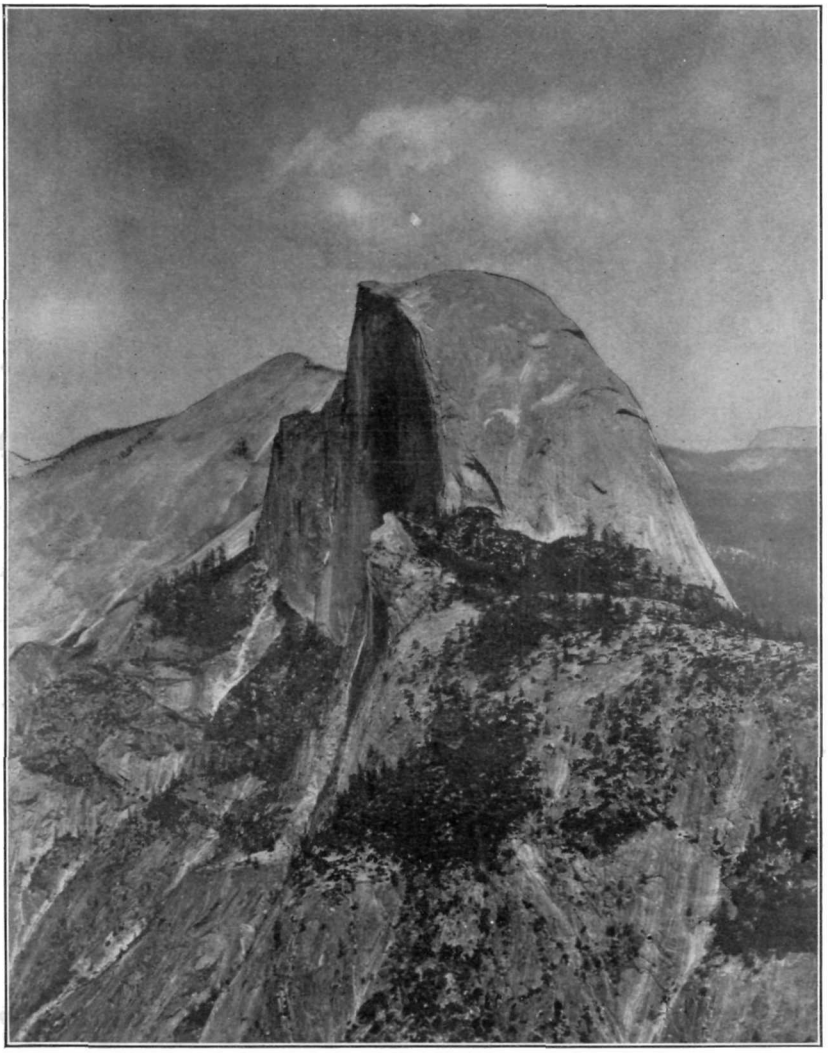
SKETCH OF YOSEMITE NATIONAL PARK AND AN ACCOUNT OF THE ORIGIN OF THE YOSEMITE AND HETCH HETCHY VALLEYS



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SKETCH OF YOSEMITE NATIONAL PARK AND ACCOUNT OF THE ORIGIN OF THE YOSEMITE AND HETCH HETCHY VALLEYS.

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INTRODUCTION.

Many people believe that the Yosemite National Park consists principally of the Yosemite Valley and its bordering heights. The name of the park, indeed, would seem to justify that belief, yet nothing could be further from the truth. The Yosemite Valley, though by far the grandest feature of the region, occupies only a small part of the tract. The famous valley measures but a scant 7 miles in length; the park, on the other hand, comprises no less than 1,124 square miles, an area slightly larger than the State of Rhode Island, or about one-fourth as large as Connecticut. Within this area lie scores of lofty peaks and noble mountains, as well as many beautiful valleys and profound canyons; among others, the Hetch Hetchy Valley and the Tuolumne Canyon, each scarcely less wonderful than the Yosemite Valley itself. Here also are foaming rivers and cool, swift trout brooks; countless emerald lakes that reflect the granite peaks about them; and vast stretches of stately forest, in which many of the famous giant trees of California still survive.

The Yosemite National Park lies near the crest of the great alpine range of California, the Sierra Nevada. To the initiated this fact in itself means a great deal, for the Sierra Nevada is a land not only of scenic wonders, but of marvelous climate—a climate paralleled by that of few mountain regions elsewhere in the world. It has a climate of sunshine and serene skies; dry, but not too dry; in summer warm, but not uncomfortably warm; withal characterized by nights that are cool, even frosty at the higher levels. The winters are cold enough to insure a snowfall of 2 to 4 feet in the lowest valleys and to maintain perpetual ice fields and glaciers on the highest crests. One goes to the Yosemite region not merely to admire its cliffs and waterfalls, nor to walk through the aisles of its great forests, but to revel in the full enjoyment of these wonders in the pure, invigorating air and the restful calm that reigns from day to day.

No wonder that the Yosemite region has acquired fame as a paradise for campers and mountaineers and is year after year invaded by tens of thousands of tourists and vacation seekers. Of late, too, it is becoming known as an attractive winter resort, frequented by those

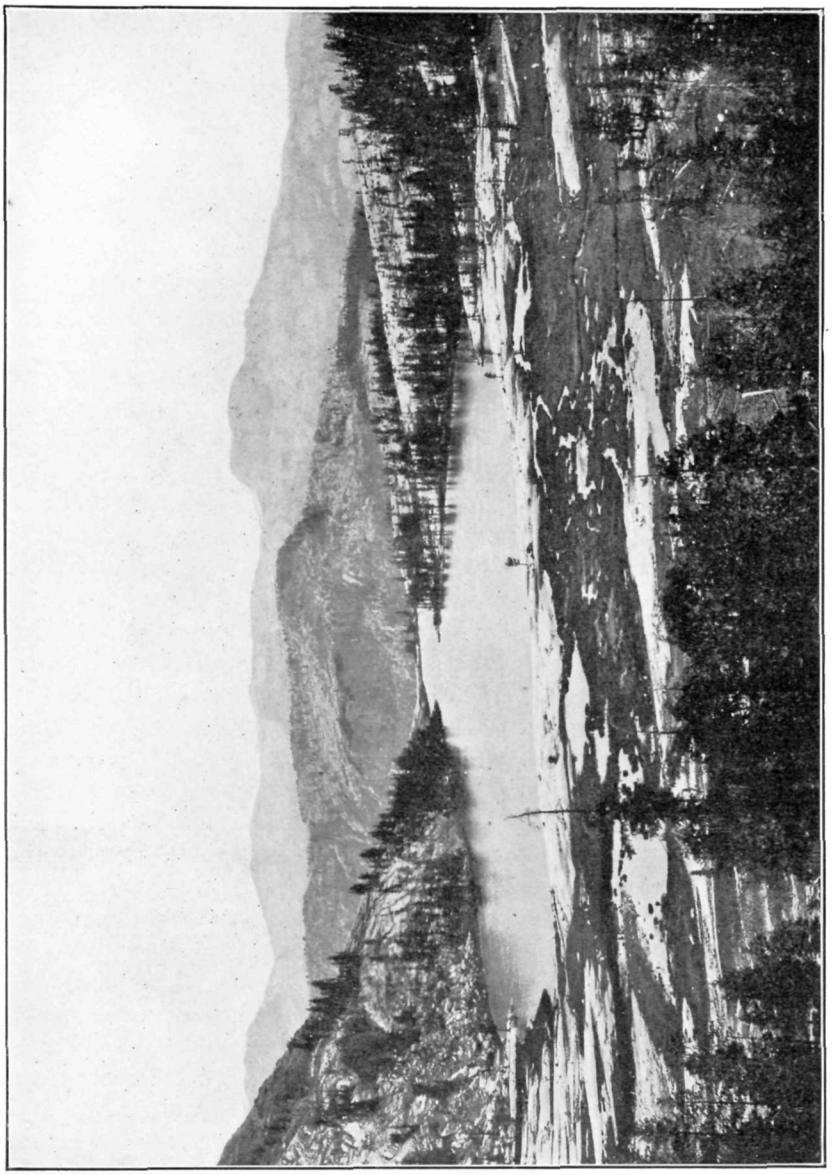

FIGURE 1.—Cathedral Lake, a typical glacial tarn of the High Sierra.

who enjoy snowshoeing, tobogganing, and other winter sports. Its possibilities in this regard have long lain neglected, partly, no doubt, because winter sports generally have not been popular on the Pacific coast, partly because the Yosemite Valley was rather inaccessible in

winter. Now, however, the railroad from Merced to El Portal, a few miles from the boundary of the park, insures ready access to the Yosemite Valley and permits the hotels there to remain open for the accommodation of tourists throughout the year. From El Portal a short stage drive over a macadamized wagon road takes the traveler to the heart of the Yosemite Valley, which, with its hotels, camps, and livery facilities, constitutes the main tourist center and the base from which excursions may be made.

HISTORY OF YOSEMITE NATIONAL PARK.

When one considers that the Yosemite Valley is to-day famed the world over, he finds it difficult to realize that it has been known scarcely more than 50 years. The valley was discovered in 1851, when a detachment of mounted volunteers under Capt. John Boling, in an effort to put an end to the depredations of the Indians that infested the region, pursued them to their mountain stronghold. The tales the soldiers brought back of the marvelous scenery of the valley induced J. M. Hutchings, who was then gathering data on California scenery, to organize in 1855 an exploratory expedition to the Yosemite Valley. The next year a trail was opened across the mountains from Mariposa and the regular tourist travel may be said to have begun. That year also the first house in the valley (just below the Sentinel Fall) was built, the same house that subsequently became known as Black's Hotel.

For many years all goods taken into the Yosemite region were carried by pack mules 50 miles over rough mountain trails from Mariposa or from Coulterville. It was not until 1874 that the first wagon roads were completed. The tourist travel then increased by leaps and bounds. The stage traffic, which at first was small, soon became a vast, well-organized business. Indeed, the Yosemite stages, especially to those who visited the valley during the decade preceding 1906, the year the railroad was constructed, are likely ever to remain prominent in mind as one of the features that added picturesqueness and pleasure—though often also weariness—to the excursion.

The present boundaries and extent of the Yosemite National Park date back only to 1906. Prior to that year the Yosemite Valley was a State park under the control of California. In 1864 Congress granted to that State "the 'Cleft' or 'Gorge' in the Granite Peak of the Sierra Nevada Mountain * * * known as the Yosemite Valley * * *," as the act quaintly puts it, and with it the tract embracing the Mariposa Big Tree Grove, near Wawona. Galen Clark, the discoverer of that grove, became the first "guardian of the valley," and served in that capacity for many years. In 1908 he died at the ripe old age of 96 years, but his name will forever remain associated with the valley as that of its "grand old man."

In 1906 the valley and the grove were receded by California to the United States and included in the Yosemite National Park, which had been established by Congress October 1, 1890, and already embraced a considerable portion of the Sierra Nevada immediately surrounding the valley. After sundry changes the boundaries of the combined tracts were definitely fixed by Congress and marked out on the ground in the alignment shown on the accompanying map[1] (fig. 10). The boundary on the northeast side follows the crest line of the Sierra Nevada, passing over the summits of Mounts Conness, Dana, and Lyell. The southern boundary is so drawn as to include the Mariposa Grove, and the western boundary to encompass the Merced and Tuolumne groves of big trees, as well as beautiful Lake Eleanor.

The wording of the act of 1864 (see p. 5) itself eloquently testifies to the ignorance and complete misconception which formerly prevailed regarding the real nature of the Yosemite Valley and the mountain region in which it lies. In order that a truer understanding of the region might be gained, the Geological Survey of California, under the direction of the late Prof. J. D. Whitney, as early as 1866 undertook the task of systematically exploring and mapping the Sierra region. This work has since been carried on by others, notably by Clarence King, Joseph Le Conte, I. C. Russell, John Muir, Waldemar Lindgren, George F. Becker, Henry W. Turner, A. C. Lawson, F. L. Ransome, and J. N. Le Conte. As a result of the labors of these men a vast body of fact regarding the region is now available, and even its most puzzling features, its strangely carved peaks and domes and canyons, have become well understood. It was not, however, until very recently that anything approaching concordance of opinion was reached about the manner of their genesis and that an authoritative statement regarding their origin was possible for the information of the layman. Such a statement it is proposed to give here, explaining how the features included in the Yosemite National Park, and especially those of the Yosemite and Hetch Hetchy Valleys, had their origin.

THE SIERRA NEVADA.

GENERAL FEATURES.

The general lay and configuration of the tract inclosed by the Yosemite National Park can be best understood by taking a broad, preliminary view of the Sierra Nevada as a whole. That range, which is one of the greatest mountain ranges of the western United

[1] The following topographic maps may be purchased from the Director of the Geological Survey, Washington, D. C.: Yosemite National Park, on a scale of 2 miles to the inch, 25 cents a copy unbound; 35 cents a copy folded and bound between covers; Yosemite Valley, on a scale of 2,000 feet to the inch, 10 cents a copy.

States, runs lengthwise through the State of California, roughly paralleling the Nevada border. More than 300 miles long and about 80 miles wide, it constitutes a huge rampart separating the desert basins on the east from the Great Valley of California on the west. Rising abruptly from the desert by a steep face or escarpment several thousand feet high, it descends to the low level of the Great Valley by a long and gentle sweep. It is thus pronouncedly unsymmetrical in cross section; its crest line, instead of occupying an axial position, runs along the top of its steep eastern face.

This one-sided configuration the Sierra Nevada acquired not through erosion of any kind, but through upheaval of the crust of the earth. One should picture the range to himself as a huge, elongated block of the earth's crust, strongly tilted to the west and bounded on the east by a great line of fractures. It did not rise as an isolated block; rather, it was originally part of a vast dome produced by the broad upwarping of the entire region now known as the Great Basin of Nevada and Utah. This dome caved in irregularly, some portions settling lower than others, thus giving rise to the alternating deserts and mountain ranges characteristic of the Great Basin. The Sierra Nevada, which constituted the westernmost margin of the dome, remained standing in its elevated position, but the blocks immediately to the east sank down to relatively low levels, leaving a high and precipitous front to mark the line of fractures.

The crest of the Sierra Nevada stands at altitudes ranging from 10,000 to 14,000 feet, culminating in Mount Whitney (14,501 feet), the highest summit in the United States. The deserts skirting its eastern base stand at elevations ranging from 3,500 to over 6,000 feet. The greatest drop is in the vicinity of Owens Lake, where the eastern scarp descends abruptly from 11,000 to 3,569 feet.

Although on the whole fairly regular in outline, the Sierra block should not be conceived as having plane sides and smooth, straight edges. Nature does not fashion her forms with mathematical exactness on so large a scale. The great fracture or series of fractures bounding the block on the east is full of irregularities, and in many places even consists of several separate, roughly parallel, lines placed in "echelon."

The surface of the block that now forms the western slope was originally diversified by hills and valleys, themselves the worn-down remnants of an earlier mountain system, and since the uplift of the range has been scarred and furrowed by new stream-cut gorges and valleys. Indeed, the present aspect of the Sierra Nevada is to be regarded as the product of a long and complicated series of events. Not even the broader outlines were formed at one bound. The fractures on the east side are of various dates. Some of them occurred

as early as the end of the Cretaceous period; others were added at different times throughout the succeeding Tertiary period. It was at the end of Tertiary time, however, that the greatest manifestation of mountain building took place, and that sharp, renewed uplifts, accompanied by a general outburst of volcanic eruptions and lava flows, gave the block its present strong westward tilt.

