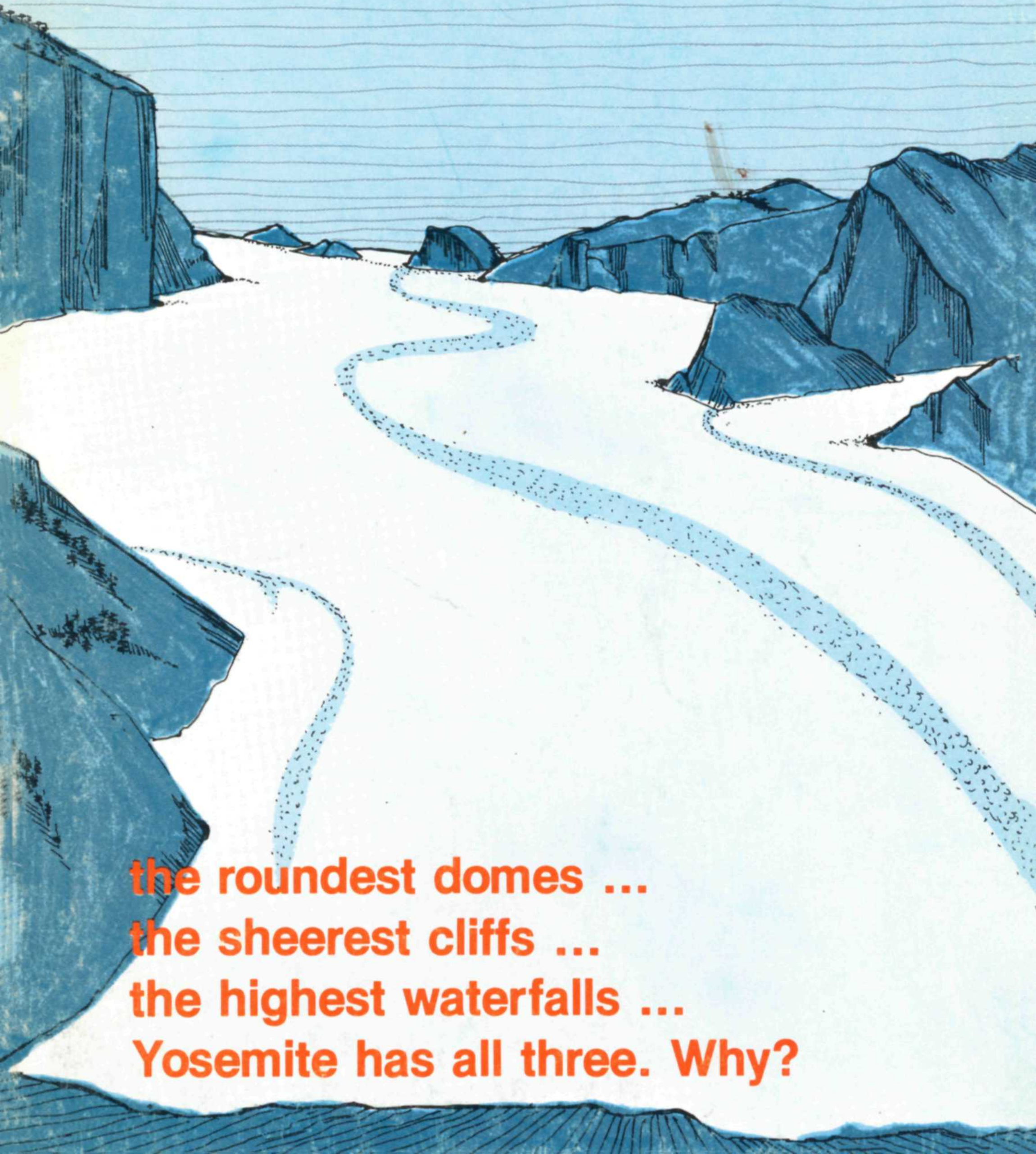
DOMES - CLIFFS - WATERFALLS

a brief geology of Yosemite Valley



the roundest domes ...
the sheerest cliffs ...
the highest waterfalls ...
Yosemite has all three. Why?

DOMES ... CLIFFS ... AND WATERFALLS ...

a brief geology of Yosemite Valley

by William R. Jones

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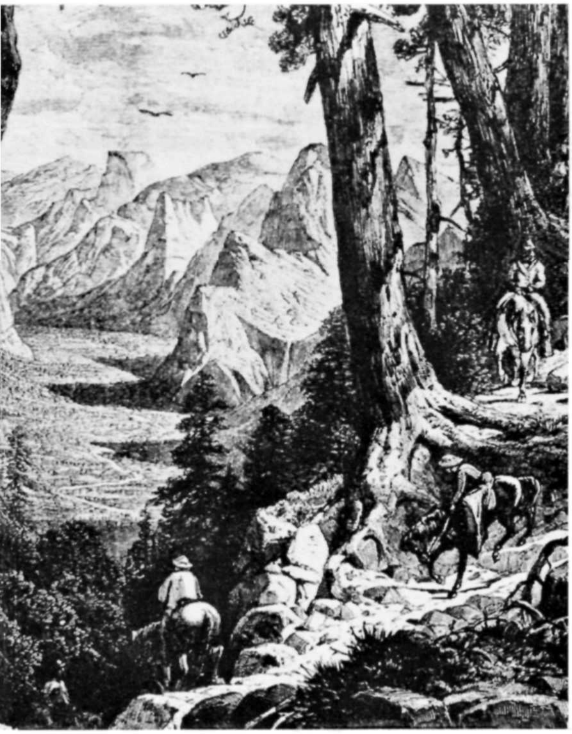

