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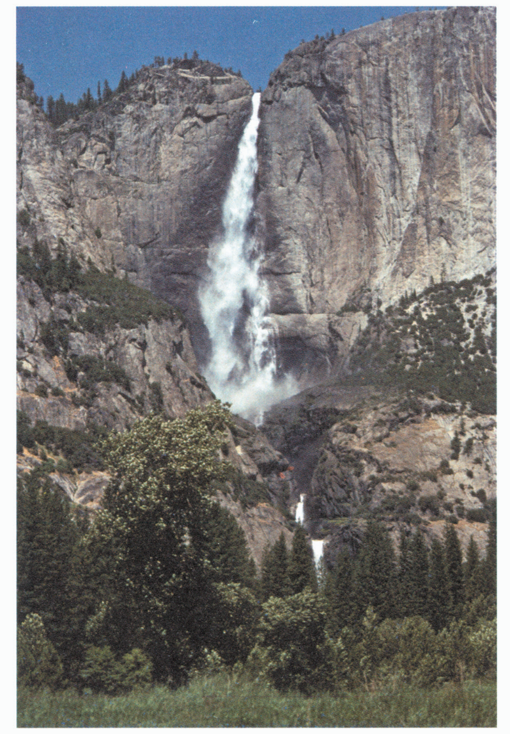

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THE GEOLOGIC STORY OF YOSEMITE VALLEY

By N. King Huber

In the Footsteps of François E. Matthes

2007

YOSEMITE COUNTRY

For its towering cliffs, spectacular waterfalls, granite domes and spires, glacially sculpted and polished rock, and beautiful alpine scenery, Yosemite National Park is world famous. Nowhere else are all these exceptional features so well displayed and so easily accessible. Artists, writers, tourists, and geologists flock to Yosemite—and marvel at its natural wonders. Yosemite Valley is deeply carved into the gently sloping western flank of the Sierra Nevada, the longest, the highest, and the grandest single mountain range in the United States outside of Alaska. And, although other valleys with similarities exist, there is only one Yosemite Valley, the "Incomparable Valley" of John Muir, California's most famous naturalist.

A SCENE OF WORLDWIDE FAME

Simply stated, Yosemite Valley, only 7 miles long and nearly 1 mile wide, is a flat-floored, widened part of the Merced River canyon. But this broad, rock-hewn trough with roughly parallel sides is boldly sculptured and ornamented with silvery cataracts. From the valley floor at an elevation of 4,000 feet, the magnificent cliffs rise 3,000 to 4,000 feet higher to forested uplands on either side (fig. 1).

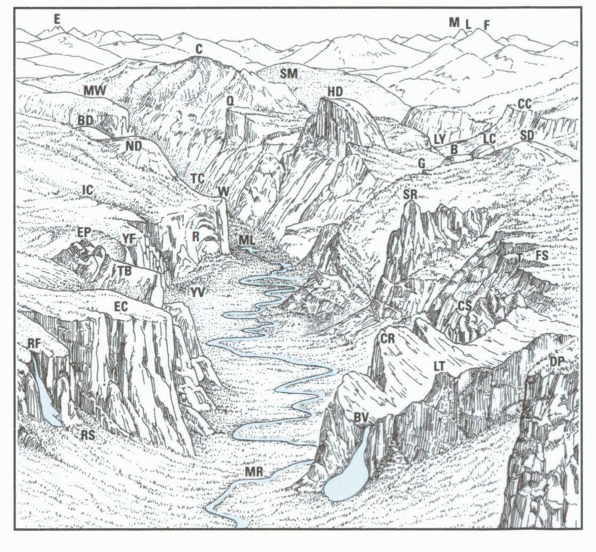

Figure 1. BIRD'S-EYE VIEW OF YOSEMITE VALLEY and the High Sierra, looking eastward up the valley.

