range was comparatively simple; yet the double summits about the head of Kern River and Lake Tahoe, and the outlying spurs of Hoffmann and Merced, would appear to indicate the primary existence of considerable depressions and elevations. Even these great features, however, may be otherwise accounted for.

All classes of glacial phenomena are displayed in the Sierra on the grandest scale, furnishing unmistakable proof of the universality of the ice-sheet beneath whose heavy folds all her sublime landscapes were molded. Her ice-winter is now nearly ended, and her flanks are clothed with warm forests; but in high latitudes, north and south, and in many lofty mountains, it still prevails with variable severity. Greenland and the lands near the south pole are undergoing
glaciation of the most comprehensive kind, and present noble illustrations of the physical and climatic conditions under which the Sierra lay when all the sublime pages of her history were sealed up. The lofty Himalaya, the Alps, and the mountains of Norway are more open, their glacial covering having separated into distinct glaciers that flow down their valleys like rivers, illustrating a similar glacial condition in the Sierra, when all her valleys and canons formed channels for separate ice-rivers. These have but recently vanished, and when we trace their retiring footsteps back to their fountains among the high summits, we discover small residual glaciers in considerable numbers, lingering beneath cool shadows, silently completing the sculpture of the summit peaks.

The transition from one to the other of these different glacial conditions was gradual and shadow-like. When the great cycle of icy years was nearly accomplished, the glacial mantle began to shrink along the bottom; domes and crests rose like islets above its white surface, long dividing ridges began to appear, and distinct glacier rivers flowed between. These gradually became feeble and torpid. Frost-enduring carices and hardy pines pushed upward along every moraine and sun-warmed slope, closing steadily upon the retreating glaciers, which, like shreds of summer clouds, at length disappeared from the young and sunny landscapes.

We can easily understand that an ice-sheet hundreds or thousands of feet in thickness, slipping heavily down the flanks of a mountain chain, will wear its surface unequally, according to the varying hardness and compactness of its rocks; but these are not the only elements productive of inequalities. Glaciers do not only wear and grind rocks by slipping over them, as a tool wears the stone upon which it is whetted; they also crush and break, carrying away vast quantities of rock, not only in the form of mud and sand, but of splinters and blocks, from a few inches to forty or fifty feet in diameter.

The whole mass of the Sierra, as far as our observation has reached, is built up of brick-like blocks, whose forms and dimensions are determined chiefly by the degree of development of elected planes of cleavage, which individualize them, and make them separable from one another while yet forming undisturbed parts of the mountain. The force which binds these blocks together is not everywhere equal; therefore, when they are subjected to the strain of glaciers, they are torn apart in an irregular and indeterminate manner, giving rise to endless variety of rock forms.

The granite in some portions of the range is crumbling like meal by the decomposition of its feldspar throughout the mass, but the greater portion has suffered scarcely any disintegration since the close of the glacial period. These harder areas display three series of cleavage or separating planes, two nearly vertical, the other horizontal, which, when fully developed, divide the rock into nearly regular parallelopipeds. The effects of this separable structure upon the glacial erodibility of rocks will be at once appreciated. In order that we may know how mountain chains are taken apart, it is important that we first learn how they are put together; and now that we have ascertained the fact that the Sierra, instead of being a huge wrinkle of the earth's crust without any determinate structure, is built up of regularly formed stones like a work of art, we have made a great advance in our mountain studies; we may now understand the Scripture: "He hath built the mountains," as not merely a figurative but a literal expression.

In order that we may obtain some adequate estimate of the geological value of this cleavage factor in the production of canons, rock forms, and separate mountains, with their varied sculpture, we must endeavor to find out its range, variations, and what forces are favorable to its development; what are the effects of its suppression in one place, and development in another; what are the effects of the unequal development of the several series. In the prosecution of these inquiries, we soon discover that the middle region of the west flank is most favorable for our purposes, because the lower is covered to a great extent with soil, and the upper, consisting of sharp peaks, is so shattered, or rather has all the various planes so fully developed, we are unable to study them in their simple, uncombined conditions. But the middle region, while it has all its cleavage phenomena on the largest scale both of magnitude and specialization, is also simple and less obscured by forests and surface
weathering, and affords the deepest, as well as widest naked sections, the former in Yosemite canyons, the latter in flat basins like those of Yosemite Creek, Lake Tenaya, and upper Tuolumne Valley, wherein broad areas of glacier-polished granite are spread out, as clean and unblurred as new maps.