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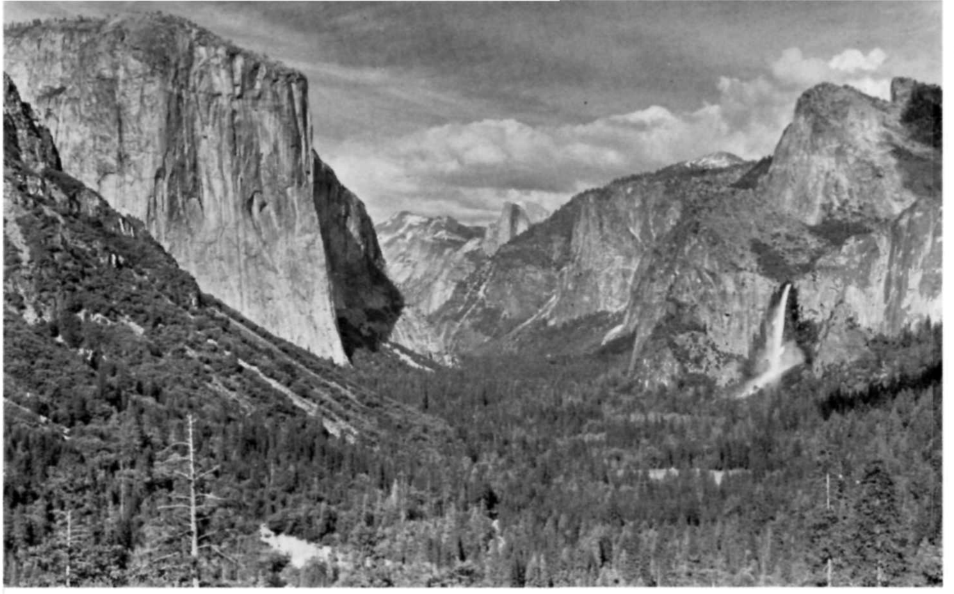
INTRODUCTION

What a puzzle Yosemite Valley was to those who first saw it - early Miwok Indians imagined rocks that grew and people turned to stone. The first white men reported a cliff that looked sliced, like a loaf of bread.

Josiah Whitney explained the scene in 1865 with his "bottom-dropping-out" theory: *Half Dome* had been "split asunder, the lost half having gone down in the wreck of matter and the crush of worlds." Next came John Muir. To him the bottom had never fallen out of anything that God had made, and he set about to answer "How did the Lord make it? What tools did He use? How did He apply them and when?" Soon Muir had his answer, advising others on how to find it: "Patient observation and constant brooding above the rocks, lying upon them for years as the ice did, is the way to arrive at the truths which are graven so lavishly upon them." Professor Whitney thought the glacier theory "absurd", and called Muir a "mere sheepherder" (which he was) and an "ignoramus".

And so it went until 1913 when twelve theories existed explaining the valley's origin. Then Francois Matthes began work, mapping and studying, and in 1930 came out in favor of Muir. Since then, debate and observation have gone on.

This brief geology, then, is the up-to-date refinement of over a century of study to understand this world's unique valley.



EL CAPITAN . . . bold granite

El Capitan means "The Chief", and it is — the tallest unbroken cliff in the world. Fully 3,000 feet high, it is made of tough granite rock.

There are seven kinds of granites in Yosemite Valley, each named for the most dramatic cliff or rock formation it composes. The El Capitan granite is the strongest and because of this, it almost closes in the lower part of the valley at the outlet and constricts it again where its El Capitan and Cathedral Rock masses project from opposite walls. But El Capitan is not purely El Capitan granite. Its summit is capped by Taft granite, and about halfway up the cliff face a "map of North America" is shaped by darker diorites.

Mineral grains of Yosemite's granites are so well formed and of such a size that they must have crystallized without interference and over a long period, as from a hot fluid deep within the insulating earth. El Capitan granite was the first to form, about 140 million years ago. While cooling, this rock shrank in size, and so cracked. Some of these cracks penetrated to the still-liquid interior, and fluids rose through them into outer areas, "healing" the cracks there and making the granite tougher still.

Silica also tends to make granitic rocks strong, and El Capitan granite has a high proportion. Other rocks having less silica or more cracks, such as the Diorites of the Rockslides just downvalley from El Capitan, now lie broken in immense piles where they fell from the hackled parent cliffs above, and the valley walls there are in retreat.

Since the granites formed, streams and glaciers wore into them to carve out Yosemite Valley, trimming away the weakest rocks the most. But "Rock Chief", the boldest granite of all, they left.

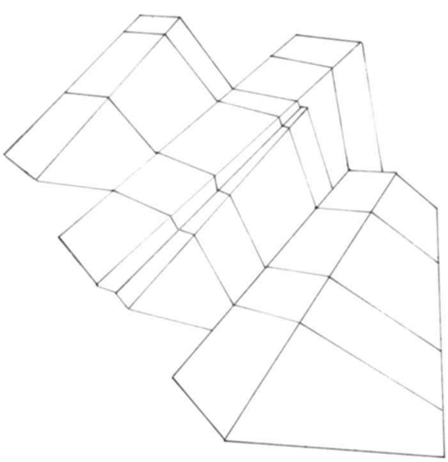
THREE BROTHERS . . . formation in triplicate

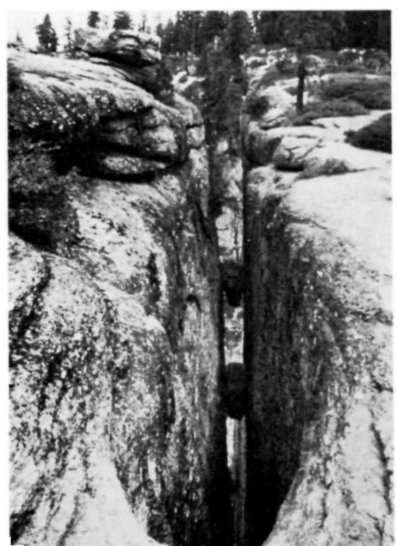
Compared to rocks at other places, Yosemite's have few cracks and often these few are spaced widely and extend great distances, cleaving the granites boldly. Frequently the cracks are parallel, and sometimes sets of them intersect. This is most common in the midsection of Yosemite Valley, with the finest expression of this characteristic in the Three Brothers. In them, three successive "roofs" rise one above another, each pitched at the same angle and truncated by equally regular vertical cliffs. Across the valley are similar asymmetric spurs, and their roofs, slanting steps, and gables can be connected by sight with those of the Three Brothers. All these forms are guided by master fractures of three intersecting sets. Such "joints" are widespread features in Yosemite, not confined to individual scenic formations or even to rock types, but crossing them sometimes for distances of many miles, showing up strongly at places and poorly at others. This trait of continuity is a clue to their origin: To crack the granites, the joints must have formed after the granites, probably from the pressures in the rise of the Sierra Nevada itself.