Once you enter Yosemite Valley, its grandeur is overwhelming. Looking eastward up the valley from its lower end, you are struck by the immensity of the sheer profile of El Capitan, the most majestic cliff in the valley (fig. 2). Projecting boldly from the north wall, its top rises 3,000 feet above the valley floor. Directly opposite stand the Cathedral Rocks, over 2,500 feet high, which also jut into the valley. Between the west end of this promontory and the Leaning Tower, Bridalveil Fall leaps 620 feet, its abundant spray commonly suffused with rainbows.

Eastward beyond the narrows at El Capitan and Cathedral Rocks, the valley abruptly widens and an embayment on the south contains the Cathedral Spires, among the frailest rock shafts in the valley (fig. 3). On the north, the gabled summits of Three Brothers (fig. 4) rise one above another, all built architecturally on the same angle. The highest summit, known as Eagle Peak, rises nearly 3,800 feet above the valley floor. Across the valley stands Sentinel Rock, a finely modeled obelisk with a pointed top (fig. 5).

A mile farther up the valley on the north side, Yosemite Falls dramatically boom among clouds of mist during the spring and early summer snowmelt (fig. 6). Upper Yosemite Fall, 1,430 feet high, would alone make any valley famous; it is the highest unbroken leap of water on the continent. Lower Yosemite Fall, which descends 320 feet, seems insignificant by comparison, yet it is twice as high as Niagara Falls. The entire

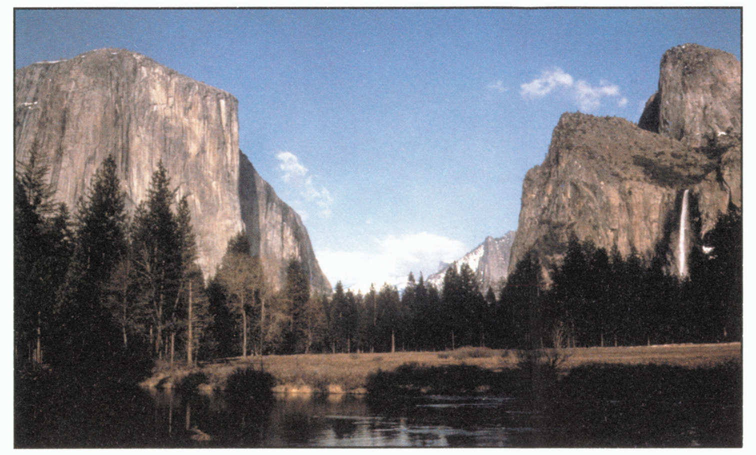

Figure 2. EL CAPITAN'S BOLD PROFILE faces Cathedral Rocks and Bridalveil Fall on the right.

chain of falls and intermediate cascades drops 2,425 feet. Ribbon Fall, west of El Capitan, descends 1,612 feet, but it is confined in a sheer-walled recess and does not make a clear leap throughout.

Farther up the valley on the north side, the Royal Arches are sculpted one within another into an inclined rock wall that rises 1,500 feet. The Washington Column, an enormous natural pillar, flanks them on the right; above them rises a smoothly curving, helmet-shaped knob of granite called North Dome. Facing the Royal Arches on the south wall, Glacier Point provides a matchless view of the valley from its summit, which stands 3,200 feet above the valley floor.

Standing at the head of the valley as if on a pedestal, Half Dome is the most colossal and recognizable rock monument in the Sierra Nevada, because it is smoothly rounded on three sides and has a sheer vertical face on the fourth (fig. 7). From its summit over 4,800 feet above the valley, you look southeast into Little Yosemite Valley, which is broad floored and has granite walls more gently sloping than in its larger namesake. From Little Yosemite's western portal, guarded by Liberty Cap, the Merced River descends a giant stairway, forming two magnificent waterfalls: Nevada Fall, dropping 594 feet, and Vernal Fall, dropping 317 feet. Looking northward from Half Dome's summit into Tenaya Canyon reveals a chasm as profound as Yosemite Valley itself, yet it is the pathway of only a small brook. To the northeast, Clouds Rest, the loftiest summit in the vicinity of Yosemite Valley, rises to 9,926 feet; beyond, spreads the vast panorama of the higher regions of the Sierra Nevada, called the High Sierra.