The greatly increased inclination thus acquired naturally gave fresh impetus to the waters running down the western slope, and as a consequence these waters eroded with greater vigor than before, intrenching themselves in deep canyons and valleys. A great series of nearly parallel valleys was created, spaced at fairly regular intervals, most of them transverse to the axis of the range. Each of these valleys heads on the Sierra crest and sends forth a powerful river to the Great Valley of California. Of these streams the most important are the Feather, Yuba, Bear, American, Mokelumne, Stanislaus, Tuolumne, Merced, San Joaquin, King, and Kern Rivers.

Throughout Quaternary time, down to the present day, this vigorous stream erosion has continued, etching the surface of the Sierra block with a network of ramifying branch valleys, between which residual portions of the old surface have remained standing in the form of mountains and ridges. During the glacial epochs, moreover, the advent of glaciers on the higher regions has served to intensify the erosion and to hasten the dismantling of the Sierra block.

The rock débris resulting from all this destructive work was little by little carried down by the rivers and deposited in the Great Valley at the foot of the range. The enormous quantities of material thus brought down filled the valley to the depth of several thousand feet, so that while the Sierra block was being denuded in its upper portions it was being cloaked with waste on its lower slopes. The present foothills, therefore, should not be taken as the real base of the range, for that lies buried under great thicknesses of sediment.

CLIMATIC ZONES AND VEGETATION.

The great height of the Sierra Nevada above the country surrounding it, together with its position close to the Pacific coast, have endowed the range with rather unusual climatic conditions. The prevailing winds in this part of the country blow in from the Pacific Ocean, laden with moisture. Forced to ascend to great altitudes in passing over a range of mountains, they gradually cool and discharge their content of water in the form of rain. The Coast Ranges are naturally the first thus to abstract some of this moisture; but, being of moderate elevation only, they are able to catch but a small percentage of it. The rest is carried farther eastward, to the Sierra Nevada, where it descends in copious rains and snow on the upper

slope and crest. Thus the upper Sierra is well watered, while the low-lying Great Valley to the west is parched and in need of irrigation many months in the year. Furthermore, the intense concentration of rain and snow on the crest of the Sierra leaves the westerly air currents passing over it to continue eastward fairly wrung dry of their moisture, so that the land east of the range is now a barren desert. Even the east face of the range partakes in some measure of this aridity, for the transition in climate from the crest of the range to its eastern base is amazingly abrupt—as abrupt, in fact, as the escarpment itself. In a few miles one descends from the frigid air of perpetual snow fields to the burning heat and glare of deserts.

As the climate of the steep east face of the Sierra Nevada is characterized by sharp and extreme contrasts, so that of the long west slope is marked by notably gentle gradations. On this slope several more or less distinct climatic zones lie parallel to one another, each recognizable by a characteristic belt of vegetation. The foothills for a thousand feet or more present essentially the same aspect as the great plain from which they rise. Verdant only a few brief weeks in spring, their sun-baked slopes remain most of the year of a uniform straw color, relieved only here and there by scattered groups of olive-colored live oaks. Farther up the slope these trees become more numerous, and low, chaparral-like brush appears. Occasional forlorn-looking specimens of so-called Digger pine (*Pinus Sabiniana*), with long, bluish needles, mingle with the oaks. Still farther up the brush becomes progressively denser and taller; the rigid, red-stemmed Manzanita grows to astonishing dimensions, 12 to 15 feet in height; oak and pine congregate in groves and become more luxuriant, until, at last, near the 3,000-foot level, the first yellow pines are reached. Here the true Sierra forest begins; the landscape loses its thirsty, parched look and displays a brilliant green foliage, bespeaking refreshing moisture. With every step upward the forest waxes in height and in majesty; the trees grow larger and more perfect. With the yellow pine (*Pinus ponderosa*) stands the incense cedar (*Libocedrus decurrens*), the Douglas spruce (*Pseudotsuga Douglasii*), and the most stately of all Sierra trees, the sugar pine (*Pinus Lambertiana*). All these attain remarkable heights, the forest in places lifting its spires 200 to 300 feet above the ground.

In this belt of maximum forestation, evidently thriving in a temperate and particularly propitious climate, grow also the giant trees of California, the Sequoias (*Sequoia gigantea*). Interspersed with the other huge trees in groves of a few dozen to several hundred, they represent the straggling survivors of a species that is threatened with extinction. In the central portions of the range they occur at levels near 6,000 feet, and it will be noted that the Mariposa, Tuolumne, and Merced groves all stand at this elevation.

From the 7,000-foot line upward climatic conditions become less favorable to forest growth. The precipitation is mostly in the form of snow and the winters are long and severe. The forest assumes a less robust and less impressive aspect; the great yellow and sugar pines gradually make way for smaller and hardier species, more especially for firs and the so-called tamarack pine (*Pinus Murrayana*). Near the 8,000-foot level the sturdy mountain pine (*Pinus*

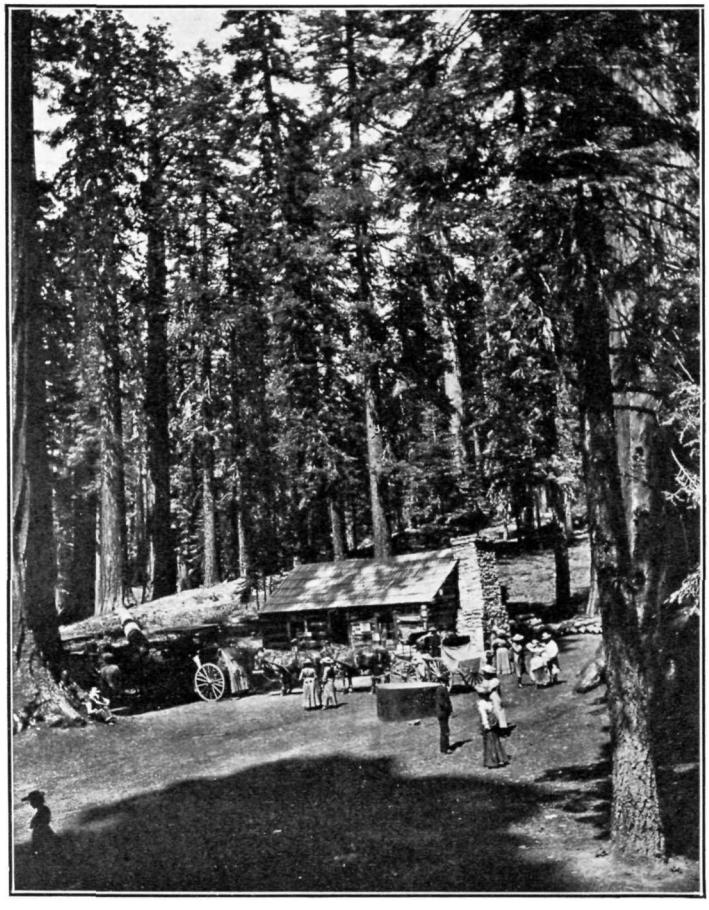

FIGURE 2.—A glimpse of the Mariposa grove of big trees.

monticola) makes its appearance and the forest thins out and seeks the sheltered slopes and basins. The increasing rigor of the winter climate becomes painfully manifest. Near the 9,000-foot level, at last, the forest gradually comes to an end. Only a few particularly resistant alpine varieties hold out, evidently against great odds. Weighted down by the heavy snows of winter, they form low-crouching, gnarled, and compact thickets, many of them even-

topped by the gales, as if trimmed by a careful gardener. Beyond these fighting outposts, constituting what is termed the "timber line," only small alpine bushes and flowering plants manage to exist, and the crags are mostly bare of soil and vegetation.

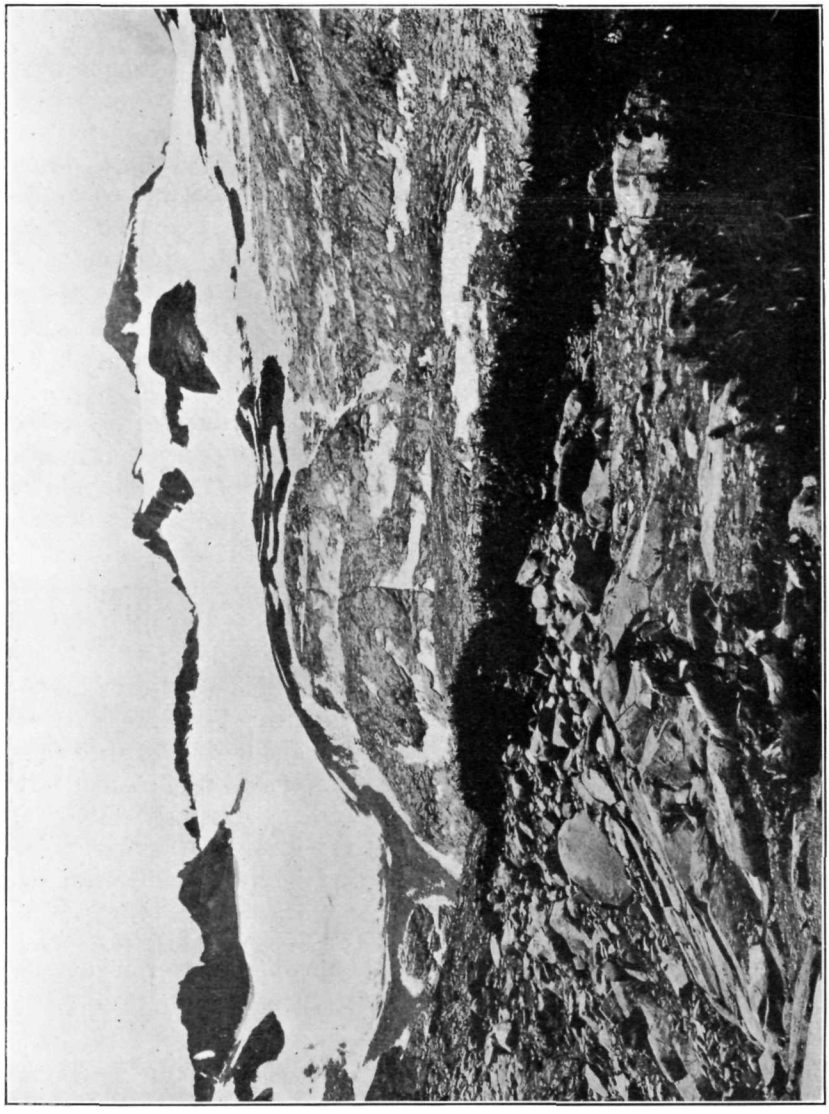

FIGURE 3.—Lyell Glacier, one of the remnants of the former glacier system of the Sierra Nevada.

Thus the extent and character of the forest cover of the Sierra slope are everywhere exactly adjusted to the conditions imposed by the climate.

As for the snow line, no distinct line of perpetual snow is traceable through the Sierra upland. The total annual snowfall is heavy,

it is true, aggregating many feet and giving the range in winter that dazzling white appearance that led the Spanish settlers on the hot plains below to name it the Sierra Nevada—the Snowy Range—yet most of this snow cover vanishes in summer under the fierce rays of the sun. Only in sheltered nooks where the wind-driven snow accumulates in eddies do banks and fields of snow of considerable thickness lie perennially from one winter to the next. In the lee of several of the main peaks there are even some large bodies of old, granular ice, which may properly be classed as glaciers. Particularly noteworthy are those on Mounts Lyell, Dana, and Conness. Situated at elevations from 11,500 feet up, on northeasterly slopes, in the lee of the westerly winds, and protected from the midday sun, these ice bodies represent the only surviving remnants of the huge glacial blanket that once covered the upper Sierra. Most of them lie on the east side of the main crest, and therefore just outside the limits of the Yosemite National Park, but they are nevertheless within easy reach of the tourist.

The peculiar climate of different parts of the Sierra Nevada and the extent and character of the forest cover are thus the natural consequences of the elevation and the geographic position of the range, and in all their features and gradations they are intimately related to its conformation.

THE YOSEMITE NATIONAL PARK.

GENERAL FEATURES.

The foregoing description of the Sierra Nevada will serve to give the reader some idea of the region in which the Yosemite National Park is situated. That reservation lies near the middle of the range, on its long western slope, extending from about the 4,000-foot level up to the Sierra crest. It embraces the great forest belt containing the sequoias and other large trees, the upper zones of sparser vegetation, and the picturesque alpine zone that reaches from timber line to snow banks and frost-shattered peaks. The lowest valleys reach down to 3,500 feet; the highest summits rise more than 13,000 feet above sea level.

A glance at the accompanying map (fig. 10) will show that the park includes the upper courses and headwaters of two of the great master streams of the Sierra Nevada—the Merced and Tuolumne Rivers. The Merced, occupying with its drainage basin the southern half of the tract, gives the park its most admired feature, the Yosemite Valley; the Tuolumne, embracing with its tributaries the northern half, produces the somewhat smaller yet scarcely less remarkable Hetch Hetchy Valley. In form each of these two canyon valleys may be likened to a short, stout tree trunk, forking upward into two or more heavy branches, which again ramify into smaller

and smaller ones, like the spreading limbs and twigs of a well-proportioned elm tree. The heads of most of these branches are on the crest of the Sierra, many of them in low gaps or passes that provide avenues for travel across the range. Especially well known are the Tioga and Mono Passes, through which trails lead down the eastern slope of the Sierra to Mono Lake and its interesting volcanic setting.

Between the Yosemite and Hetch Hetchy Valleys, which, sunk deep in the Sierra flank, lie roughly parallel to each other, is a 10-mile stretch of forested upland, embossed with rounded hills and traversed by shallow vales. The traveler through this upland is impressed chiefly with the subdued character of the relief and the general absence of strongly accentuated sculptural features; nor does he find anywhere so much as a hint of the proximity of a chasm until he emerges upon the brink of the trough of the Merced or the Tuolumne Rivers.

As the tourist ascends to higher altitudes he perceives a gradual change come over the landscape. He observes not only that the timber becomes sparser and shorter in stature, but that the topography assumes a distinctly novel aspect. As he enters the so-called "High Sierra" he notes that the regular alternation of ridge and valley, spur and ravine, which is characteristic of the lower slopes, makes way for a less orderly, less obviously systematic arrangement of topographic forms. Irregularly grouped knobs and domes of granite fill the landscape; the streams are capricious in course; the valleys descend with irregular gradients; picturesque ponds and lakelets appear in odd places, many of them without outlet; the soil is scanty and over large tracts is entirely wanting; the bare rock of the mountain swells shines white through the thinning trees, which, with their roots wedged in fissures, are stunted for lack of nourishment.

The farther up one goes the more accentuated becomes this peculiar topographic facies, until, as the timber line is reached, it dominates the entire landscape. The nearly bare peaks and mountains, hewn of solid granite, present a most varied and spectacular array of sculptural forms, ranging from smoothly rounded domes to pinnacled, castellated crags and spires. Among them wander the streams, in parts of their courses lost in valleys disproportionate to their size, in other parts following no defined valleys or channels of their own; here meandering in broad, swampy meadows, there rushing wildly down over rocky slopes or cliffs.