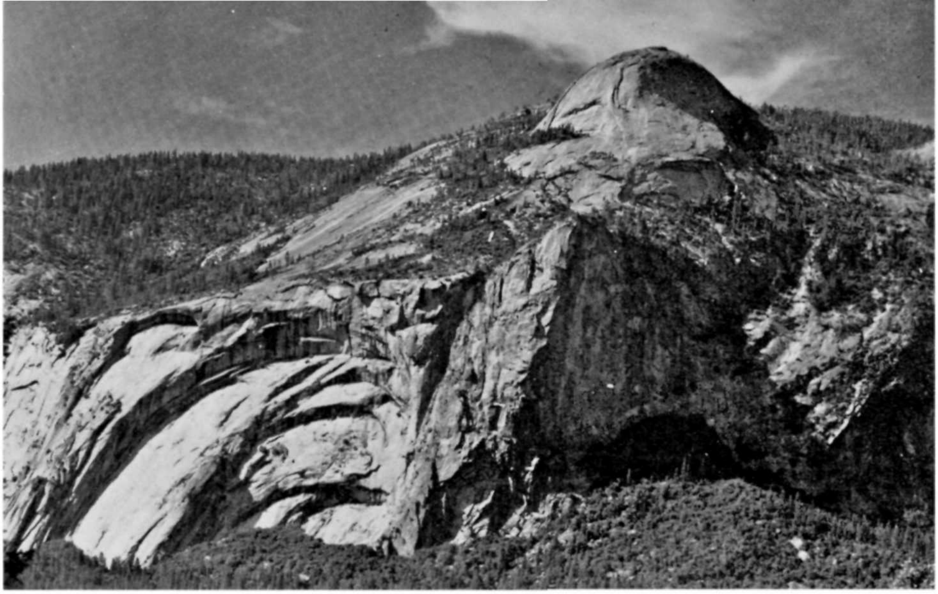
Along these fractures, streams can do little except follow. One streamlet in this midvalley area, for instance, is not cutting downward vertically, but obliquely along a slanted joint plane, sliding sidewise against one canyon wall, undercutting it into an overhang.

Water enters the joints initially in small quantities, weathering the rock's fresh crystals into loosened grains which can be washed or blown away, broadening the original tiny cracks. Such cracks at The Fissures, originally too narrow for a knife-blade to enter, are now gaping abysses too wide to stride across.

Glaciers are able to carry off bigger blocks. Those that flowed through Yosemite Valley nearly overwhelmed the Three Brothers on the north wall, pressing against its slopes. Deep within the ice quarried away large chunks along planes of weakness parallel to the great faces, exposing the strong inner cores and leaving an architectural whole — in triplicate.





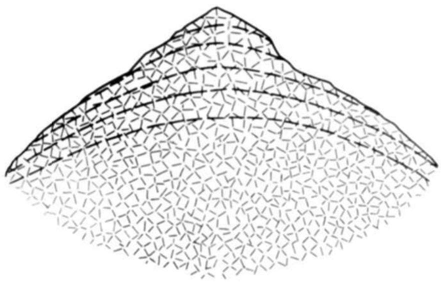


ROYAL ARCHES AND NORTH DOME . . . geologic sisters

Granite is the only rock that forms dome, and of the seven kinds of granite in Yosemite Valley, only two make domes. That named for Half Dome makes up the walls and rims at the head of Yosemite Valley, including Half Dome, North Dome, Basket Dome, Liberty Cap, Mount Broderick, Mt. Starr King, Mt. Watkins, and several lesser domes. El Capitan granite composes the walls and rims in parts of the middle and lower valley, including Sentinel Dome, El Capitan, and Turtleback Dome.

The story of the domes, thus, begins with the story of the granites. That is, deep within the earth, 85 million years ago for the domes associated with Half Dome, 140 million years ago for those with El Capitan. Estimates on how deep these molten rocks were when they crystallized into granites range down to five or ten miles below the surface.

You can imagine the pressure beneath water that is miles deep. Triple this for rock, nearly three times as heavy. Such was the pressure on the Yosemite granites when they formed. But now they are at the surface, with only the air upon them, the miles of overburden having been removed by erosion. Meanwhile, however, the internal pressure remains. Normally this pressure is released along the myriad of close cracks that develop as rocks are exposed to lower pressure and erode. But these two Yosemite granites have unusually few internal cracks, and so in these the pressure pushing outward breaks new cracks under the surface. Over time, this process pops layers loose from the host rock, eliminating surface irregularities and allowing longer, more smoothly curving cracks to be generated underneath when the internal pressure is next relieved. These in turn cause more massive layers to "exfoliate", with even bigger "leaves" falling away. And so the outer zones of the granite outcrops begin to resemble the concentric layers of an onion, like North Dome. The Royal Arches below the dome, with exfoliation slabs up to 200 feet



thick, shows the process in cross-section.

You may have seen other kinds of exfoliation. Rocks in a campfire circle or fireplace expand from the heat and may break off in big flakes. Where a rock is wetted by spray, its mica minerals expand and this pressure, too, causes the outside rock layers to separate.

These kinds of exfoliation produce only small-scale effects, easier to observe than that of load relief responsible for massive domes. But exfoliation by load relief is just as active as these — plates continue to warp outward on the bald-rock exposures about Yosemite Valley. Its domes are still forming!

HALF DOME . . . and its other half

Domes are rare in the world. To have one with a part so cleanly missing is stranger still. Half Dome, symbol of Yosemite, has no counterpart.

Half Dome was once whole. In fact, the granite rock of which it is made still occurs as bedrock over a wide surrounding region. The frontal cliff is indeed the remaining side of a great cracked block of granite! This cliff is aligned with a series of long cracks through the earth here, part of a system of internal block structure prevalent throughout the rest of Yosemite and the entire Sierra Nevada mountain range. The same system in finer fractures can be seen also in the shoulder to the left of the famous cliff, too.