The present Yosemite Valley is the result of many different geologic processes operating over an incomprehensible length of time measured in millions of years. These processes are by themselves not unique, but their unrivaled interaction has created this "Incomparable Valley." The accumulated observations, studies, and interpretations by many individuals through the years allow us to reconstruct much of the valley's geologic history, which adds to our appreciation of its scenic majesty.

ROCK, THE SCULPTOR'S MEDIUM

For any form of sculpture, whether it is a finely chiseled statue or a massive landform, the resulting shape strongly depends on the nature of the material being sculpted. In Yosemite Valley the sculpting material is granite. Indeed, granite forms the bedrock of much of the Sierra Nevada, including most of Yosemite National Park. Granite in the Sierra Nevada typically is a rock with a salt-and-pepper appearance caused by random distribution of light and dark minerals. The mineral grains are generally coarse enough to be individually visible to the naked eye.

Throughout the park, granitic rock varies considerably in the relative proportions of the individual light and dark minerals, and these compositional differences are represented by a variety of specific names, such as granodiorite and tonalite, in addition to true granite as defined by geologists.

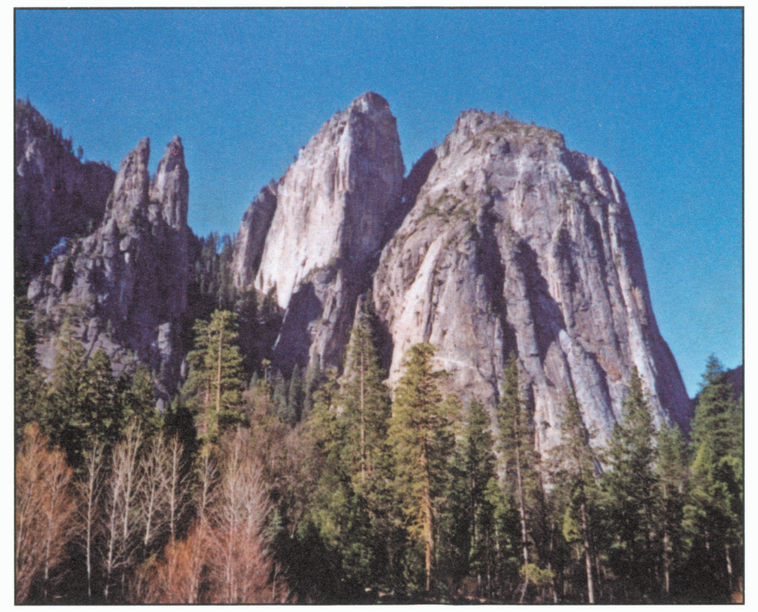

Figure 3. THE CATHEDRAL SPIRES project skyward to the left of Cathedral Rocks.

From a distance, all of Yosemite Valley's granitic rock looks the same. But it actually consists of individual rock bodies, each with its own characteristic mineral composition and texture, which describes the coarseness of their crystals and uniformity or variation in grain size. All of these variations affect the rock's resistance to abrasion, fracturing, and weathering—all important to the sculptor and the final form. The imposing cliffs of El Capitan and Cathedral Rocks, for example, are composed of a particularly tough and resistant variety of granitic rock.

THE ROLE OF JOINTS

The bedrock structures that have the greatest effects on Yosemite's landform development are *joints*. Although granitic rock is unbroken on a small scale, on a larger scale the rock is broken by joints, which are more or less planar cracks commonly found as sets of parallel fractures in the rock. Regional-scale joints commonly determine the orientation of major features of the landscape, such as the planar face of Half Dome, the series of parallel cliffs at Cathedral Rocks, and the westward-sloping faces of the Three Brothers. In contrast, smaller, outcrop-scale joints determine the ease with which rock breaks and erodes. Joints wield an overwhelming influence on landform development in granitic terrain, because they form greatly contrasting zones of weakness where water and air enter and contribute to weathering and disintegration of otherwise homogenous, erosion-resistant rock.