The larger valleys and canyons, moreover, assume a character entirely in harmony with these strange features. Steep sided and flat floored, they impress one more as smoothly gouged channels of huge proportions than as valleys slowly gullied out by streams. Depressed below the general level of the upland, they also seem overdeepened

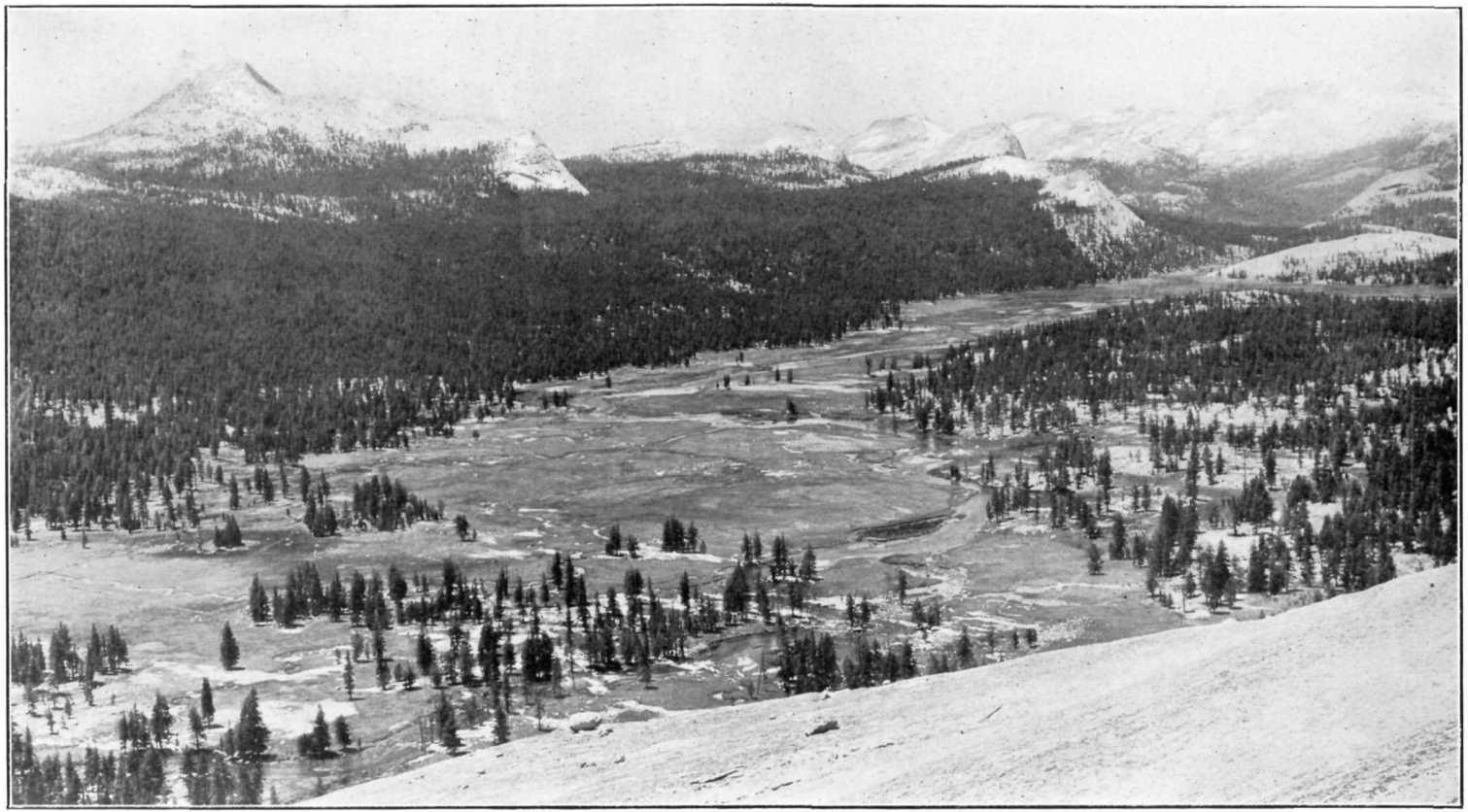

FIGURE 4.—Tuolumne Meadows and the granite peaks of the High Sierra.

with respect to their lesser tributaries, which have a strangely disjointed appearance, hanging, so to speak, at some height above the canyon floors, to which they send their waters down in cascades and waterfalls.

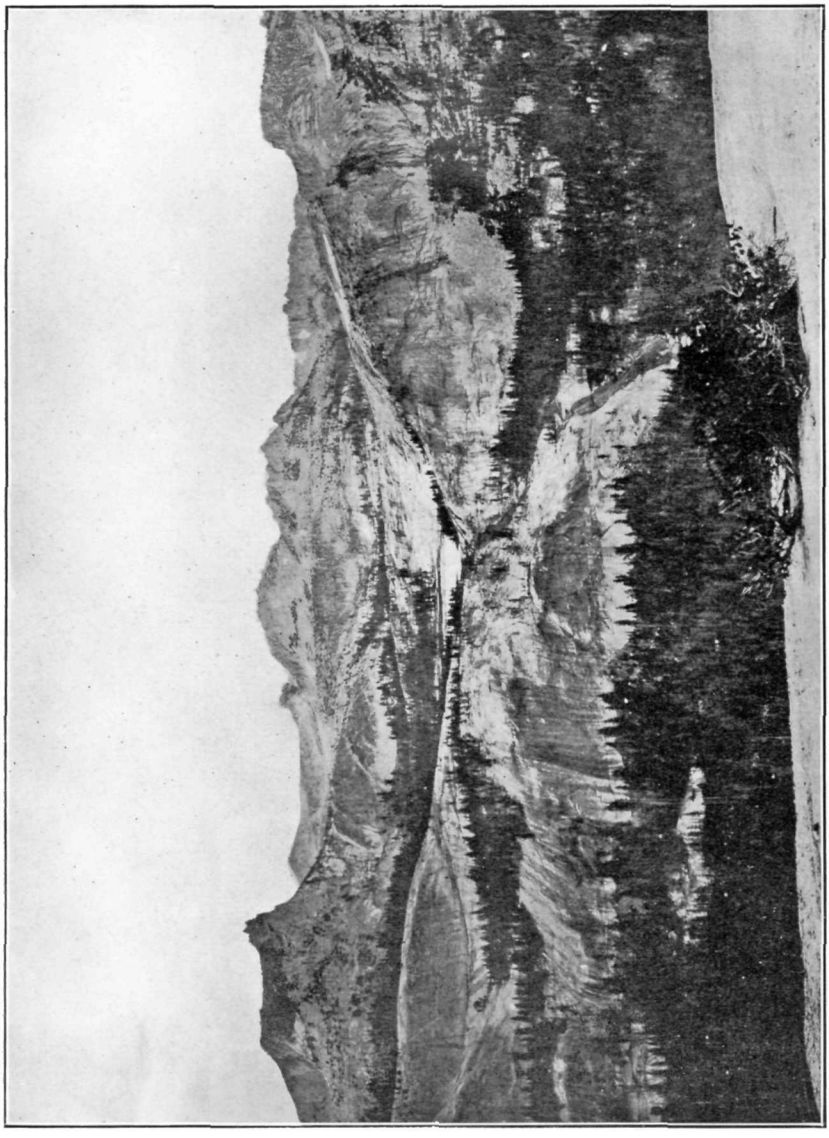

FIGURE 5.—Cathedral Peak and the strangely wrought mountains of massive granite surrounding it.

Nor do the main canyons themselves descend by even, steady gradients, but stairwise, by alternating steps and flats. The length of the flat treads varies considerably, from a few hundred yards to several miles, and the steps range in height from scores to hundreds

or even thousands of feet. Many of the treads, moreover, are hollowed and inclose lake basins.

Strangest of all are the valley heads. They are not ordinary narrow, steep-sided, deeply incised ravines or gulches, but they open out,

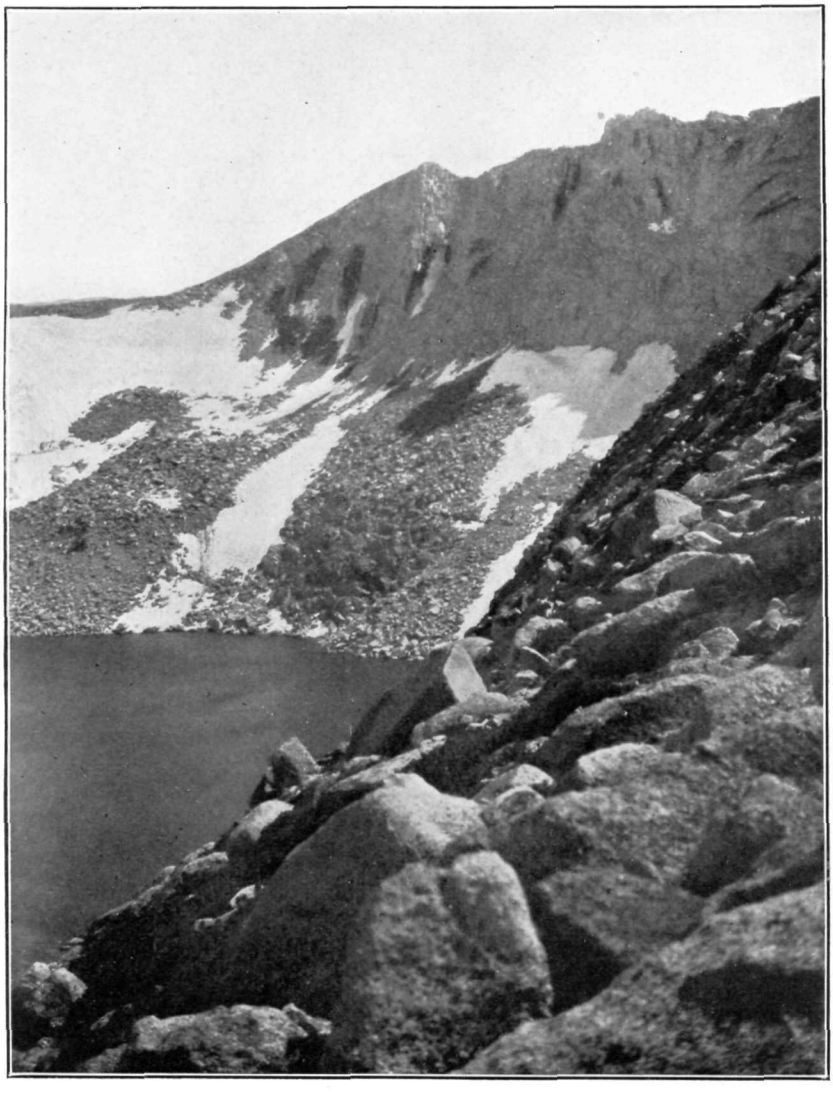

FIGURE 6.—Glacial cirque with lake on Kuna Crest, near head of Tuolumne River.

as a rule, into broadly rounded, bowl-shaped hollows, scooped out in the solid rock, and in the bottom of each of these amphitheaters usually lies ensconced a small lake or tarn in a smooth rock basin of mysterious molding.

As one surveys this assemblage of unwonted features he can not but intuitively feel that they were not produced by the ordinary processes of weathering and stream erosion, by which the familiar hill-and-valley landscapes are known to have been evolved. Running water, judging from the general arrangement of the valley systems, undoubtedly has played an important part in sculpturing this land, but its work appears to have been interfered with and disordered by another agent, which operated on a somewhat different plan. And this, indeed, is what has happened. The mysterious remodeling agent was none other than the ice of the glacial epochs. After the valley systems of the High Sierra had been established by the waters running off the slanting Sierra block, they were invaded by great ice tongues or glaciers that extended down from the summit regions, and through the erosion of these glaciers they were in various ways remodeled and changed.

GLACIAL EROSION.

As is well known, large portions of the North American Continent and of Europe, in times geologically not remote, were covered by extensive sheets of ice. Over the low-lying regions of moderate relief these ice sheets spread broadly and in great thickness—probably thousands of feet—much as they spread to-day in Greenland. But in the rugged mountains of the far West, as in the European Alps, the ice was more local, originating on the crests of the ranges and descending thence down the valleys and canyons in the form of individual streams or glaciers. This was the condition in the Sierra Nevada. The summit regions of that range, except a few of the highest wind-swept peaks and crests, were buried in snow, which, in the valley heads, reached depths of 1,000 to 2,000 feet.

Snow masses so enormous, it scarcely need be said, do not remain stationary and inert, as do snow banks only a few feet deep. Compacted to the consistency of granular ice their very weight suffices to overcome their rigidity and to bring on a slow, flowing motion which has been likened to that of a highly viscous substance, such as tar. The ice masses that occupied the upper valleys of the Sierra Nevada therefore moved forward like broad, sluggish streams, each in a separate valley, and thus formed a system of glaciers corresponding to the system of valleys previously carved by the rivers. The superabundant snow supply in the crestal regions caused the glaciers to lengthen downward to lower and lower levels, and finally to protrude far beyond the zone of glacial climate into regions where the snows of winter entirely melted away during the warmer seasons, the conditions resembling those presented to-day by the glaciers of the Canadian Rocky Mountains and the Alps of Switzerland. On the

east side of the Sierra Nevada, indeed, the ice tongues reached down to the level of the desert, but on the west side they terminated at some distance above the range foot, withering away under the hot sun.

It is obvious that a moving ice mass 1,000 feet deep or more exerts considerable force on the sides and bottom of the valley it occupies. Even though its lower layers are retarded by friction their forward movement, combined with the great weight of the overlying masses, is sufficient to scour the valley of all loose débris and to dislodge fresh blocks from the rock bed as fast as these are loosened up by frost and the solvent action of percolating waters. Glaciers therefore tend to clean out their valleys and to widen and deepen them. By their lengthwise motion they plane away the spurs and ravines that corrugate the valley sides; they undercut and truncate the valley slopes so as to transform the original constricted V-shaped cross-section of the valley to a broadly open U-shaped one. They widen sharp, angular turns in the valley course to broadly sweeping bends, substituting a succession of smooth-flowing curves for the zigzag alignment that is characteristic of stream erosion. The net effect is to give each valley the appearance of a simple, steep-sided, U-shaped trough. Lyell Canyon is a particularly excellent example of this trough type. (See fig. 7.)

The amount of excavational work that glaciers are capable of performing, however, depends so largely upon their thickness that the major ice streams deepen the main canyons much faster than their weaker tributaries can excavate the side valleys. The smaller glaciers, in other words, can not keep pace with the larger ones, and, as a consequence, after the ice has disappeared, the mouths of the smaller valleys are found "hanging" at some height above the floors of the larger ones. The strangely overdeepened aspect of the main canyons of the High Sierra, with respect to the upland vales, is thus a direct result of the glacial occupancy of the region.

A word further about the manner in which glaciers deepen their channels. Without going into the details of the process, it may be stated that, in general, the tendency of glaciers is to accentuate the unevennesses of the longitudinal valley profile. For mechanical reasons the ice mases erode most vigorously at the foot of the steeper stretches where the valley profile is concave, while in the flatter stretches, and especially where the valley profile is convex, they accomplish least. The net effect, therefore, is to replace the original stream-worn profile by a pronouncedly stairlike one, possessing alternating steps and treads. At the foot of each declivity, moreover, the descending ice tends to hollow out a lake basin in the tread below. Thus the step-wise descent of the Sierra canyons and the frequent occurrence of lakelets on their flat reaches are seen to be characteristically glacial traits.