On a shelf just above this shoulder, a mountaineer can find a boulder foreign to its resting place, an "erratic". It could have been deposited here so high above today's streams only by a glacier that brought it down from the High Sierra. It tells us that the ice sea, when deepest, covered all but the top 700 feet of Half Dome's 4,800 foot height above yosemite Valley. The dome's rounded summit, in fact, has been standing much as it is today for as long as 10 million years — before, during, and since the Ice Age — its strength making it nearly impervious to time's effects.

Now it should be easy to imagine the glacier flowing slowly but persistently past the great elongate dome, transfiguring the mass to its shape today — quarrying away block after block along its one weak zone of vertical cracks, but elsewhere where the rock was firm only smoothing and polishing.

Still, where did the other half (probably only a third) go? The glacier lowered some pieces to the floor of Yosemite Valley, and they are now buried there. Other parts eventually were dumped at the snout of the glacier along with rock debris from other areas, clogging the Merced River until its waters sluiced them downcanyon to the San Joaquin Valley.

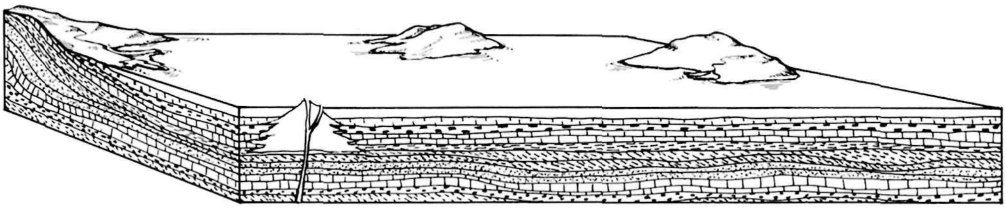
Pieces of rock just like that in Half Dome can be found there today. Someday all of it will be there, or in the ocean beyond.

500 MILLION YEARS IN YOSEMITE VALLEY

The Story Starts Here . . .

1

500 to 150 million years ago — most of the West is a shallow sea. Sediments are deposited on the seafloor.



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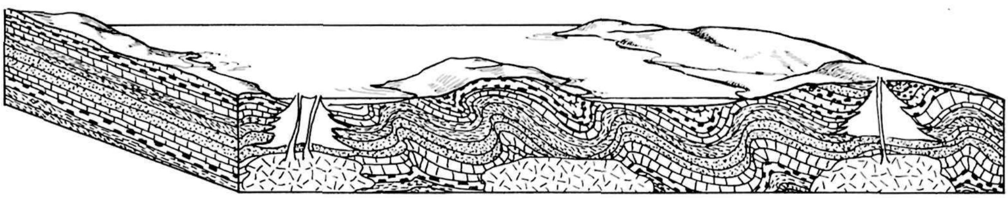
250 to 80 million years ago — molten rocks rise from below. Fluid offshoots break out the surface to form volcanoes. The covering sedimentary and volcanic rocks are crumpled into folds, and their higher strata uplifted above sea level.



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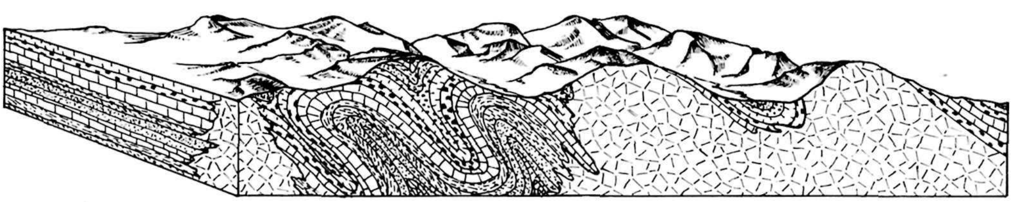
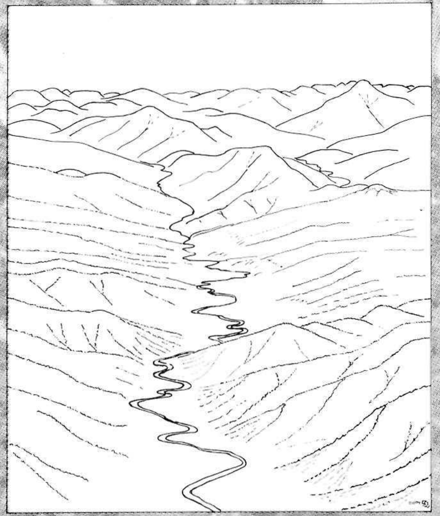
80 to 10 million years ago — erosion strips away almost all of the old sedimentary and volcanic rocks in the Yosemite region, exposing the granites.





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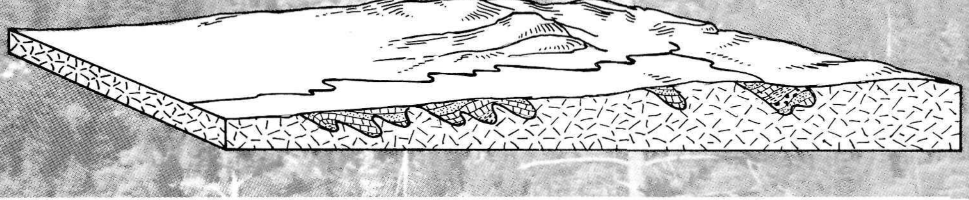
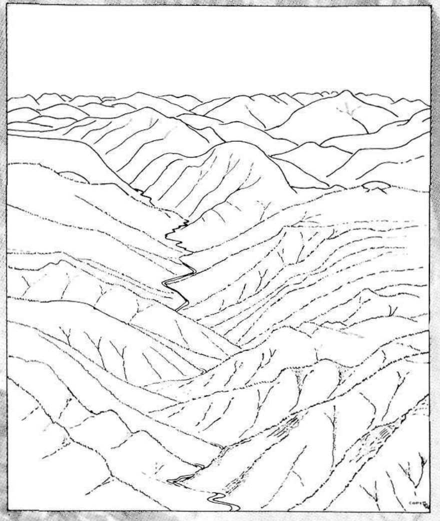
10 million years ago — a rolling surface of rounded low hills and broad valleys — including the primordial Yosemite Valley — is left. The Merced River meanders, 3,000 feet above its present position.