Figure 4. THE THREE BROTHERS, have angled summits sloping westward.

The type of jointing that most influences the form of Yosemite's landmarks, however, is the broad, onion-skin-like *sheet jointing* formed by a process referred to as *exfoliation*. Granitic rocks originate at considerable depth within the Earth while under great pressure from overlying rock that may be miles thick. As the overlying rock erodes, the decrease in the pressure that once confined the granitic rock causes it to expand toward the Earth's surface. When the outer expanding zone exceeds the strength of the rock, it cracks away from less-expanded rock beneath and bursts loose as a sheet; subsequent cracks release successive layers of expanding rock. Because the expansion that forms these sheets takes place perpendicular to the local surface, the shape of sheets generally reflects topography and curved surfaces mimic hill and valley. Sheet joints also tend to parallel the walls of canyons and cliffs that may appear to be unbroken monoliths, such as El Capitan, but that may have hidden fractures behind and parallel to the cliff face. The curved upper surfaces of North Dome and Half Dome (fig. 7) and the undulating surface of Clouds Rest are magnificent examples of sheet joints or sheeting.

Admiring Yosemite Valley's intricately sculptured walls as they appear today and knowing something about the granitic rock from which they were carved, we can look back in time to speculate on the evolution of the valley's formation—its geologic history.

A STORY THAT BEGAN MILLIONS OF YEARS AGO

The last touches to Yosemite Valley's architecture were applied relatively recently, geologically speaking. But the rock from which the valley is carved originated mainly during the Cretaceous period, about 100 million years ago, when dinosaurs roamed the Earth. At that time molten rock, *magma*, generated deep within the Earth, rose upward within the Earth's crust, or upper layer, and crystallized far beneath the surface to form granitic rock along a linear belt that was to become the future Sierra Nevada. The granitic terrain that makes up the Sierra, once thought to have only local variations in one huge mass of rock, is actually made up of a mosaic of individual rock bodies that formed from repeated intrusions of magma over many millions of years.

Some of the magma broke through to the surface, building a string of volcanoes atop hidden granitic roots, and we can, perhaps, envision an ancient majestic mountain range somewhat like the modern Cascade Range along the coast of the Pacific Northwest. Because of the high elevation of this ancestral range, however, the volcanic and other rocks covering the granite soon eroded away; by Late Cretaceous time, about 70 million years ago, the granitic rocks became exposed at the Earth's surface. By middle Cenozoic time, a few tens of millions of years ago, so much of the upper part had been removed that, in the vicinity of Yosemite, the surface of the range had a low relief of only a few thousand feet.

Later, the continental crust east of the Sierra Nevada began to stretch in an east-west direction, developing into a series of north-south-oriented valleys and mountain ranges. Through a combination of uplift of the Sierran Nevada and down-dropping of the area to the east, the Yosemite region acquired a tilted aspect with a long, gentle slope westward to the Central Valley of California and a short, steep slope separating it from the country to the east.