It is in the extreme valley heads, however, that glaciers have the fullest play for their distinctive mode of sculpturing, for here the ice masses are powerfully seconded in their erosional work by the rapid diurnal changes in temperature characteristic of high altitudes, which effectually shatter the cliffs, and by frequent frosts which,

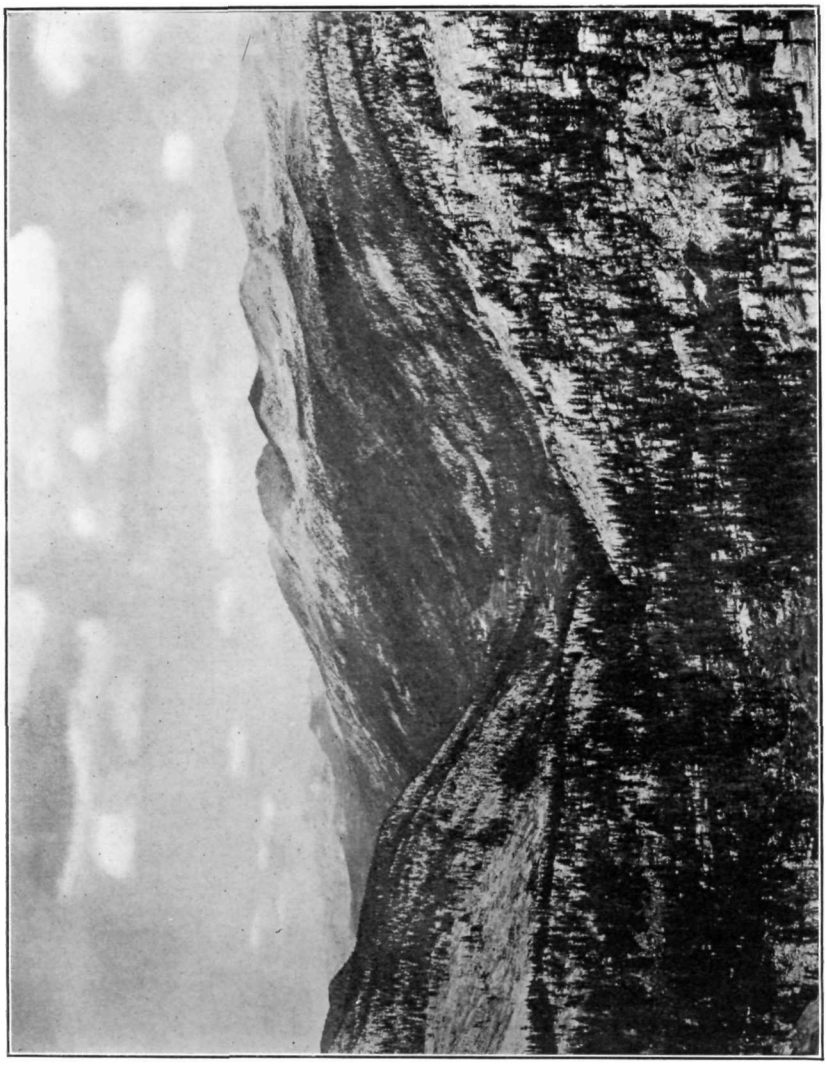

FIGURE 7.—Lyell Canyon, a typical glacial trough.

congealing the water held in crevices, disrupt the rock by their distending force. Under the attacks of these auxiliary agents the cliffs crumble rapidly and recede, so that the valley heads become enlarged into bowl-shaped amphitheaters, or "cirques," as they are technically termed. (See fig. 6.) An examination of the administrative map

of the Yosemite National Park[1] will show how prevalent such cirques are along the Sierra crest. These horseshoe-shaped hollows occupy a large part of the summit region, and, as is obvious from the courses of the contour lines on that map, have eaten into the peaks and ridges and developed at their expense.

No one who has penetrated the highest portions of the Yosemite Park can have failed to be impressed with the clean-cut, well-preserved appearance of its rock-hewn forms, as compared with the canyons and other erosional features farther down the Sierra slope. It seems as if it were only yesterday that the ice had left them. Fresh and unweathered, like new quarries, are the cirque walls, while smooth, glassy "glacier polish," the result of long-continued grinding and "sandpapering" by the débris-laden ice, still shines upon their bare rock floors. In the canyons below such polish may also be found in places, but there it has a more aged look. The luster has grown dim and much of the smooth enamel has already flaked off from the weathered, porous rock.

The reason for this notable difference in freshness of the ice marks in the summit regions and farther down is twofold. In the first place, it should be understood that what is popularly referred to as "the glacial period" really consisted of a succession of glacial epochs, separated from one another by intervals of milder climate. Each glacial epoch brought on an extension of the ice. The glaciers gradually lengthened from the summit downward until they reached a maximum limit, and then as gradually melted back to the cirques that gave them birth. In duration each epoch probably amounted to several thousand years, but so slow was the advance of the glaciers, and so slow the retreat of their fronts, that although the cirques and upper canyons were ice-filled for long periods, the lower canyons were invaded for only a fraction of the time. In the second place, it is but quite recently that the last glacial epoch came to a close. Indeed, in one sense it has not ended yet, for on the Sierra crest a few small ice bodies still hold their own. The uppermost cirques, there is good reason for believing, have only just been released from the dominion of the ice, but the lower canyons have been ice free for a considerable lapse of time and subject to normal weathering and to stream erosion.

The gradual change in the character of the upland between the canyons, which one notices in ascending from lower to higher levels, is similarly explained. In the lower portions of the Yosemite Park the ice has existed for only brief periods and at long intervals; its influence on the topography has been slight, and in the long stretch of time since the final retreat of the ice has become partly

[1] To be had for 25 cents on application to the Director of the U. S. Geological Survey.

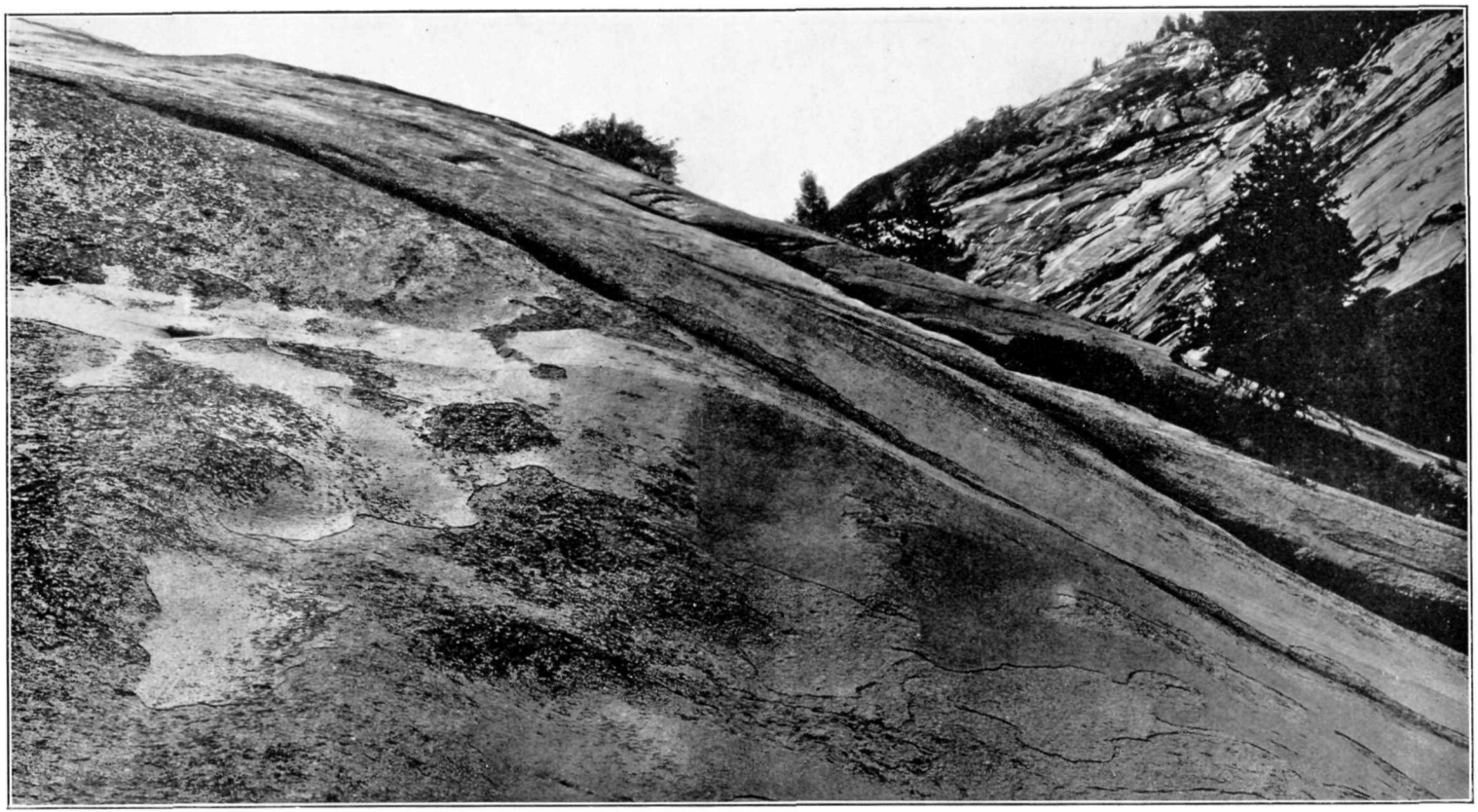

FIGURE 8.—Glacial polish flaking off from weathering rock in Upper Merced Canyon.

obliterated by ordinary erosional processes and by the advent of vegetation. But higher up the glaciation has been prolonged and

FIGURE 9.—Bird's-eye view of Yosemite Valley looking eastward to the crest of the Sierra Nevada.

1, Clouds Rest; 2 Half Dome; 3, Mount Watkins; 4, Basket Dome; 5, North Dome; 6, Washington Column; 7, Royal Arches; 8, Mirror Lake and mouth of Tenaya Canyon; 9, Yosemite Village; 10, Head of Yosemite Falls; 11, Eagle Peak (the Three Brothers); 12, El Capitan; 13, Ribbon Fall; 14, Merced River; 15, El Capitan Bridge and Moraine; 16, Big Oak Flat Road; 17, Wawona Road; 18, Bridalveil Fall; 19, Cathedral Rocks; 20, Cathedral Spires; 21, Sentinel Rock; 22, Glacier Point; 23, Sentinel Dome; 24, Liberty Cap; 25, Mount Broderick; 26, Little Yosemite Valley.

intense, and has persisted until a relatively late day. Its characteristic effects have therefore become strongly accentuated, and are still well preserved.

Such, then, in brief, is the explanation of the singular physiognomy of the High Sierra. Much of its charm and grandeur is inherited from the former reign of ice—that mysterious chain of events in the earth's recent geologic history that has wrought so effectively for the scenic endowment of several of our finest national parks.

THE YOSEMITE AND HETCH HETCHY VALLEYS.

EFFECT OF GLACIATION.

The question may be raised at this point whether the foregoing general explanation also applies to the Yosemite and Hetch Hetchy Valleys. These two valleys, though in many respects resembling the glacial canyons of the High Sierra, nevertheless possess a distinctive, if not exceptional, character that places them in a category by themselves. They may be described as deep-hewn, clean-cut moats bordered by precipitous rock walls that sharply trench across the surface of the uplands and spring abruptly from broad, level, grassy floors. Waterfalls and cascades of great height and beauty leap down into both chasms from the hanging valleys of the upland, and the cliffs themselves are sculptured into a variety of bold and picturesque forms, such as are scarcely known elsewhere.

In length the Yosemite Valley measures about 7 miles; in height its walls range from 3,000 to 4,000 feet; its floor width averages 1 mile. The Hetch Hetchy Valley, which is essentially similar in its characteristics, is only 3 miles long, half a mile wide, and some 2,000 feet deep. Both valleys lie at fairly low levels, the elevation of the floor of the Yosemite above the sea being 3,960 feet, that of the Hetch Hetchy Valley 3,660 feet.

Better, perhaps, than any verbal description, the accompanying bird's-eye view (fig. 9) will enable one to gain an understanding of the general character of the Yosemite Valley and the location of its various scenic features. The appended table further will furnish some idea of their altitudes above sea level and their heights above the valley floor.

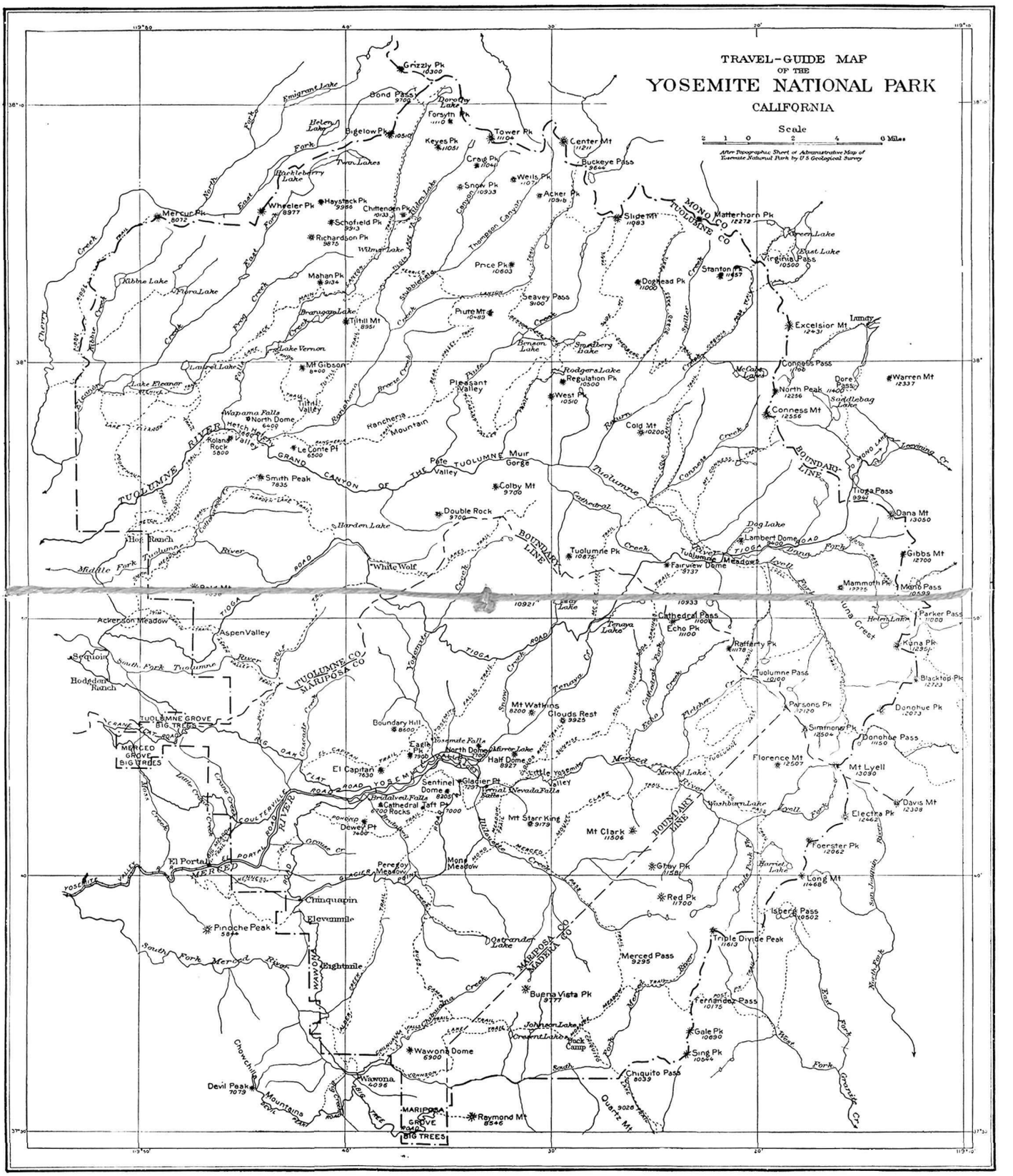

FIGURE 10.—Map of the Yosemite National Park.

Altitude and height of land features.

	Altitude above sea level.	Height above valley floor.
	Feet.	*Feet.*
Valley floor (concrete pier near Sentinel Hotel)	3,960	00
Clouds Rest	9,924	5,964
Half Dome	8,852	4,892
Mount Watkins	8,235	4,275
Basket Dome	7,602	3,642
North Dome	7,531	3,571
Washington Column	5,912	1,952
Yosemite Point	6,935	2,975
Eagle Peak	7,773	3,813
El Capitan (crown)	7,564	3,604
El Capitan (rim)	7,100	3,140
Cathedral Rocks (highest)	6,638	2,678
Cathedral Spires (highest)	6,114	2,154
Sentinel Rock	7,046	3,086
Glacier Point	7,214	3,254
Sentinel Dome	8,117	4,157
Little Yosemite	±6,150	±2,200

Altitude and height of waterfalls.