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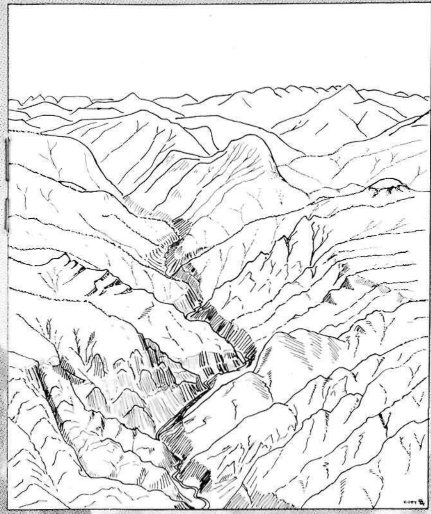
Renewed uplift of the Sierra Nevada steepens the Merced River; it cuts a mountain valley within the broad valley.



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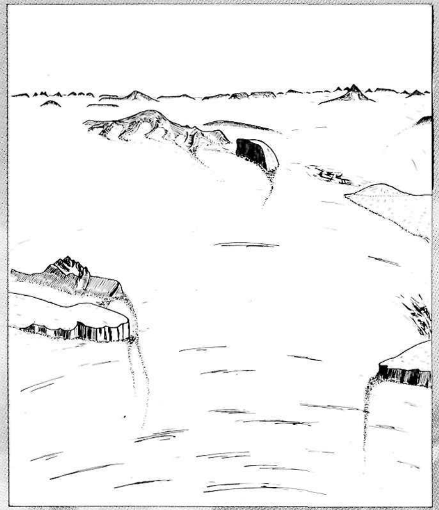
Further uplift again steepens the Merced River; it cuts a canyon within the mountain valley.



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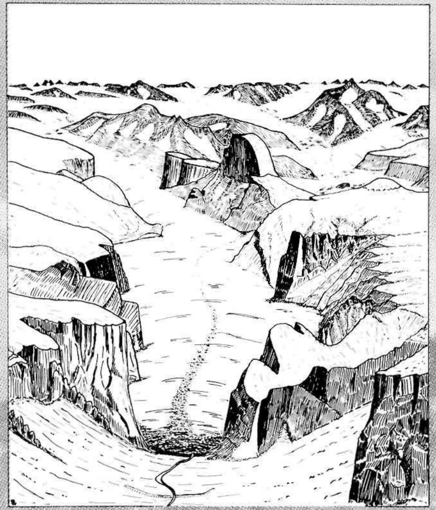

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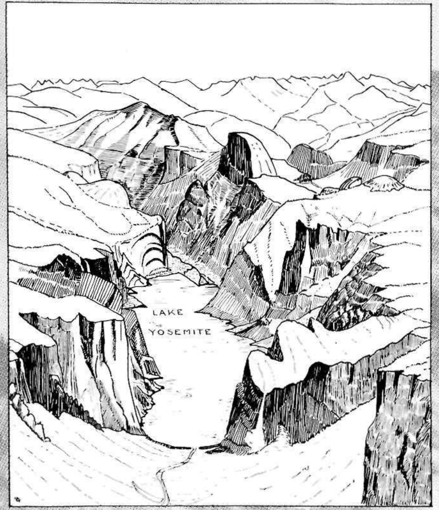

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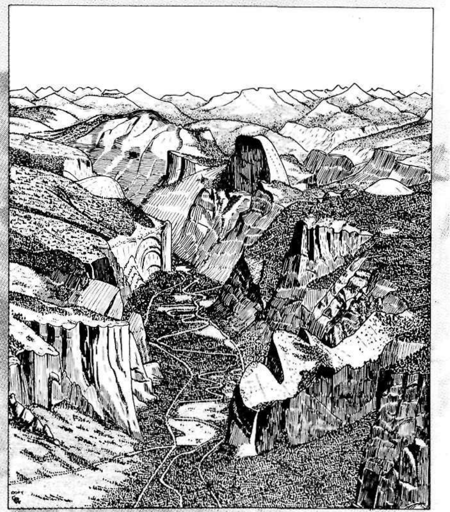


10

7

1 million years ago — the Ice Age. A glacier from the High Sierra nearly buries Yosemite Valley, widening the canyon and steepening the walls, where waterfalls will leap once the ice melts.

8

30,000 years ago — the last glacier to pass through Yosemite Valley reaches El Capitan and Bridalveil Fall, leaving a moraine ridge.

9

Behind the glacier's moraine ridge, Ancient Lake Yosemite forms.

10

Today — the lake is filled. Meadows and forested flats serve as a base for millions of park visitors to admire the scene.

BRIDALVEIL FALL . . . a "hanging" valley

Looking up from the floor of Yosemite Valley, Bridalveil Fall seems to drop over a wall directly from the sky. Behind the clifftop, however, is a valley leading up to a rolling plateau.

Usually sidestreams join their trunkstream at its same level. Those that do not are said to be in "hanging valleys", a phrase particularly descriptive of the source of Bridalveil Fall, for it hangs 620 feet above the Merced River below. (Yosemite Falls' valley hangs 2,425 feet!)

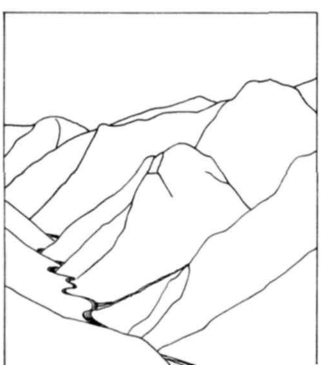
How did this come to be?

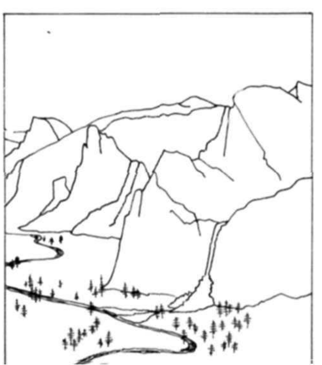
The Sierra Nevada mountain range has not always been. Before it, there was only a sea. But some 150 million years ago, the sediments on the bottom of this sea began to be slowly raised up. Uplift was not continuous, coming in pulses. During an especially long pause in the rise of this great block of the earth's crust, a period lasting until about ten million years ago, the streams evened off the block's surface. (This is the surface now above Yosemite Valley; it has been modified only slightly since.) When lifting resumed, the east edge of the block rose faster than the west, tilting the surface. This steepened the main stream flowing down the slope through the broad and low primordial Yosemite Valley, and so this ancestral Merced River ran faster, cutting into its bed. Meanwhile its Bridalveil Creek sidestream, flowing more nearly across the tilting slope, was steepened only little and could not erode much more than before. So the Merced River left Bridalveil Creek behind, stranding it high above (except for its mouth, where the main river was cutting downward, and a short section upstream).