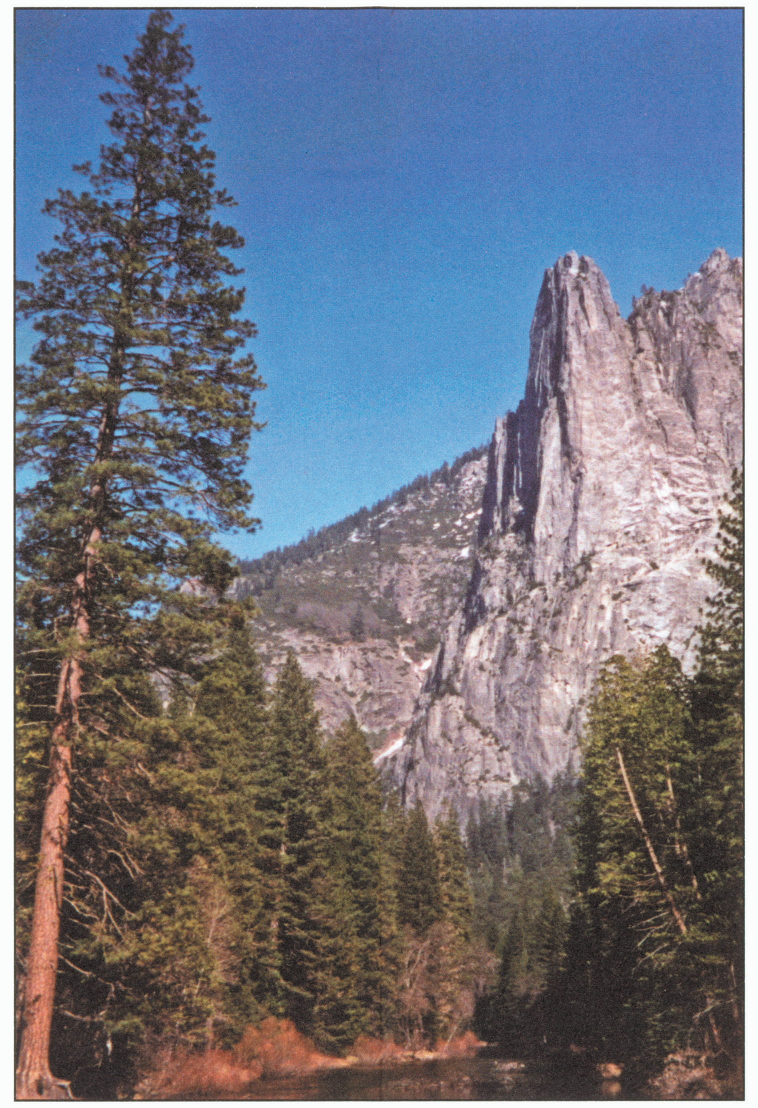

Figure 5. SENTINEL ROCK'S PINNACLE juts boldly upward.

AGENTS OF EROSION

Erosion, simply stated, is the removal of earth materials from high areas to lower areas, modifying the landscape in the process. Two agents of erosion are chiefly responsible for sculpting the present Yosemite landscape—flowing water and glacial ice: flowing water had the major role, and glacial ice added additional touches. The general Sierran landforms were all well established before glaciation, and the major stream drainages provided the avenues along which the glaciers would later follow. Some of the glacial modifications, however, were profound: the creation of alpine topography in the High Sierra, the rounding of many valleys from V-shape to U-shape, and the straightening of valleys in the process. Still another agent of erosion is simply gravity. The downslope movement of rock materials produces landslides and rockfalls. Although generally of local extent, such movement is important, particularly in mountainous terrain and on the over-steepened slopes in Yosemite Valley.