I should have stated that the three series of cutting planes mentioned above are not the only ones existing in these rocks, but we will consider them first, because they are most marked in their modes of development, and have come most prominently into play in the formation of those unrivaled canyons and rocks which have made the Sierra famous. In studying their direction and range, we find that they extend along the west flank from latitude 36° to 40° at least, and from the summit to the soil-covered foot-hills, and in all probability further observation would show that they are co-extensive with the length and breadth of the chain. We measured the direction of the strike of hundreds, belonging to the two vertical series, many of which run unbrokenly for miles in a tolerably uniform course, the better developed ones nearly at right angles to the axis of the range, the other parallel with it. Cañon sections show that they cleave the granite nearly vertically to a depth of 5,000 feet without betraying any tendency to give out. The horizontal series appear also to be universal. In some places these divisional planes are extended within a few inches of each other, while in others only one conspicuous seam is visible in a breadth of bare rock half a mile in extent. Again, many large domes occur that exhibit none of these planes, and appear to be as entirely homogeneous in structure as leaden balls. Thus, let Fig. 1 represent a horizontal section of the range; A, B, C, D, cones and co-"noides where none of the cleavage planes appear. The question here arises, are these domed portions cleavageless, or do they possess the same cleavage as the surrounding rock, in an undeveloped or latent condition? Careful observation proves the latter proposition to be the true one, for on the warm and moist surfaces of some of the older domes we detect the appearance of incipient planes running parallel with the others, and in general wherever any rock apparently homogeneous in structure is acted upon by the spray of a water-fall, its cleavage planes will appear. We may conclude, therefore, that however numerous the areas may be which seem solid and equal in structure, they are still traversed in definite directions by invisible cutting planes, which render them separable when the conditions required for their development have been supplied.

Fig. 2 represents the side of a dome at the head of Yosemite Fall, with parallelopipedal blocks developed along its base.
The development of the brick structure is probably due to spray blown back from the brow of the fall in storms. It is to the development of these brick-making planes by long-continued atmospheric action, that the picturesque ruins so frequently met with on lofty summits are due. Where only one of the cutting vertical series has been developed in a granitic region otherwise strong in its physical structure, and a sufficient amount of glacial force exerted in a favorable direction has been concentrated upon it, its rocks have been broken up in flakes and slabs, and those majestic mural precipices produced which constitute so sublime a part of the Yosemite scenery of the Sierra. Fig. 3 represents a granite tower on the crest of Mount Hoffmann, composed of jointed blocks.

Another series of cutting planes which pass diagonally through those we have been considering, give rise to pyramidal and roof-shaped forms. This diagonal cleavage is found in its fullest development in the metamorphic slate of the summit, producing the sharp-pointed peaks for which the summit region is noted. To it is also due the huge gables which are found in Yosemite and Tuolumne canions, such as the Three Brothers, and the pointed rock adjoining the Royal Arches. Fig. 4 represents the highest of the Three Brothers, Yosemite Valley, illustrating diagonal cleavage in granite; and Fig. 5 is a gable on the south wall of the big Tuolumne Cañon. It will be at once perceived that the forms contained in Fig. 6 (a rock situated near the small side-cañon which separates El Capitan and the Three Brothers, in Yosemite Valley), have resulted from the partial development of both diagonal and rectangular cleavage joints. At a, b, c, d, incipient diagonal planes are beginning to appear on the otherwise solid front. Some of the planes which have separated the two summit blocks, e and f, may be seen at g.

The greatest check to the free play and controlling power of these divisional planes is the occurrence, in immense num-

Fig. 3.

Fig. 4.

Fig. 5.

Fig. 6.
rounded forms, may be designated the dome cleavage, inasmuch as the dome is apparently the most perfect typical form of the group.