	Altitude of crest above—		Height of fall.
	Sea level.	Valley floor.	
	Feet.	*Feet.*	*Feet.*
Upper Yosemite Fall	6,525	2,565	1,430
Lower Yosemite Fall	4,420	460	320
Ribbon Fall	7,008	3,048	1,612
Widows Tears	6,466	2,506	1,170
Bridalveil Fall	4,787	827	620
Sentinel Fall	5,886	1,926	619
Illilouette Fall	5,816	1,856	370
Vernal Fall	5,044	1,084	317
Nevada Fall	5,907	1,947	594

So extraordinary is the appearance of both the Yosemite and Hetch Hetchy Valleys that one involuntarily asks himself whether ice erosion alone is really sufficient to account for all their peculiarities or whether one should appeal to other forces for an explanation, as some of the earlier investigators have done. The tendency at first was, not unnaturally, to look for causes of a violent, cataclysmal sort. Features so extraordinary seemed to demand an unusual explanation, but the adequacy of slow-working everyday erosional processes to produce the results seen has come to be more and more universally recognized. It may be of interest, nevertheless, to briefly review the older theories here before giving what is now generally accepted as the correct explanation.

Prof. J. D. Whitney, the first scientist to study the Sierra, thought the deeply incased character of the Yosemite Valley to be the result of the sinking of a local block of the earth's crust having the exact outlines of the valley. Glaciers, he stoutly asserted, had never so much as entered it.

Galen Clark believed the valley to have originated by the exploding of a number of close-set domes of molten rock, subsequent stream and ice erosion having smoothed out the chasm to its present form.

Prof. Silliman considered the Yosemite as a great rupture caused by subterranean forces—a rent later partly filled with rock débris.

Clarence King was the first to point out the prominent rôle which the ice of the glacial epochs must have played in the elaboration of the Yosemite Valley. John Muir goes further and holds that the Yosemite, like all the canyons and other features of the Sierra Nevada, was sculptured almost wholly by ancient glaciers.

In contrast to this view is that of H. W. Turner and several others, according to whom the Yosemite is nothing but a stream-cut valley which has suffered little if any modification at the hands of the ice, but which owes much of its peculiar shaping to the influence of the strong vertical joints displayed in its walls.

Willard D. Johnson, a close student of ice erosion, considers the Yosemite and Hetch Hetchy Valleys to be products of stream erosion, subsequently widened by the characteristic sapping action of the ice. Others, notably E. C. Andrews, of New South Wales, and Douglas W. Johnson, have followed, all uniting in attributing considerable importance to glacial erosion, but differing somewhat in their estimates of the amount of work they believe should be assigned to it.

The most probable explanation is that the Yosemite and Hetch Hetchy Valleys both, like the other canyons and valleys of the High Sierra, have been developed through stream erosion consequent to the uplift of the Sierra block, and have later been greatly deepened and enlarged by repeated ice invasions; further, that they owe their strangely clean-cut, moat-like forms and the diversified sculpturing of their cliffs to the structure of the country rock, which has locally controlled the action of the eroding agents.

There is every reason to believe that the Yosemite and Hetch Hetchy Valleys are, in the first place, of stream-cut origin. Their relations to the other parts of the Merced and Tuolumne Valley systems leave no room for doubt on this point.

That both valleys have been visited by glaciers descending from the Sierra crest is now also settled beyond dispute. No one familiar with the evidences of ice work could be misled in this regard. Indeed, it is difficult to see how so eminent a scientist as Whitney could have overlooked the unmistakable signs of glaciation in the Yosemite Valley and should have pronounced that valley to have been ice-free at all times while admitting the Hetch Hetchy Valley to have been glaciated.

There are many indubitable proofs of the former glaciation of the Yosemite and Hetch Hetchy Valleys, but one of the best is found

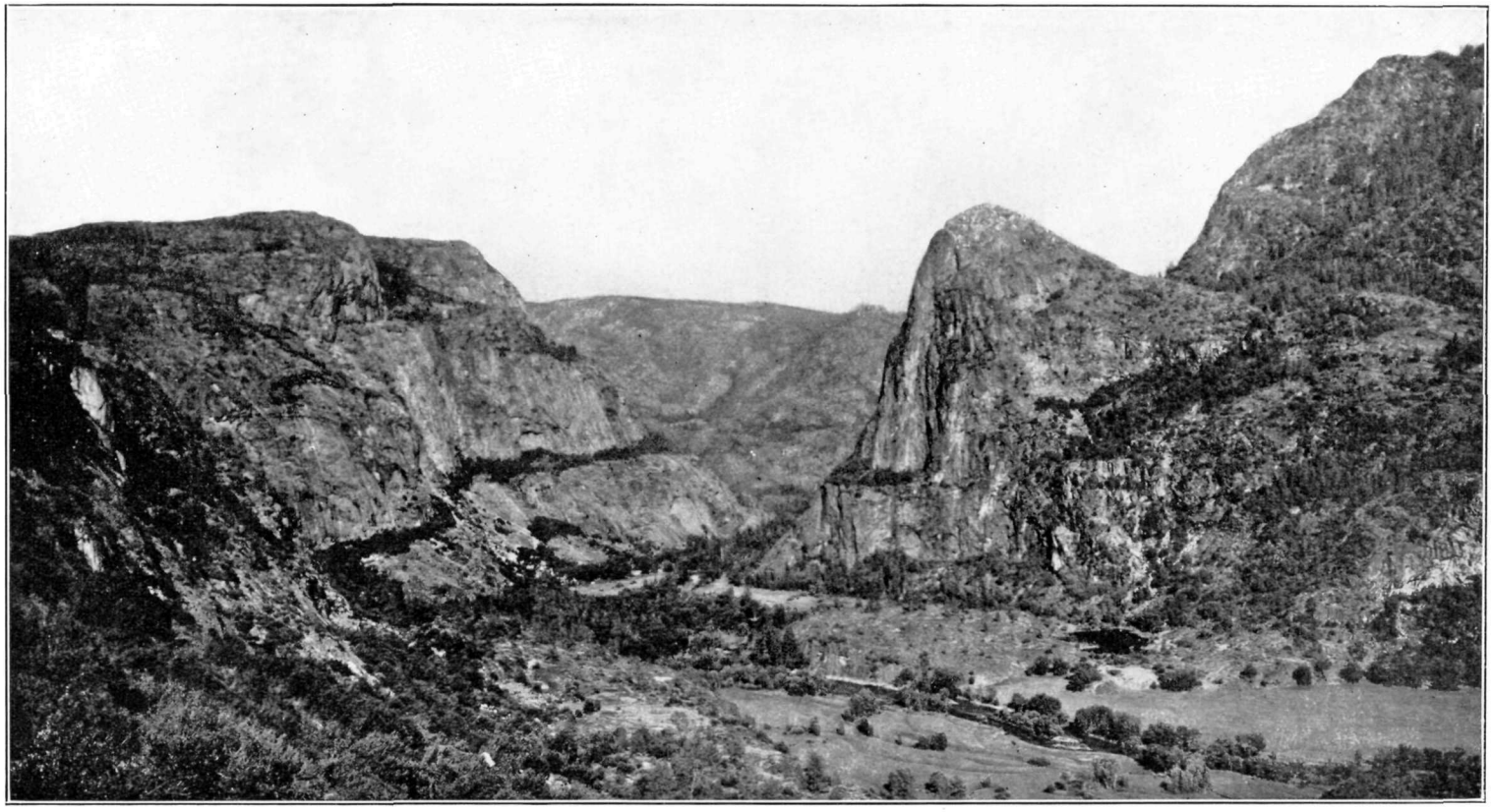

FIGURE 11.—View of Hetch Hetchy Valley. The meadows show the extent of the filled lake basin.

in the fact that both have deeply eroded rock basins in their floors. Running water does not erode inclosed rock basins of any considerable size or depth. Glaciers are the only agents known to produce such features by erosion. As for the possible formation of either of the basins by the subsidence of a local block, as contended by Whitney, or by the damming action of a landslide or volcanic eruption, there is no evidence whatever pointing to an origin of that sort.

To the layman the basins in the Yosemite and Hetch Hetchy Valleys may not at once be apparent. The fact is that they have long been filled with river sediment, and the picturesque lakes which they once held have been transformed into level expanses of meadow land. To the trained eye, however, this does not render the basins any less easy to recognize. The lake in the Yosemite Valley must have measured some 6 miles in length; that in the Hetch Hetchy Val-

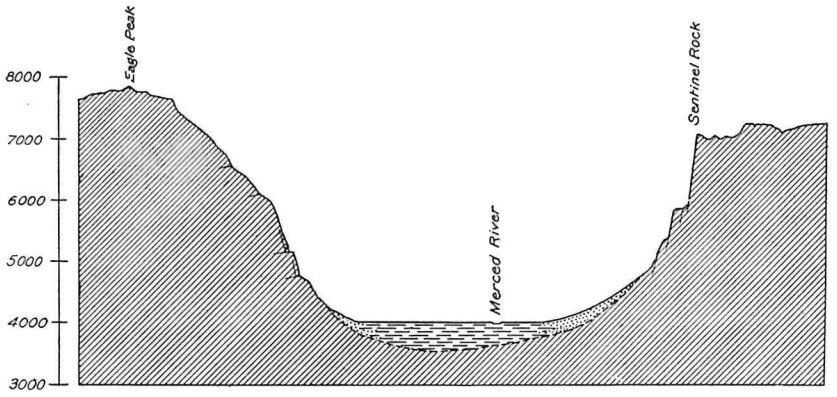

FIGURE 12.—Cross section of Yosemite Valley from Eagle Peak to Sentinel Rock, showing probable depth of filling.

ley about 3 miles. In the Hetch Hetchy Valley the heavy rock sill that closes the basin at its lower end is still plainly visible, but in the Yosemite Valley the rock sill is buried under a ridge of glacial débris or "moraine," and its existence is only to be surmised. There is, however, ample justification for the conjecture, as few of the moraines in the Yosemite region measure more than a hundred feet in height, whereas cross sections of the valley, based on careful measurements and drawn without vertical exaggeration, seem to indicate that the depth of the present sand filling in the valley may amount to at least 500 or 600 feet. (See fig. 12.)

A few additional words about this interesting moraine may not be out of place. Consisting of rock débris carried by the glacier and dropped at its lower end, that ridge marks the position which the ice front occupied during a halt in its final recession. Stretching across the entire width of the valley from the base of the Cathedral Rocks

to El Capitan, the moraine, after the ice had melted away, acted as a dam, raising the level of the waters in the rock basin until they rose within a few feet of its crest. But the Merced River, pouring through a low saddle in the ridge, has since cut a sharp notch, the very gap now spanned by the El Capitan Bridge.

It is noteworthy that glacially excavated lake basins also occur on the treads of the great branch canyons of the Yosemite Valley. A lake 3 miles long, now filled with sediment, once occupied the entire extent of the Little Yosemite; and on the tread immediately above the Vernal Fall a small but none the less typical tarn still remains in the form of Emerald Pool. Tenaya Canyon once contained four lakes, situated at successively higher levels. Of these the three upper ones are filled, but the lowest and longest is still partly in existence. Mirror Lake is its last remnant, and though fast being extinguished by the ever-advancing delta of Tenaya Creek, it is likely for a long time to continue to please the sight-seer with its wonderful reflections.

Many other evidences of ice work in the Yosemite and Hetch Hetchy Valleys might be adduced, such as moraines, erratic bowlders, and striated rock surfaces, but it is desired only to invite attention to the testimony furnished by the great waterfalls. These are to be regarded as something more than mere spectacular features of the landscape; they afford a rough measure of the depth to which the main troughs have been overdeepened with respect to the "hanging" valleys on the upland. It is worth while in this connection to inspect the table of altitudes and heights of waterfalls on page 26. Many of the hanging valleys, it will be seen, debouch at heights ranging from 2,000 to 2,500 feet above the floor of the Yosemite Valley. It has been estimated from these figures, making due allowances for the lowering of the side valleys themselves and a number of other factors, that the Yosemite trough may have been excavated at least 2,000 feet. Whether all of this work is to be accredited to the ice, however, or in part also to stream erosion is a question that can not yet be determined with certainty.

INFLUENCE OF ROCK STRUCTURE.

Ice erosion alone does not explain all the characteristics of the Yosemite and Hetch Hetchy Valleys. It does not explain, for instance, why each of these valleys should so utterly differ in shape and general character from its own branch canyons. These also have been glaciated, but for some reason the ice in them appears to have modeled on essentially different lines. Thus, Tenaya Canyon, which enters the Yosemite at its head, though even more profound than that valley (4,500 feet deep opposite Clouds Rest) is relatively narrow in proportion to its depth. It is a constricted gash with sloping rock walls, a canyon or gorge rather than a valley. In antithesis to it

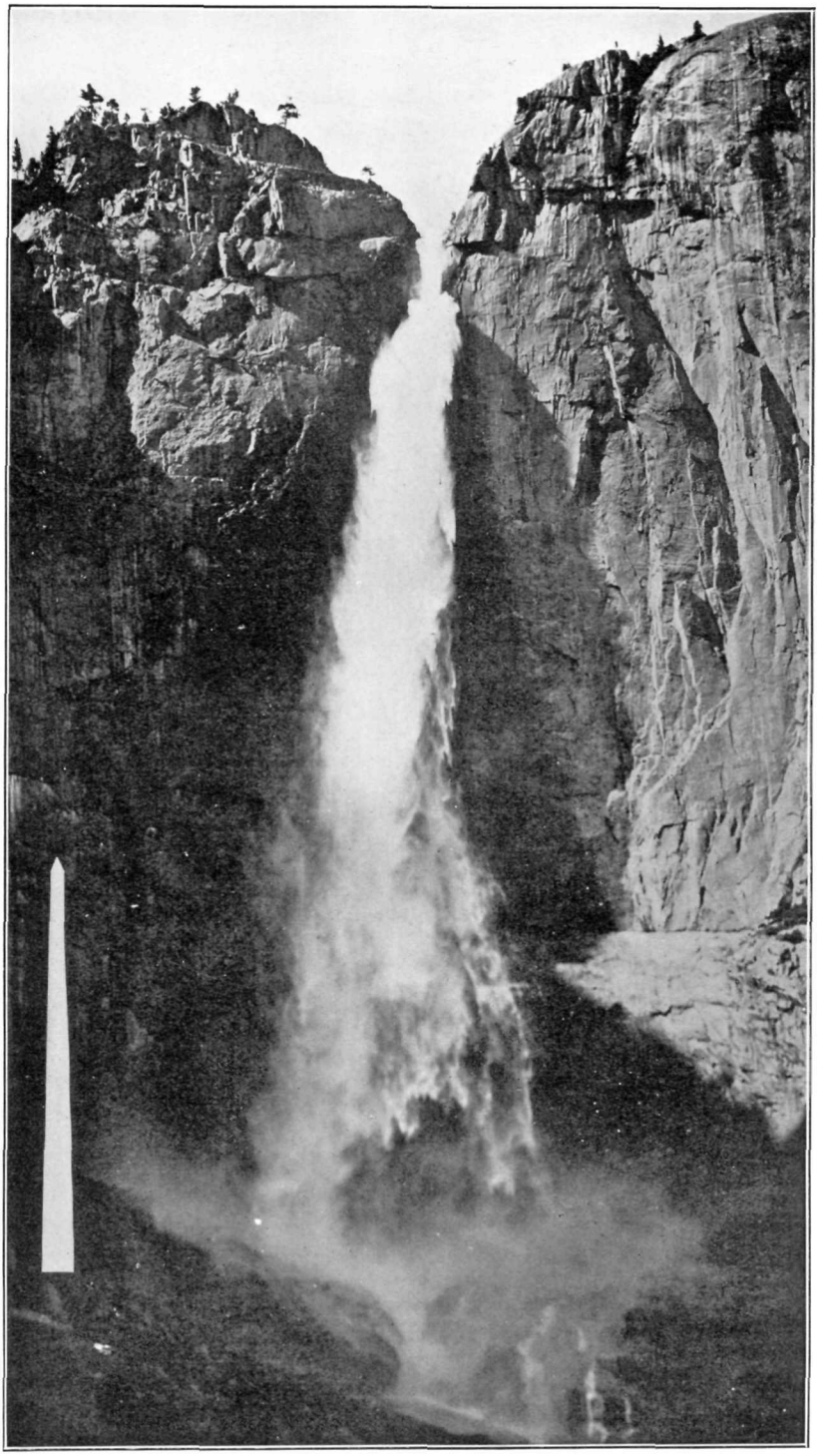

FIGURE 13.—Upper Yosemite Fall, 1,430 feet in height. The top is 2,565 feet above the valley floor. Figure representing Washington Monument is shown on the left.