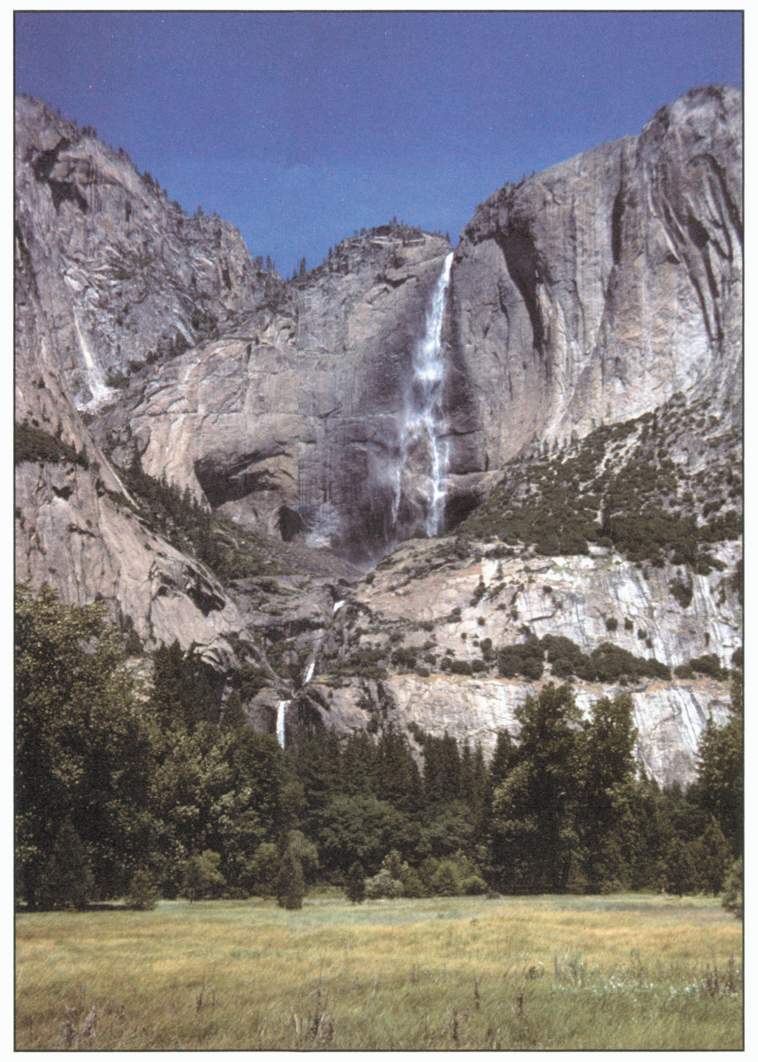

Figure 6. UPPER YOSEMITE FALL now leaps from the hanging valley of Yosemite Creek. In the not-too-distant geologic past, its water cascaded down through the prominent ravine to the left (fig. 11). The tree-covered bench at middle left marks the approximate upper limit of the Tioga-age glacier in Yosemite Valley.

The Role of Flowing Water

The effectiveness of erosion by flowing water depends both on processes of weathering—the breakdown of larger rocks into smaller individual rock and mineral fragments that can be transported—and on stream volume and velocity, which determine the size and amount of material that can be transported. Because of increasing late Cenozoic elevation of the Yosemite region, the major streams coursing down the western flank of the Sierra Nevada were rejuvenated and made more vigorous by the increased slopes. Under these conditions, the major canyon-cutting stream channels became progressively deepened relative to the upland areas between them, areas which even today retain comparatively moderate relief. The upper basins and middle reaches of the Merced and Tuolumne Rivers, for example, were later modified by glacial erosion, but the initial canyons were cut solely by the action of streams. Two sketches depict an artist's conception of the evolution of the Merced River canyon at the site of the future Yosemite Valley before the onset of glaciation (fig. 8).

The Role of Glaciers

The Yosemite landscape as we see it today strongly reflects the dynamic influence of flowing ice that long ago covered much of its higher regions. Geologists are still uncertain how many times ice mantled Yosemite, but at least three major glaciations have been well documented elsewhere in the Sierra Nevada. In the higher country, ice fields covered extensive areas, except for the higher ridges and peaks. Lower down the western slope at middle elevations, glacial tongues were confined to pre-existing river canyons, such as those of the Merced and Tuolumne Rivers. Thus, our focus will be on the nature and activities of these valley glaciers, particularly as they apply to Yosemite Valley and Hetch Hetchy Valley 15 miles to the north, while remembering that the valley glaciers derived their flowing ice from ice fields higher in the Sierra Nevada.