Domes of close-grained silicious granite are admirably calculated to withstand the action of atmospheric and mechanical forces. No other rock form can compare with it in strength; no other offered so unflinching a resistance to the tremendous pressure of the glaciers. A dam of noble domes extends across the head of Yosemite Valley, from Mount Starr King to North Dome, which was effectually broken through by the combined force of the Hoffmann and Tenaya glaciers; but the great south Lyell glacier, which entered the valley between Starr King and Half Dome, was unable to force the mighty barrier, and the approach of the long summer which terminated the glacial epoch, found it still mazing and swedging compliantly among the strong unflinching bosses, just as the winds are compelled to do at the present time.

The Starr King group of domes (Fig. 7) is perhaps the most interesting of the Merced basin. The beautiful conoid, Starr King, the loftiest and most perfect of the group, was one of the first to emerge from the glacial sea, and ere its new-born brightness was marred by storms, dispersed light like a crystal island over the snowy expanse in which it stood alone. The moraine at the base is planted with a very equal growth of manzanita.

There appear to be no positive limits to the extent of dome structure in the granites of the Sierra, when considered in all its numerous modifications. Rudimentary domes exist everywhere, waiting their development, to as great a depth as observation can reach. The western flank was formerly covered with slates, which have evidently been carried off by glacial denudation from the middle and upper regions; small patches existing on the summits and spurs of the Hoffmann and Merced mountains are all that are now left. When a depth of two or three thousand feet below the bottom of the slates is reached, the dome structure prevails almost to the exclusion of others. As we proceed southward or northward along the chain from the region adjacent to Yosemite Valley, dome forms gradually become less perfect. Wherever a broad sheet of glacier ice has
that a series of concentric shells which form a dome may be cut by another series of the same kind, giving rise to domes within domes and domes upon domes.

Fig. 12 represents bricks, thirty or forty feet in height, placed directly upon a smooth, well-curved dome, which dome, in turn, is borne upon or rather stands out from a yet larger dome-curved surface forming a portion of the east side of El Capitan rock, near the top.

The Tuolumne middle region presents a sublime assemblage of glacier-born rocks, of which a general view may be obtained from the summit of Mount Hoffmann. These were overswept by the wide outlets of the great Tuolumne mer de glace. The Tuolumne Cañon outlet flowed across the edges of the best developed or north 35° east vertical cleavage planes, which gave rise to an extraordinary number of rocks, like Fig. 8, with their split and fractured faces invariably turned down stream and round abraded sides up against the ice-current.

This glaciated landscape is unrivaled in general effect, combining as it does so many elements of sublimity. The summit mountains, majestic monuments of glacial force, rise grandly along the azure sky. The brown Tuolumne meadow, level as a floor, is spread in front, and on either side a broad swath of sombre pines, interrupted with many small meadow openings, around the edges of which the forest presses in smooth close lines. On the level bottom of the mer de glace, mountains once stood, which have been broken and swept away during the ice-winter like loose stones from a pavement. Where the deep glacial flood began to break down into the region of domes, a vast number of rock forms are seen on which their glacial history is written in lines of noble simplicity.

No attribute of this glacial landscape is more remarkable than the map-like distinctness of its varied features. The directions and magnitudes of the main ice-currents, with their numerous subordinate streams, together with the history of their fluctuations and final death, are eloquently expressed in the specific rocks, hills, meadows, and valleys over which they flowed. No commercial highway of the sea, edged with buoys and lamps, or of the land, with fences and guide-boards, is so
If, from some outlook still more comprehensive, the attentive observer contemplates the wide flank of the Sierra, furrowed with canions, dimpled with lake basins, and waved with ridges and domes, he will quickly perceive that its present architectural surface is not the one upon which the first snows of the glacial winter fell, because, with the simple exceptions of the jagged summit-peaks from whose névé fountains the glaciers descended, there exists over all the broad flank of the range not one weak rock form. All that remain to roughen and undulate the surface are strong domes, or ridge-waves, or crests, with pavement-like levels or solid-walled canions between. All the rest have been broken up and swept away by the glaciers. Some apparent exceptions to this general truth will present themselves, but these will gradually disappear in the light of patient investigation. The observer will learn that near the summit ice-fountains there are absolutely no exceptions, even in appearance, and that it is only when he follows down in the paths of the glaciers, and thus comes among rocks which were longer left bare by them in their gradual recession, that he begins to find instances of rocks at once weak in structure and strong in form.