stands the Little Yosemite, which is the path of the Merced. Only distantly analogous to the main Yosemite Valley, it is remarkable, above all, for its great width and relative shallowness. Further

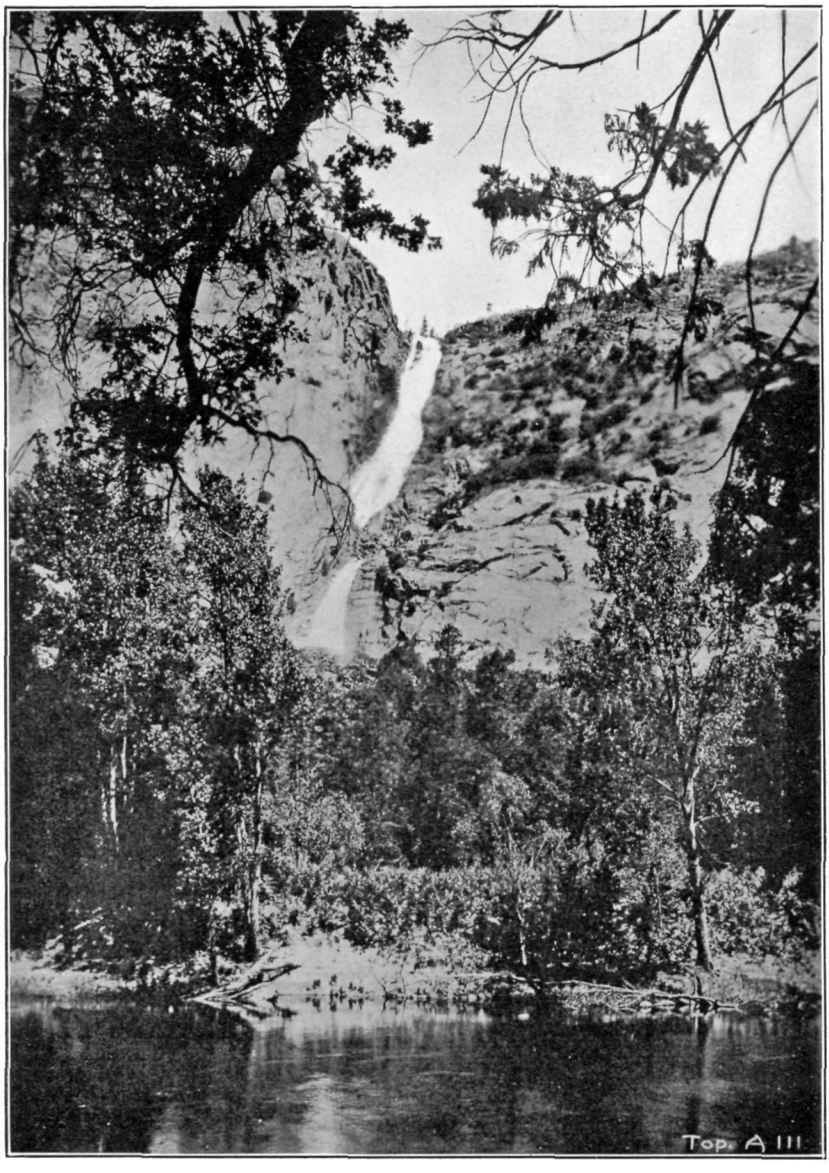

FIGURE 14.—Wapama Falls, Hetch Hetchy Valley.

Tenaya Canyon debouches practically at the level of the main valley floor, whereas the Little Yosemite lies a full 2,000 feet above that floor. It has paradoxically the relations of a hanging valley, though

really occupied by the master stream itself, which descends from it by a gigantic stairway, making two successive plunges, the Nevada Falls (594 feet) and the Vernal Falls (317 feet).

The Hetch Hetchy Valley is somewhat different in detail, but the problem involved is essentially similar. What most strikes one here is the difference between the open character of the Hetch Hetchy Valley, and the narrow, closed-in aspect of Tuolumne Canyon, the stupendous chasm debouching into it, which is about 15 miles long and fully a mile deep. So great is the disparity in the configuration of these two features, that at first it is difficult to understand how the two could have been produced by the same agent.

Further, there are a host of minor details that, on closer examination, seem anomalous and demand special explanation. Thus, to confine our attention to the Yosemite Valley, that trough, as will be patent from the bird's-eye view, is strangely constricted near its middle by two great promontories that advance out into it from opposite sides, while immediately above and below this gateway the valley is wider than anywhere else. The hanging valley of Bridalveil Creek projects like a headland into the main trough, and the Bridalveil Fall itself anomalously leaps from the end of a cape. No less puzzling is the occurrence of the two ponderous granite bosses, Liberty Cap and Mount Broderick, that bar the Little Yosemite at its lower end. The valley walls themselves present an array of rock forms surprising both in size and in sculptured shape. Colossal undivided masses, such as El Capitan, thousands of feet high and broad, contrast with forms of utmost fragility, such as the finger-like minarets of the Cathedral Spires. Huge blank walls of mural straightness, as those under Glacier Point or the Yosemite Falls, alternate with sharp-cut reentrants and overhanging recessed arches, while upward the rock masses terminate for the most part in bare, rounded, helmet-like forms, such as North Dome and Sentinel Dome. Finally, at the head of the Yosemite Valley, dominating the entire landscape, stands that most enigmatic of all rock monuments of the High Sierra, the famous Half Dome.

To understand how these peculiar features have come into existence it is necessary to have some insight into the character of the rocks of the Yosemite region and also into the manner by which their structure has affected the sculpturing action of ice and water.

The Yosemite and Hetch Hetchy Valleys lie hewn in granite, or, more strictly, in granitic rocks of various kinds. The larger part of the Sierra block consists of such rocks, all of them of igneous origin—that is to say, of rocks solidified from a molten state deep under ground. Stripped of their former rock cover by the long-continued denudation that took place in times preceding the Sierra uplift, they now appear at the surface. A few scattered remnants

of the sedimentary rocks that once overlay them may still be found along the Sierra crest, mostly in the form of slates and quartzites.

The most marked peculiarity of the Sierra granites is the exceedingly irregular distribution of the so-called joints or natural partings in them. Most rocks in disturbed mountain regions are trav-

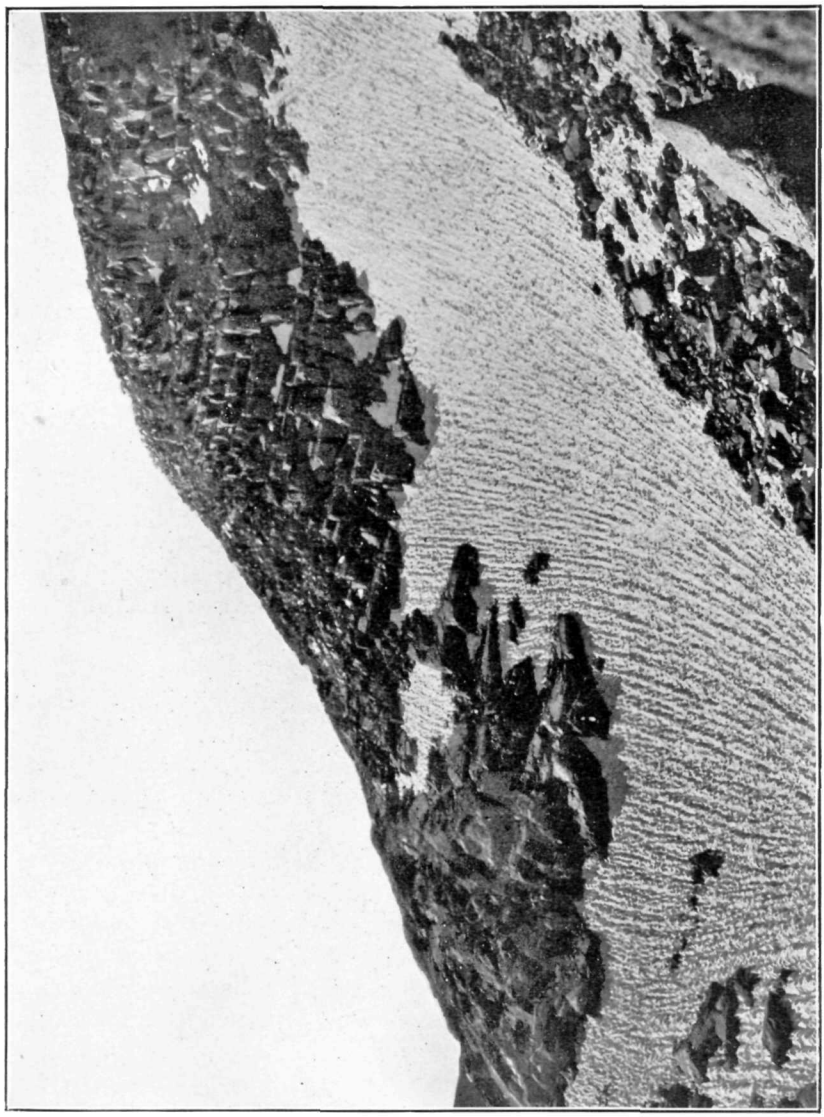

FIGURE 15.—Regularly jointed granite, an easily eroded rock. Kuna Crest.

ersed by such partings, and these ordinarily occur in several sets crossing one another, the fissures of each set being parallel and spaced at more or less regular intervals. The entire rock mass thus is divided into fairly regular, flat-sided, smooth-edged blocks, called joint blocks.

Throughout the Sierra Nevada the jointing of the granites is full of vagaries, the partings being but a few feet, or even only a few inches, apart in places, while elsewhere they appear to die out, leaving the rock entirely massive and undivided. Figure 15 shows a typical example of jointed granite; figure 16 one of essentially massive rock. It is easy to see how the fissured rock must readily yield

FIGURE 16.—Massive granite, not susceptible to glacial plucking, abraded and polished by the ice.

to erosive forces of any kind. It affords many avenues for percolating water and other weathering agents, and naturally tends to be converted into an aggregate of loose blocks and fragments, ready for removal. That it is especially susceptible to erosion by glaciers will also be clear; under the powerful drag of a heavy, overriding ice mass it is literally "plucked" or "quarried" away block by block.

The massive rock, on the other hand, because of the sparseness of its fissures, stands much better chance to resist the elements. Only its outer surface is vulnerable to the attacks of weathering agents, and consequently it is much slower to decay. As for erosion by glaciers, its individual joint blocks are so enormous in size and weight that no ice mass has the power to dislodge them. The only process by which the ice can reduce materials so massive is by abrading and grinding them with the rock débris held in its grip. But this process of abrasion is exceedingly slow and its results are not comparable with those of the quarrying method. Its characteristic products, the so-called glacier polish and striæ, so often seen on ice-eroded valley floors, seem so impressive that one is apt to overestimate the amount of erosional work they represent. One would do better to regard them as evidences of retardation of glacial excavation due to the great resistance offered by the massive rock.

It will be clear, then, that in a region of highly varied rock structure, such as the Sierra Nevada, erosion must necessarily proceed at locally varying rates. Where the rocks are most densely jointed they will succumb most rapidly and be worn into deep hollows, while the undivided massive rocks will resist the longest and in time remain standing out in high relief. All the knobs and domes that are so characteristic of the Sierra landscape have developed in this way; they are composed of sparsely fissured, essentially massive granite, and have survived the denudation that has swept away the weaker rocks that once surrounded them. As one studies more minutely the cirques and canyons along the Sierra crest he will see that they have largely been hollowed out in fissured material and that their individual peculiarities and minor details have all been determined by local inequalities in the structure of the rock. The High Sierra, one thus gradually comes to realize, owes its peculiar aspect not to ice erosion simply, but to ice erosion guided by the structures in the country rock.

And this, as a matter of fact, is also the explanation of the extraordinary character of the Yosemite and Hetch Hetchy Valleys. These two chasms may differ from the other valleys and canyons of the High Sierra, but the difference is not one of kind but of degree; they are characteristic of the Sierra landscape, but they represent its most extreme phase.

It is in the neighborhood of the Yosemite and Hetch Hetchy Valleys that the structural peculiarities of the Sierra granites reach their climax, for here the contrasts between fissured and unfissured rock are most extreme and abrupt. Zones of finely sheared granite, consisting wholly of thin plates and slivers in some places pass through bodies of more or less coarsely and regularly jointed rock; in other places they lie contiguous to undivided masses of enormous

extent. Perhaps the best mental image one can form of the structure of the rock of these localities is that of many huge, solid, massive lumps, hundreds and even thousands of feet in diameter, embedded in a matrix of jointed material, the whole mass being traversed in sundry directions by narrow zones of shearing and occasional single master joints.

To one who has gained a thorough appreciation of the effect which such exceedingly diverse structures must have on the action of the eroding agents, the mystery of the apparently anomalous character of the Yosemite and Hetch Hetchy troughs vanishes at once. The pronounced differences noted in the shape and aspect of these two troughs and their respective branch canyons are seen to correspond to the differences in the structure of the rock masses which these chasms respectively traverse. The Yosemite Valley evidently was carved from prevailingly fissured materials in which the ice was able to quarry to great depth and width. Tenaya Canyon, on the other hand, was laid along a rather narrow zone of fissuring, flanked by close-set, solid masses; and the glacier that flowed through it, while permitted to carve deeply—more deeply even than the mightier Yosemite glacier—was impeded in its lateral excavating and has been able to produce only a narrow, gorge-like trough. The Little Yosemite, again, afforded conditions of an essentially opposite nature. Here the ice was allowed to quarry sidewise, but its downward cutting below a certain level was arrested by the huge horizontal beds of massive granite that form the valley's basement. All the ice could do was to abrade and polish these, as one may see in many places where the solid rock floor is exposed to view, notably at the head of the Nevada Falls.

But even in the Yosemite Valley itself the ice did not erode with equal facility at every point; some of the rock materials were more readily quarried away than others, and various inequalities in the trough form have resulted. The great width of the valley near the Cathedral Spires, as one might expect, is due to the particularly close jointing that is characteristic of the rock in that locality, which greatly facilitated the glacial quarrying. The narrowest place, on the other hand, occurs, it goes almost without saying, between two rock masses of exceptional solidity and strength—El Capitan and the Cathedral Rocks. Scarcely susceptible to glacial plucking, they have stubbornly resisted reduction by the passing ice, which was thus forced to squeeze through a narrow strait. Immediately below the constriction the valley walls flare out again, widening in proportion as the rocks become more fissile, and the trough regains its former width. The anomalous projecting character of the hanging valley of Bridalveil Creek is thus explained by the protection afforded it by the bulwarks of the Cathedral Rocks, though these have

nevertheless seriously suffered at the hands of the ice; for the rocks as they now appear are merely the remnants of what was once a strong, continuous ridge. Its east half has been pared away by the ice, almost up to the crest line.