In contrast to the sinuous V-shaped valleys of normal streams in unglaciated mountainous terrain, glaciated valleys tend to be straighter and have U-shaped profiles. Whereas streams erode the outsides of bends preferentially, making its course more sinuous, glaciers concentrate erosion on the insides of bends, removing the protruding spurs of the original stream valley and leaving a wider, straighter valley. The resulting modification, in detail, depends on the nature and structural integrity of the bedrock over which the glacier is flowing. In granitic bedrock, jointing promotes removal of rock that is otherwise highly resistant to glacial erosion.

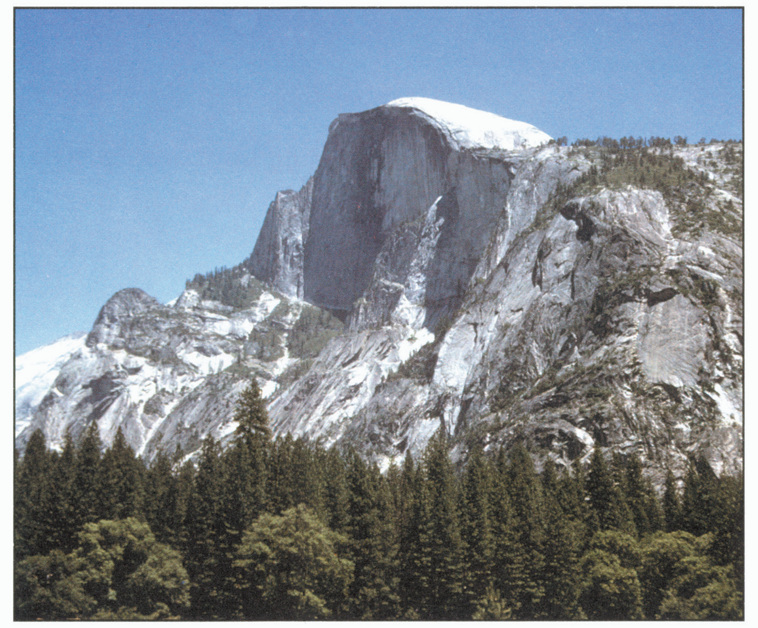

Figure 7. HALF DOME'S CLEAVED FACE dominates the east end of Yosemite Valley.

YOSEMITE VALLEY AND ITS GLACIERS

Yosemite Valley is often called a classic glacial valley. But what glacially derived features does it display to deserve this designation? A glacier tends to straighten a valley and smooth its walls as it grinds past them. But the walls of Yosemite Valley are extremely ragged and have many pinnacles and spires projecting upward from them—Leaning Tower, Cathedral Spires, Sentinel Rock, and Lost Arrow stand out strikingly. All of the waterfalls and lesser cascades along the sides of the valley are ensconced in alcoves, except for Upper Yosemite Fall, whose story will be told in upcoming paragraphs. Eagle Creek and Indian Canyon Creek actually issue from deep ravines. All of these seemingly anomalous features would doubtless be obliterated by a glacier that filled the valley to its brim. And yet glacial erratics—boulders transported and deposited by a glacier—that are found scattered above the valley's rim tell us that a glacier once filled the valley to its brim. How can we explain this anomalous appearance if the valley was shaped by a glacier? The anomaly is even more apparent if we compare Yosemite Valley with another glaciated valley that is about the same size and elevation, Hetch Hetchy Valley, which has comparatively smooth walls and an absence of pinnacles and spires (fig. 9).