At this time the Ice Age began. For tens of thousands of years, glaciers followed down the pre-existing stream valleys, filling them to their brinks. They eroded downward and also trimmed back the walls, widening the valley. When the ice melted, Bridalveil Creek was uncovered without its former cascading mouth and instead with a waterfall drop to the Merced River.

Since then, in a time span of perhaps 30,000 years, spray has billowed against the Fall's cliff, wetting it especially at the base. The moisture has penetrated the granite's mica grains, expanding them until whole layers of rock have broken loose to fall away, leaving a recess at the bottom, so that today the waterfall is steeper than when the melting glacier first revealed it.

This history is true not only for Bridalveil Fall, but also Yosemite Falls, Sentinel Falls, and Ribbon Fall — all on similar sidestreams off the Merced River. But Nevada and Vernal Falls, on the main trunkstream flowing down the range take another story.





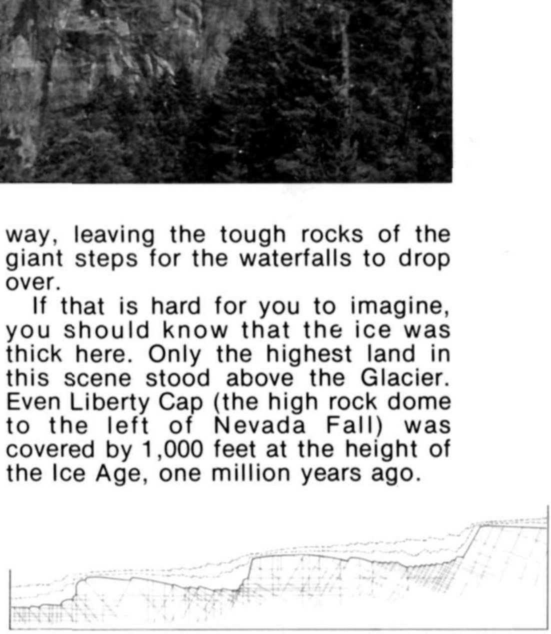
VERNAL AND NEVADA FALLS . . . giant stairway

Linking the head of Yosemite Valley with Little Yosemite Valley above are the two imposing steps of the Giant Stairway. Directly in the path of the Merced River, they force that stream to tumble in fine waterfalls. Vernal Fall (the closer one) is 317 feet high, Nevada Fall is 594 feet.

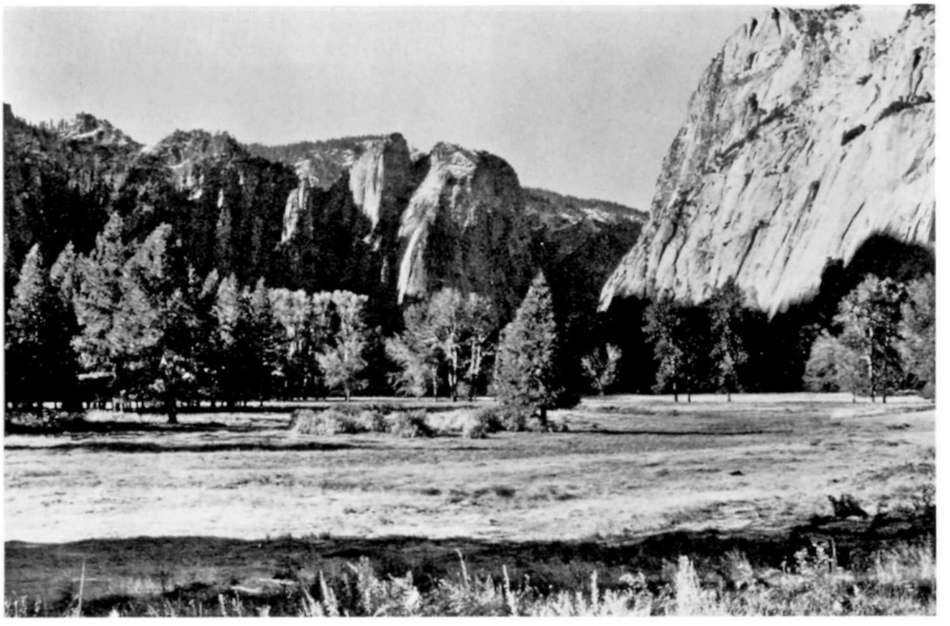
Notice the cliffs over which the falls drop. They are at a right angle to each other, and each cliff is parallel to one of the two master fracture patterns that occur throughout the Sierra Nevada. The Nevada Fall cliff (the upper one) is also parallel to the cliff face of Half Dome.

Notice, too, that the steps are much broader than the stream. They are canyon steps, not channel steps. Here, ice was responsible. The glaciers that coursed down this gorge from the High Sierra rasped away at the granite, trimming away the downstream sides of the fracture planes, leaving a lowered tread below each. These eroded zones may have been where the bedrock was more finely cracked. They also could have been the sites, during prior stream-erosion phases, of soil-filled depressions then being deepened by chemical weathering (whereas the sites of the cliffs-to-be would have been exposed to rain-wash and so kept clean and unweathered). Either or both processes explain how the glaciers excavated just portions of the stairway, leaving the tough rocks of the giant steps for the waterfalls to drop over.

If that is hard for you to imagine, you should know that the ice was thick here. Only the highest land in this scene stood above the Glacier. Even Liberty Cap (the high rock dome to the left of Nevada Fall) was covered by 1,000 feet at the height of the Ice Age, one million years ago.



Glaciers tend to accentuate irregularities in their channels. They erode with greatest vigor just where their ice is thickest, as where depressions occur in their beds, descending into these with a plunging motion and pressing heavily on the weaker rock there that initially caused the depression. But where projections caused by strong rocks occur, glaciers flow horizontally or even upslope, thus eroding the strongest rocks the least. Where the rocks are truly obdurate, then, these peculiar erosional process makes them stand out even more, as they do in the extreme in the Nevada and Vernal Falls cliffs, intact relics from the Ice Age.