The constriction at the mouth of the Little Yosemite Valley is similarly explained. It was the essentially massive, unquarriable nature of the rock composing Liberty Cap and Mount Broderick that enabled these two bosses to hold out against the ice. The glacier coming down the Little Yosemite not only impinged against them, but at times even entirely overrode them, as is attested by the glaciated bowlders still lying on their summits. It was able, however, to reduce them but relatively little, though it was successful in stripping away the surrounding weaker rocks as well as the material from the fissured zone between them, now hollowed out into a profound, gaping cleft.

DETAIL SCULPTURE.

Not all the rock forms of the Yosemite and Hetch Hetchy Valleys, however, are of ice-hewn origin. The detailed carving of the cliffs has been mostly the work of the dismantling agents that took hold after the ice had left its task. Weathering, frost, and percolating water are the sculptors that have done the finer chiseling; the glaciers only modeled in the rough. Like the glaciers they have throughout followed the dictates of the structure, and being inherently more subtle in their action than the ice, with its coarse quarrying process, they have wrought far more minutely and with greater delicacy of touch. They have responded to every local change in fissuring and have brought out every structural incident in bas-relief.

Thus it is the exceptional solidity of its granite that has enabled El Capitan to maintain the rare boldness of its 3,000-foot front. So little débris has fallen from it since the days of the ice as to be scarcely noticeable at first glance. El Capitan, more than any other cliff, may be said to typify the "rock of ages." Yet immediately to the west of El Capitan is a deeply incised gulch, excavated along a zone of shattering, from which the crushed materials have fairly vanished before the onslaughts of the weather. (See bird's-eye view, fig. 9.)

Similar but narrower zones are being etched out into clefts gashing deeply into the otherwise massive Cathedral Rocks and threatening to sever them from each other. Hard by, again, in the region of the Cathedral Spires, wholesale ruin has overtaken considerable portions of the canyon wall, and the crumbling materials now rest in huge débris slopes from which only two lone, tottering shafts emerge. Farther up the valley the rock is firmer, but is traversed by many inclined joint planes, which appear to have guided the sculpturing

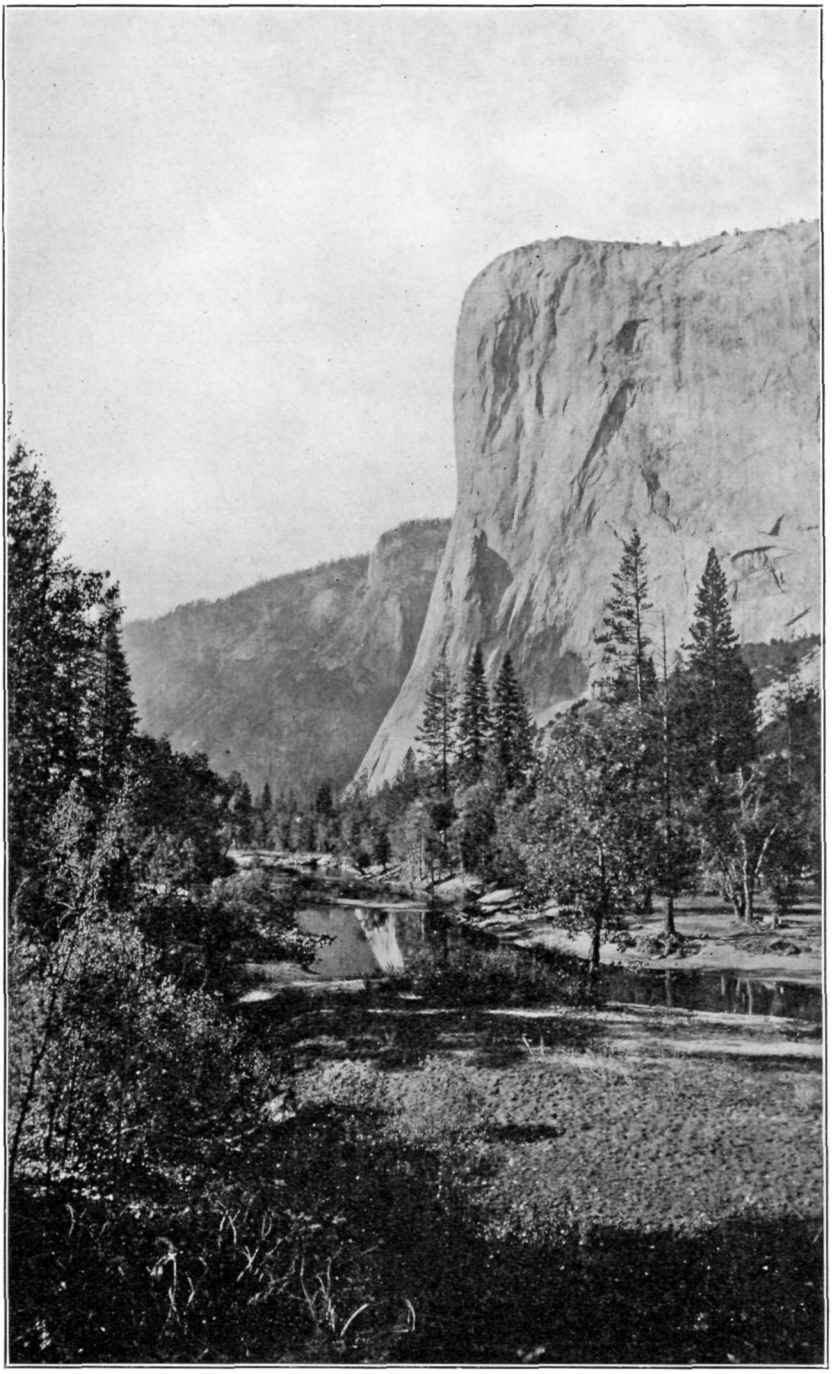

FIGURE 17.—El Capitan from the east.

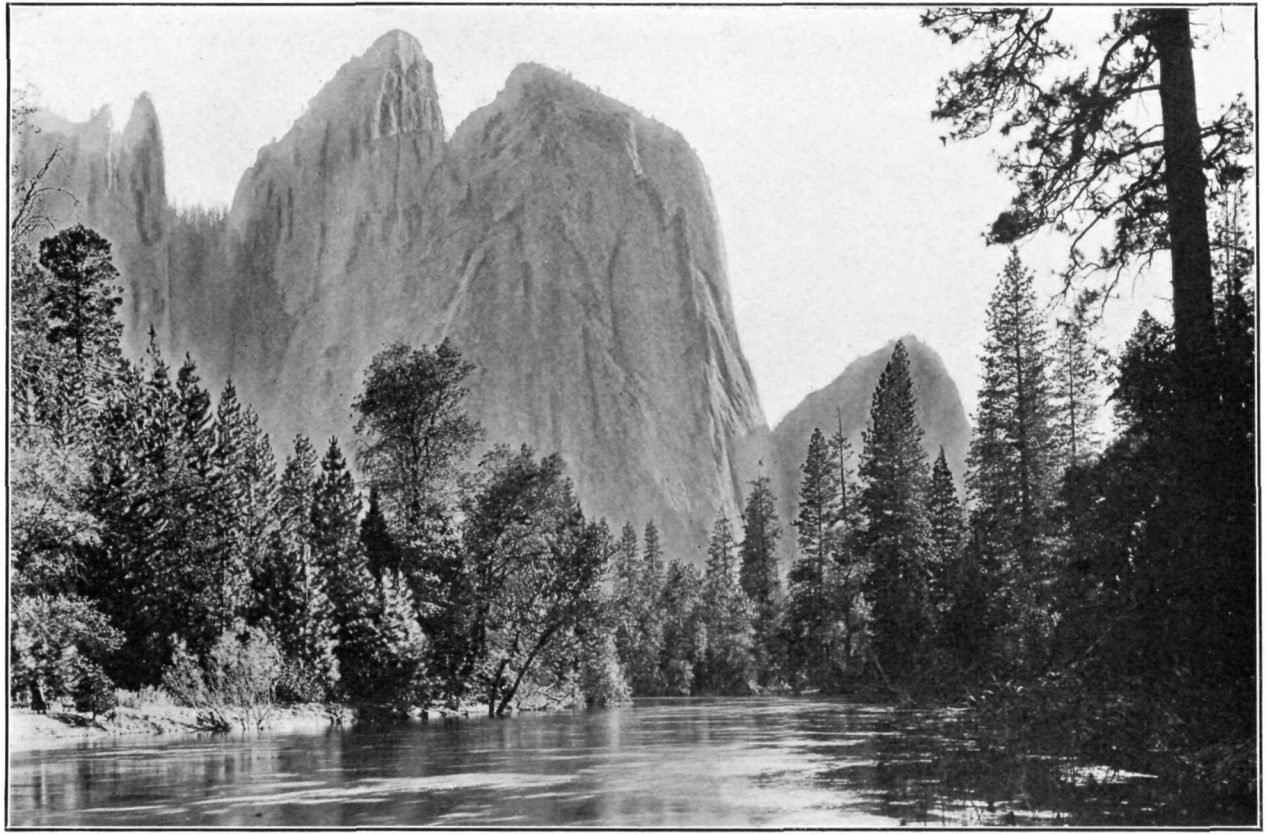

FIGURE 18.—Cathedral Rocks and Spires. Notice the deep, narrow clefts etched out along zones of shattering.

agents and have given rise to strangely unsymmetrical, faceted shapes. The Three Brothers (fig. 19) afford the most impressive form of this type.

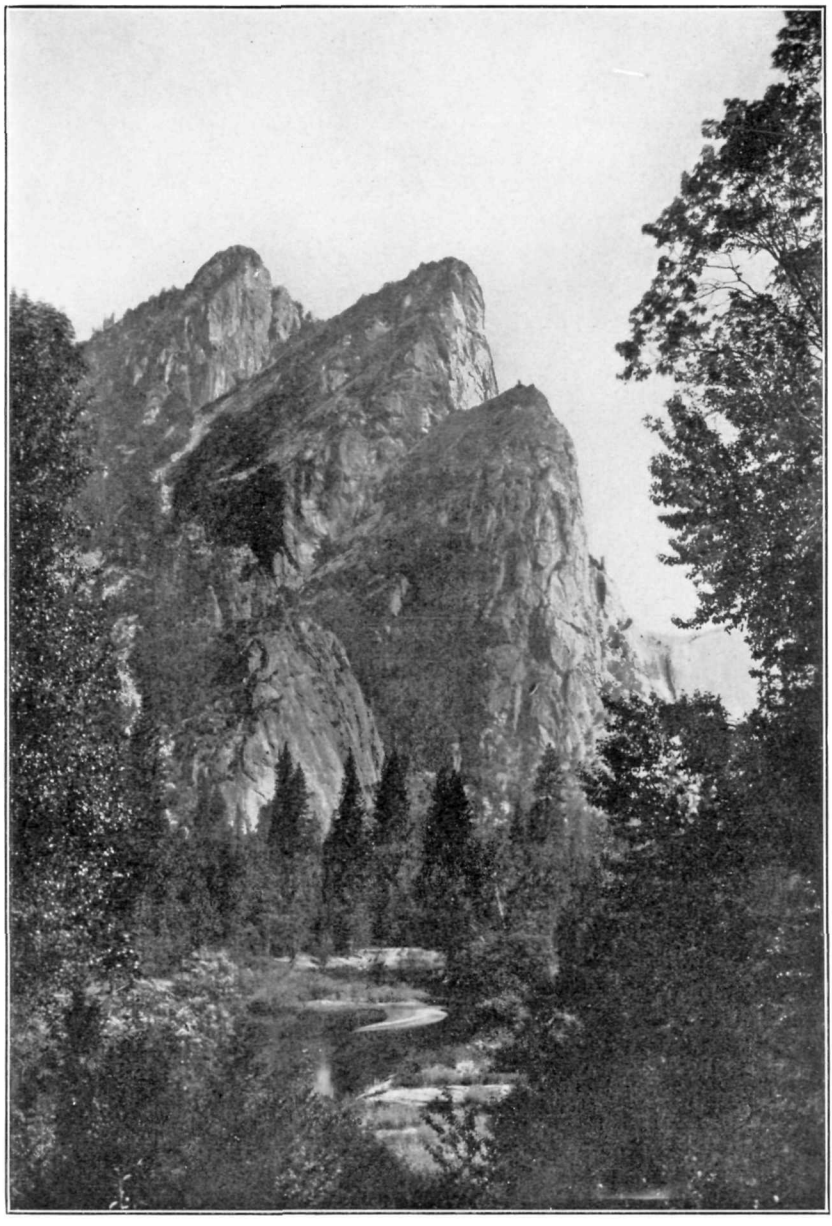

FIGURE 19.—The Three Brothers, sculptured along slanting joint planes. The highest point, known as Eagle Peak, is 3,183 feet above the valley.

Vertical joint planes have evidently determined the face of Sentinel Rock, and of the great blank walls under the Yosemite Fall and Glacier Point. Indeed, as the tourist studies the great cliff walls

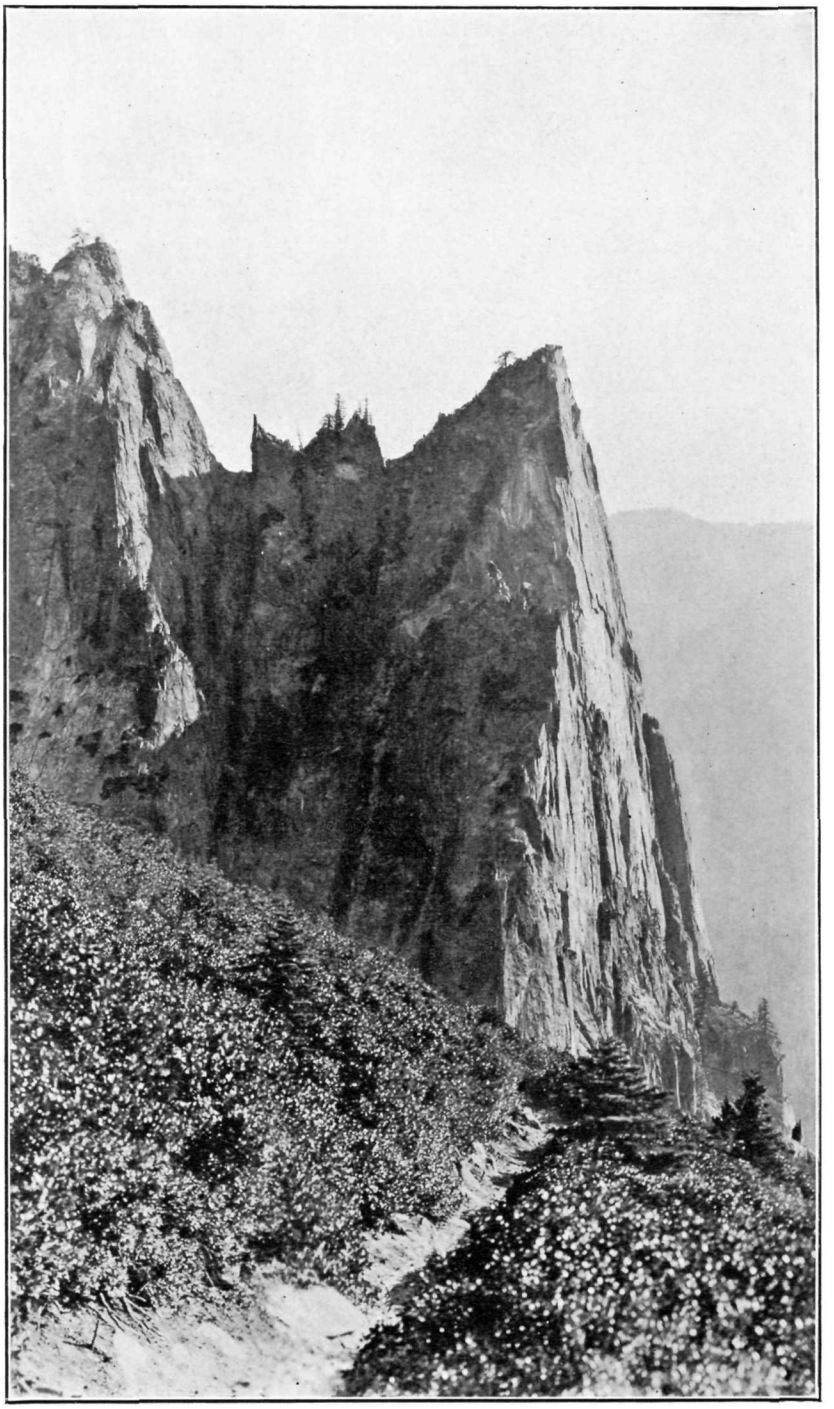

FIGURE 20.—Sentinel Rock, 3,000 feet high. Its face has been determined by a joint plane.

of the Yosemite Valley, he soon finds that each one coincides with a flat joint plane. It is worth while, in this connection, to take up the large-scale map of the Yosemite Valley,[1] and to note thereon how these cliffs accord in their respective trends. Many of them run in northeast-southwest directions; others at right angles to these—northwest-southeast. Evidently these are the directions of the two preponderant joint systems of the region, but there are also others, some running north-south, others east-west. The Glacier Point and Yosemite Falls cliffs belong to the east-west system.