The regular transition from strong to weak rocks will indicate that the greater weakness of those farther removed from the summits, is due to some force or forces which acted upon them subsequently to the time they were sustaining the wear and tear of the glaciers. The causes of this after-weakness are various. First we may note the most apparent—the slow decomposition of the mass of the rock by the atmosphere, under favorable conditions of heat and moisture. Some varieties of granite crumbled rapidly by the decomposition of their feldspar throughout the mass. Rocks traversed by feldspathic veins, that are otherwise strong, fall apart on the decomposition of the veins, into a heap of loose blocks. Frost also, combined with moisture, produces a wasted, shattered appearance. But by far the most general and influential cause of the feeble condition of old rocks, which formerly withstood the terrible ordeal of glacial action, is the subsequent development of one or several of their cleavage planes. For example, here is (Fig. 13) a boulder of hard metamorphic slate, which, after withstanding many a crush and blow in its winter history, until its angles were worn and battered, at length, on the recession of the glacier to which it belonged, came to rest on a smooth hard pavement, so level that it could not have rolled or fallen to its present position. Yet it is now split in two, having fallen apart by its own weight, on the ripening of one of its cleavage planes, just as the valves of seeds ripen, open, and fall.

Fig. 14 is a profile view of a rock 200 yards from the head of the Yosemite Fall, which is now weak and ready to fall apart by the development of the vertical north 35° east cleavage planes, the edges of which are seen in front; yet it is certain that this rock was once subjected to the strain of the oversweeping Yosemite basin glacier, when on its way to join the main trunk Yosemite glacier in the valley. Fig. 15 is a ruinous dome-top on the divide between Yosemite Creek basin and cascade. The beginner in such studies would not perceive that it had been overswept; yet hard portions near the base show clear evidence of glacial action, and, though ruinous and crumbling, it will at once appear to the educated eye that its longer diameter is exactly in the direction of the oversweeping ice-current, as indicated in the figure by the arrows. Rock masses, hundreds or even thousands of feet in height, abound in the channels of the ancient glaciers, which illustrate this argument by presenting examples in every stage of decay, the most decayed always occurring just where they have been longest exposed to disintegrating and general weathering agents. The record of ice phenomena, as sculptured, scratched, and worn upon the mountain surfaces, is like any other writing, faint and blurred according to the length of time and hard usage to which it has been exposed. It is plain, therefore, that the present sculptured condition of the Sierra
is due to the action of ice and the variously developed cleavage planes and concentric seams which its rocks contain. The architect may build his structures out of any kind of stone, without their forms betraying the physical characters of the stone employed; but in Sierra architecture, the style always proclaims the nature of the rock.

In walking the sublime cañon streets of the Sierra, when we see an arch spanning the pine groves, we know that there is the section of a glacier-broken dome; where a gable presents itself, we recognize the split end of a ridge, with diagonal cleavage planes developed atop, and these again cut by a vertical plane in front. Does a sheer precipice spring from the level turf thousands of feet into the sky, there we know the rock is very hard, and has but one of its vertical cutting planes developed. If domes and cones appear, there we know the concentric structure predominates. No matter how abundant the glacial force, a vertical precipice cannot be produced unless its cleavage be vertical, nor a dome without dome structure in the rock acted upon. Therefore, when we say that the glacial ice-sheet and separate glaciers molded the mountains, we must remember that their molding power upon hard granite possessing a strong physical structure is comparatively slight. In such hard, strongly built granite regions, glaciers do not so much mold and shape, as disinter forms already conceived and ripe. The harder the rock, and the better its specialized cleavage planes are developed, the greater will be the degree of controlling power possessed by it over its own forms, as compared with that of the disinterring glacier; and the softer the rock and more generally developed its cleavage planes, the less able will it be to resist ice action and maintain its own forms. In general, the grain of a rock determines its surface forms; yet it would matter but little what the grain might be—straight, curved, or knotty—if the excavating and sculpturing tool were sharp, because in that case it would cut without reference to the grain. Every carpenter knows that only a dull tool will follow the grain of wood. Such a tool is the glacier, gliding with tremendous pressure past splitting precipices and smooth swelling domes, flexible as the wind, yet hard-tempered as steel. Mighty as its effects appear to us, it has only developed the predestined forms of mountain beauty which were ready and waiting to receive the baptism of light.