THE VALLEY FLOOR . . . ancient lake bed

Here is perhaps the strangest feature of all for a rugged valley in a bold mountain range — a flat floor. Seven miles long and about half a mile wide, this floor has level forested flats, lush meadows, sand beaches, and a meandering river with deep quite pools. When glaciers flowed through Yosemite Valley during the Ice Age, they found the rock in the central part slightly weaker than at the head of the valley or at the outlet. The fact that two trunk glaciers converged here in their flow down the range must have contributed as well to the valley's erosion. And so the ice gouged downward, excavating a basin as deep as 2,000 feet below the present floor, but rising at the lower end of the valley to carry the debris up over the bedrock lip there and then on down the canyon. Probably most of the depth was dug nearly one million years ago by the first glacier, also the largest. After it melted, the first Lake Yosemite formed in its bed, finally filling with sediment and rock. Later glaciers dug into this loose material in their turn. The last glacier happened to stop in the lower valley near Bridalveil Fall. There, because it had been carrying rock along its surface, and because of bulldozing action by its thin snout when that pushed ahead as stiff ice, it built a series of rubble ridges. Behind these the ice melted again, forming the last of the lakes in the valley. This one was nearly five miles long, its waters at first milky white with finely ground rock ("glacial flour"), then pale green, and finally

blue, reflecting the magnificent formations about, doubling their beauty.

But this lake did not last, either. In the 30,000 years since its birth, Ancient Lake Yosemite filled in. The Merced River brought pebbles and sand down the canyon to the lead of the lake, dropped them in the still water, and slowly built a delta down the valley. Sidestreams built their deltas outward. Some rocks fell in from the cliffs. Finally, the lake was filled; forests and meadows now take the water's place.

Thus, the same glacial force that set the stage with cliffs, domes, and falls, built the platform from which to view its creations.

MIRROR LAKE . . . change

Ancient Lake Yosemite finally filled in with sediment, forming rootholds for sedges and willows, then meadow grasses and forest trees. We could only imagine this, except for clues at Mirror Lake, just above the head of Yosemite Valley in the Tenaya Canyon side-drainage. There this same process can be observed, for up this canyon is a mile-long flat, reminiscent of the flat Yosemite Valley floor, through which Tenaya Creek meanders on its way to the lake.

This cannot be a remnant of Ancient Lake Yosemite, for it is at a higher altitude than the Valley floor. Neither can it be a glacial lake, for none of the rocks in the ridge across its outlet are like those up the canyon where the glacier came from. Instead, they are the same as the bedrock in the slopes of Half Dome and North Dome above the lake. It was from these cliffs, therefore, that the rocks came, falling perhaps during an earthquake or a sharp frost when ice expanding in a crack pressed them loose, to tumble into the canyon and block the little stream, backing it into the lake that now so magnificently reflects the sources of its creation. Thus, although the chasm in which it is located once bore the mighty Tenaya Canyon glacier, this little lake formed since the Ice Age.

Early visitors recall Mirror Lake being much larger, and it was. It probably would be gone now except that the natural dam across its outlet was built up in the middle 1800s to raise the water level. But some day geological processes will prevail here, and we will then call this "Ancient Lake Mirror."

HIGH SIERRA . . . source of glaciers

In winter, many feet of snow fall in Yosemite Valley. But at 4,000 feet above sea level, the valley is too warm in summer for the snow to remain.

Yet we know that ice streams once nearly buried Half Dome, that the Glacier was over a mile thick where it passed through Yosemite Valley, and that it went down the canyon below to an altitude of less than 2,000 feet! But even during the Ice Age, glaciers could not form in this region much below 8,000 feet. So, where did the ice come from?

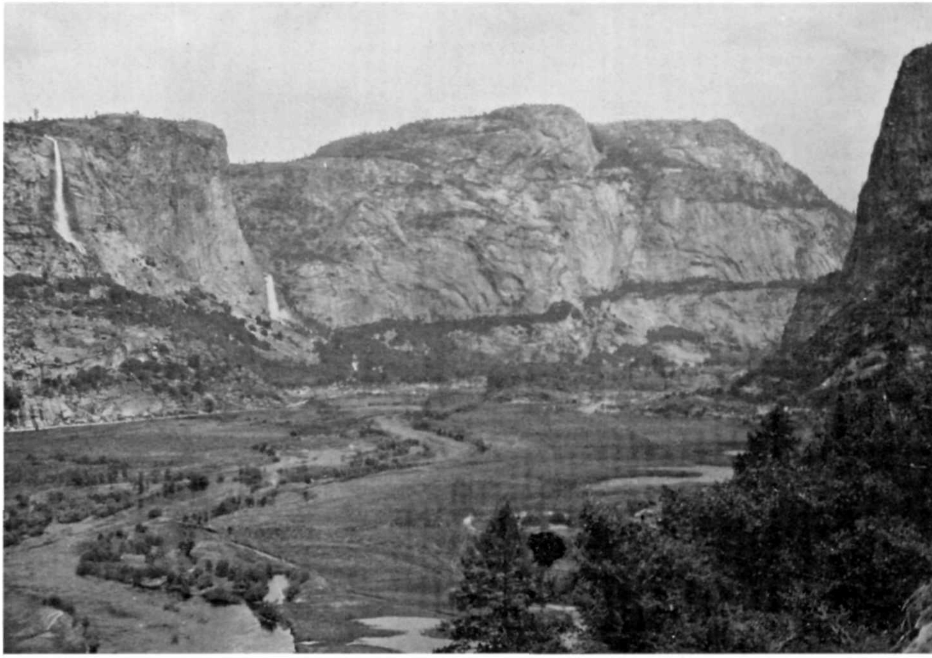
In much of the United States, the ice that plowed and furrowed the landscape as far south as Kansas came down from North America's continental ice cap. In the West, however, that cap did not extend south of Washington. Here in the Sierra Nevada, it happened that the range had risen to its full height just about the time the Ice Age began. The High Sierra caught the snow then as now, and, either because the climate was colder then or more snow fell, or both, the snow accumulated over the years rather than melting away. The broad Tuolumne Meadows, for instance, at 8,600 feet was in its entirety a zone of snow accumulation.