The peculiar orientation of the cliffs of the Nevada and Vernal Falls was determined by the trend of certain joint planes. These cliffs are two of the great glacial steps cut out in the valley floor by the ice. Neither of them, however, extends squarely across the valley; both run obliquely to its axis. A glance at the map mentioned suffices to show that the upper one is controlled by a joint of the northeast-southwest system, the lower one by a northwest-southeast joint. However potent the glacier descending from the Little Yosemite may have been, clearly it was unable to carry on its excavating without regard to the structures of the locality, but was compelled to quarry in directions strictly according with their trends.

DOMES.

Not all the Yosemite cliffs, however, are of this rectilinear, clean-cut sort; a surprisingly large number are laid out on rounding curves. The dome-shaped eminences bordering the valley evidently belong to the same category of rock forms. Placed apparently at random in the landscape, these huge, bulging masses of bare granite give it in no small degree its unusual character. What is the explanation of their origin?

They represent the great, massive lumps in the Sierra granite that refused to fracture under the earth stresses which elsewhere produced the various systems of joints. Essentially solid and undivided, they are monoliths in the true sense of the word. Yet it is noteworthy that they tend to flake off, so to speak, and are invariably covered with thin, concentric shells, fitting one over the other like the layers of an onion. The real origin of this peculiar structure is not yet fully understood, but this much can be said with certainty, that it develops only at the surface and must be due to expansive stresses in the rock which have come into play since the domes were uncovered by denudation and became exposed to the weather.

The remarkable roundness of the Sierra domes has by some been attributed to ice erosion, but this view is clearly based on a misconception. However much of the peculiar rock topography of the

[1] May be had for 10 cents on application to the Director of the U. S. Geological Survey.

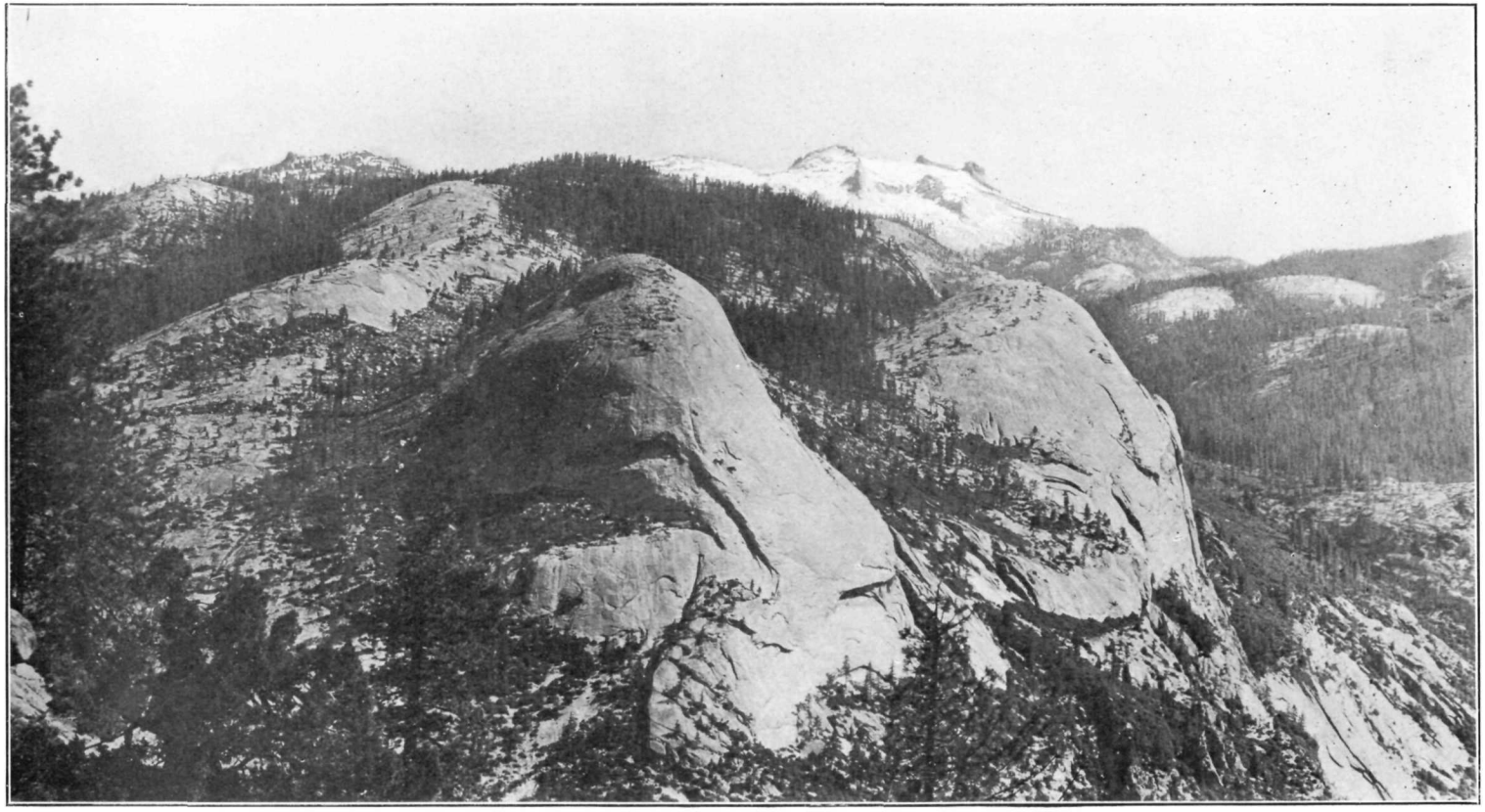

FIGURE 21.—A typical dome landscape. North Dome and Basket Dome in middle distance.

Sierra landscape the ice may have sculptured, it did not carve the domes. Indeed, the domes should rather be looked upon as masses which by virtue of their extreme solidity have escaped remodeling by the ice. It is true that many of them have been overridden by the glaciers, but, aside from tearing off the loosened shells, the ice can not be said to have either produced or accentuated their rotundity. Stone Mountain, in the State of Georgia, affords as fine an example of a smoothly rounded granite dome as any to be found in the High Sierra, yet it has not been touched by the ice of the glacial epochs, for it stands hundreds of miles south of the southernmost limit reached by the ice.

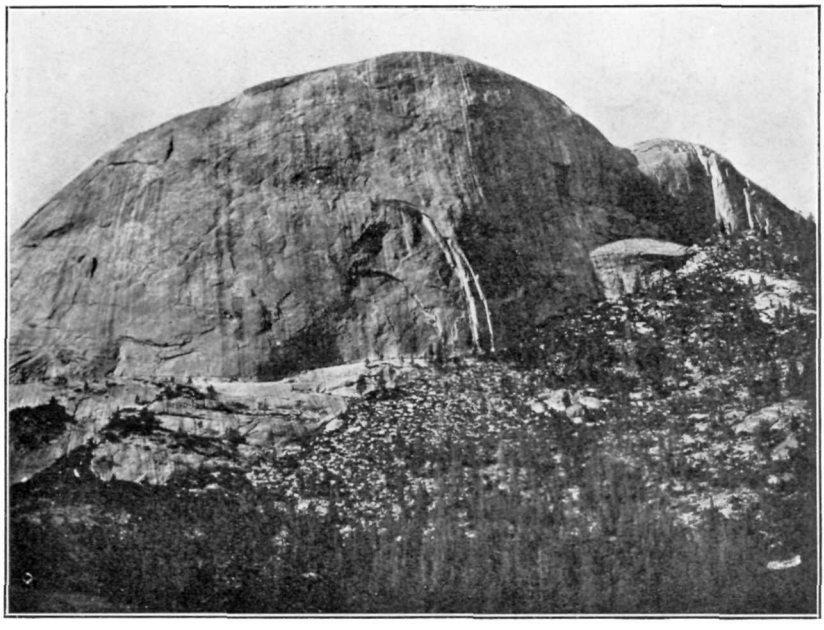

FIGURE 22.—Back view of Half Dome. (Note the deep water-worn grooves.)

The fact is that the domes have acquired their roundness largely by casting off successive shells. In the course of this process they have become progressively simpler and smoother in outline and more compact in form. It is highly probable that most of them did not possess smooth exteriors at the start, but that they were prevailingly irregular and angular in outline. As exfoliation went on, however, these initial irregularities were gradually subdued until at last they were entirely eliminated.

A few domes, nevertheless, even in their present outlines, still carry a suggestion of the strongly marked features which they formerly possessed. The most notable and interesting of these is Half Dome.

Cut down a sheer 2,000 feet on its northwest side, it at first impresses one as the remnant of a huge rock sphere, one-half of which

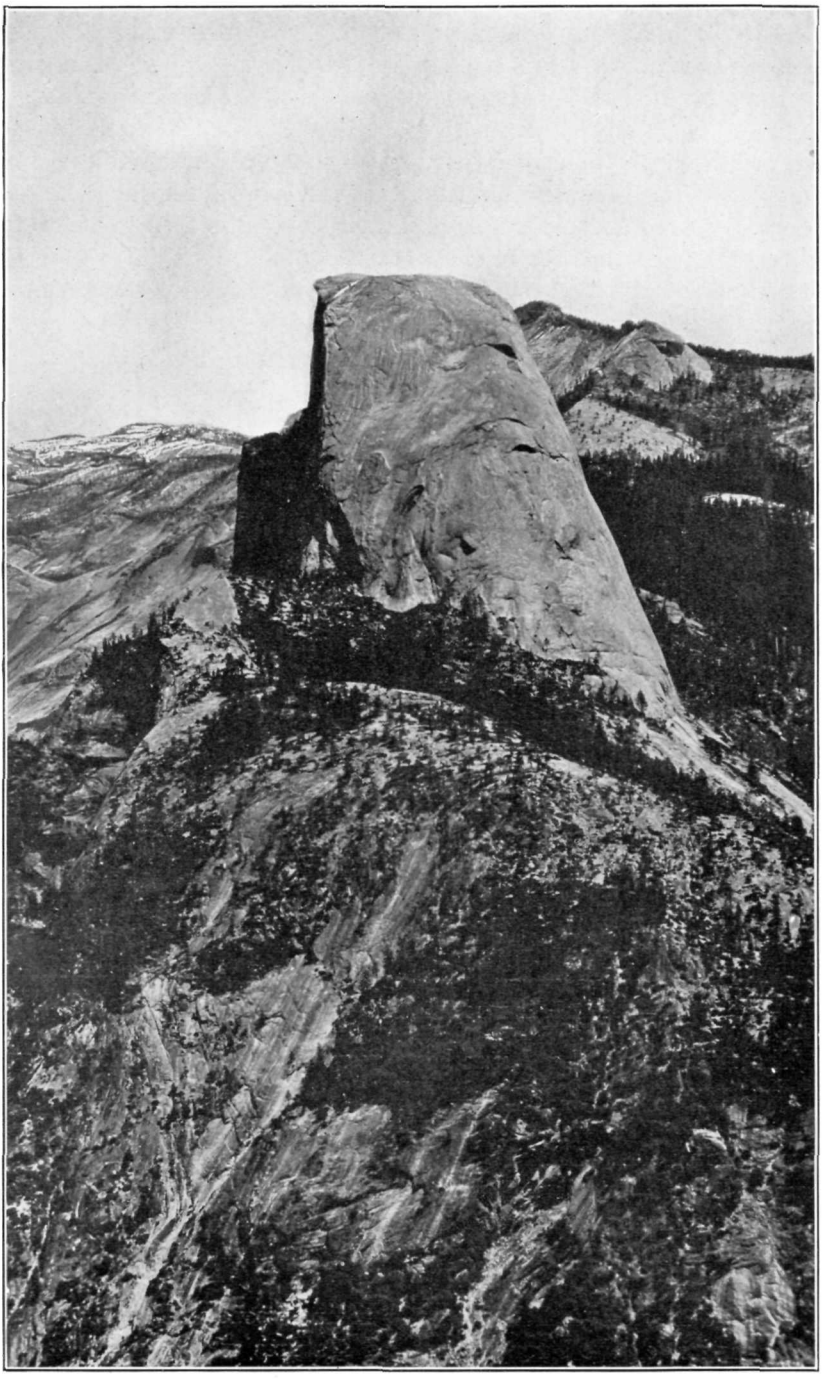

FIGURE 23.—Telephoto view of Half Dome taken in line with its sheer northwest face.

has suddenly been engulfed. Examination of its cross profile and rear side from well-chosen points of view, however, soon reveals it to be a narrow, elongated rock mass, the steep front and rear sides of which are essentially parallel. (See figs. 22 and 23.) A look at the large-scale map of the Yosemite Valley further discloses the fact that the trend of these two faces accords with the northeast-southwest system of joints. There is every reason to believe, therefore, that originally the block was bounded on both sides by strongly jointed structures belonging to that system.

The front and back of Half Dome, however, are by no means alike in aspect. The back seems normal in appearance in spite of its faint curvature, but the precipitous front, trenching abruptly across the otherwise flowing outlines, seems aberrant and demands special explanation.

In general, the back may be said to be the old side of the dome. It has evolved through normal shelling at an exceedingly slow rate. The length of time a single shell may remain clinging to its surface is strikingly attested by the deeply fluted aspect of the enormous shell that now envelopes the entire back of the dome. The loosened rock particles that for ages have been washed from the crown of the dome have worn deep furrows, which are visible at a distance of several miles.

The front of the dome, on the other hand, appears by contrast smooth and fresh. It has been formed rather recently through the rapid scaling off of successive thin plates or sheets cleft by close-set parallel partings of an accentuated fissure zone. A body of these plates still clings to the dome front at its northeast end, and it is there that one may observe the character of the fissure zone noted. Ice that formerly lodged at the foot of the great precipice no doubt has served to accelerate its recession. As for the remarkable overhang at the top of Half Dome, this is explained by new exfoliation, beginning on the exposed front of the monolith, by which the older shells on the summit are being undercut.

Thus every detail in the configuration of Half Dome is seen to be expressive of some structural attribute. The very hugeness and uniqueness of the rock monument are themselves the direct outcome of the exceptional character of the rock masses involved. And this characterization also holds for the Yosemite and Hetch Hetchy Valleys in their entirety; they are what they are inherently by virtue of the structural peculiarities of their rocks. In these materials streams and glaciers have modeled boldly and on unusual lines, while rain and wind and frost and sunshine, as well as the less obtrusive chemical processes of disintegration, have added the finer touches, bringing out the subtler structural phases of the country rock in the detail sculpture of the walls.

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