Ice, of course, is brittle in small pieces or thin slabs and will crack and break in this form. But when it reaches a depth of a hundred feet or so, the lower layers are under such pressure that they are actually pushed away, downhill normally but in other directions if that path is blocked. And so in the Sierra the ice flowed mainly down along the pre-existing stream valleys. It flowed slowly, any given point moving only a few tens of feet per day. Obviously such a slow rate would require a great volume in order to move away all the snow that accumulated annually, and so the glaciers were immensely thick.

The Ice Age was characterized by several glacial pulses. As it waned, the advances became shorter. The last major one did not reach Yosemite Valley, although it did pass through

Little Yosemite Valley above. Now we are in the midst of one more ice period, a minor one. The High Sierra peaks once again have glaciers. These were in their zenith in the later 1800's, pushing actively against their moraine ridges; but now they're only half as big as then, growing some years, shrinking others. So, is the Ice Age over? If not, what will Half Dome, Bridalveil Fall, and El Capitan look like after the next glacier goes by?

OTHER YOSEMITES . . .



The word "yosemite" is sometimes used as a generic term denoting a type of valley similar in origin and appearance to Yosemite Valley. Several of these are in the Sierra Nevada — all at about the same place on the western slope, situated along west-flowing master streams, carved from granite, and glaciated. Little Yosemite Valley, up the Merced River from its namesake, is the most obvious. Just north on the Tuolumne River is Hetch Hetchy Valley, with waterfalls, a cliff like El Capitan, and a dome. To the south are Tehipite Canyon with a tall dome, and the open Kings River Canyon. Others are in glaciated mountains the world over — Rocky Mountains, Alps, Himalayas, Andes — and in the sea level fjords of the north. Antarctica must have them, too; perhaps under its ice one is now being made that will surpass Yosemite itself.

MERCED CANYON . . .
clue to Yosemite Valley's original V-Shape

Mountain streams characteristically cut canyons that are V-shaped in cross-section, and down from Yosemite Valley below the extent of its glaciers the Merced Canyon has just that shape. Probably Yosemite Valley looked much the same until the glaciers trimmed out the bottom of its V, widening it into the U-shape typical of glacial valleys.

OLDEST ROCKS . . .

Yosemite Valley is now composed almost entirely of granites, but these were not the first rocks. Instead, the granites intrude still earlier oceanic sediments and volcanic rocks deposited here during the time span from 500 to 150 million years ago. These strata had been pressed so deeply into the hot earth that their mineral grains recrystallized. Remnants of these older "metamorphic" rocks can be seen on all the Yosemite approaches — Tioga, Big Oak Flat, Wawona, and Merced Roads. They are usually dark gray or red in color, and often still show their original sedimentary layers as bands, sometimes in contorted folds.

TIOGA PASS . . . ancestral river valley

When the Sierra Nevada rose as part of a broad upwarp of the earth's surface, so did much of western Nevada. Thus, streams from Nevada then drained westward down the slope of the Sierra into the San Joaquin Valley of California. (This is shown by the gravel channel-deposits that they left, as on lower Mount Dana near Tioga Pass.) But beginning 10 million years ago, the land east of the present range crest began to collapse, at a rate accelerating 700,000 years ago and still active. The ancestral Nevada headwaters were thus "beheaded" from their former Sierran streams, and are now diverted to flow into desert sinks. Open summit passes through the range crest (like that at Tioga Pass), however, still show where these ancient rivers once coursed through their broad valleys, flowing down the same surface that now remains as the plateau above Yosemite Valley.

SYNTHESIZING THE STORY

Yosemite Falls drops into the valley as the star performer, especially in the spring when the air at the base throbs from the compression, reverberating up and down the valley. But the stage was a long time in the setting.

In several pulses between 150 and 85 million years ago, the granite rocks in view crystallized from a molten state deep within the earth. At the time, the Sierra Nevada was just beginning its long rise from below the sea; a pause in this uplift ten million years ago allowed the streams to wear down the surface into a rolling plateau, across which Yosemite Creek still flows as it heads for the falls. Renewed uplift quickened the Merced River trunk stream flowing down the slope, and it wore deeply into its bed, carving a sloping-walled canyon 3,000 feet deep, predecessor to today's Yosemite Valley.

A million years ago the first glacier began widening this out into a U-shaped gorge, and when the last of these finally melted away, Yosemite Creek was left hanging high above the valley floor, its former cascading connection with the Merced River removed.

The Upper Fall's leap ends just where a brushy ledge intersects its course, and the Lower Fall's begins just where another, Sunnyside Bench, crosses. These are master fractures, nearly horizontal, in the otherwise sparsely-jointed granite here, and they pre-determined that there would be two Yosemite Falls and how each one would look.

Beside the Upper Fall, the great Yosemite Point cliff stands, eroding hardly at all, but slowly forming exfoliation slabs parallel to the surface due to the pressure from within. A freestanding sliver of one of these remains as the Lost Arrow.

Below, the Valley floor is flat, the Merced River meandering along to receive the waters from Yosemite Creek, just as the river and creek once joined in filling the ancient lake left there by the last glacier.

But the scene is not static. The waterfalls steepen slightly as slabs fall from their bases, rocks fall from the cliffs to build piles below, and the river moves it load of sand shed from the granites through the valley and on to the sea.

BIRD'S-EYE VIEW OF YOSEMITE VALLEY

RF	Ribbon Fall
EC	El Capitan
TB	Three Brothers
YF	Yosemite Falls
RA	Royal Arches
WC	Washington Column
M	Mirror Lake
TC	Tenaya Canyon
F	Fissures
ND	North Dome
BD	Basket Dome
MW	Mount Watkins
C	Clouds Rest
HD	Half Dome
ML	Mount Lyell
LY	Little Yosemite
LC	Liberty Cap
MB	Mount Broderick
GP	Glacier Point
SD	Sentinel Dome
SR	Sentinel Rock
CR	Cathedral Rocks
BF	Bridalveil Fall
YV	Yosemite Village
MR	Merced River
TP	Taft Point

Copied from a drawing by C. A. Weckerly