Little doubt exists that Yosemite Valley represents the profound glacial modification of the Merced River canyon, because no other erosive process could have accomplished such excavation. A glacier filling the valley to its rim (fig. 10*A*) created the basic broad shape of the valley and gouged out a deep bedrock basin whose bottom locally, in its eastern part, lies close to 2,000 feet below the present valley floor. That glacial episode was named the El Portal glaciation by François Matthes in his monumental Yosemite study, because he thought that its glacier advanced down the Merced River canyon nearly to the community of El Portal, 10 miles downstream from Yosemite Valley proper. Today we correlate that glaciation with the Sherwin glaciation, defined from studies along the eastern side of the Sierra Nevada. The Sherwin was the most extensive and longest

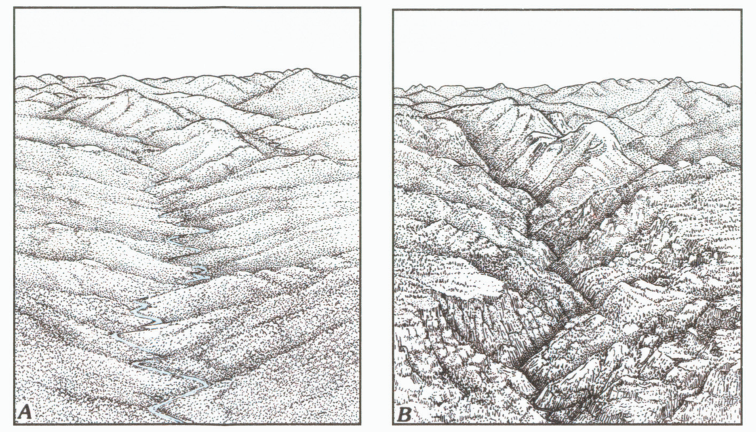

Figure 8. THE ROLE OF FLOWING WATER. A few tens of millions of years ago, the Yosemite area was a rolling surface of rounded hills and broad valleys that contained meandering streams ***(A)***. Before the onset of glaciation more than a million years ago, the elevation of the range increased and streams incised deep canyons into the western flank of the Sierra Nevada ***(B)***.

glaciation documented in the Sierra. It may have lasted almost 300,000 years and ended about 1 million years ago. A Sherwin-age glacier was almost surely responsible for the major excavation and shaping of Yosemite Valley within the Merced River canyon.

Later glaciations in the Sierra Nevada were less extensive and briefer than the Sherwin. The best documented are the Tahoe and Tioga glaciations, which probably peaked about 130,000 and 20,000 years ago, respectively; together they are equivalent to Matthes' Wisconsin glacial stage, which he did not subdivide. The last glacier in Yosemite Valley—Tioga in age—advanced only as far as Bridalveil Meadow (fig. 10*B*), where the forward movement of the glacier equaled melting at its front, or terminus. A terminal or end moraine—a low ridge crossing the valley—was constructed with rock debris transported by the glacier and deposited at its terminus as the ice melted. The extent of the earlier Tahoe-age glacier in the valley is uncertain, but evidence elsewhere in the Sierra suggests that it was probably somewhat longer than the Tioga. Nevertheless, since the original excavation of Yosemite Valley by a Sherwin-age glacier, no subsequent glacier has filled the valley to its rim, a conclusion that has important consequences for the present scenery.

Figure 9. HETCH HETCHY VALLEY before damming. Note the absence of Yosemite-like pinnacles. *Photograph from National Park Service archives.*

From its terminus at Bridalveil Meadow, the ice surface of the Tioga glacier would have sloped upward toward the east end of the valley, and the ice reached a thickness of perhaps a little over 1,000 feet at Columbia Rock west of Yosemite Falls, 1,500 feet at Washington Column, and 2,000 feet in Tenaya Canyon below Basket Dome, as reconstructed by Matthes. Thus, the Tioga and similar Tahoe glaciers could do very little to further modify or smooth the walls of Yosemite Valley. Above the ice surface of these glaciers, the valley walls have had a million years to weather: joints widened, rock fractured and crumbled, and waterfalls and cascades eroded back into alcoves and ravines. The pinnacles and spires that seem so anomalous for a glacial valley actually had a million years to form and, being above the level of later glaciers, remain to amaze us today. In Tenaya Canyon, Tioga ice was thicker and reached farther up the walls, smoothing them and removing irregularities; no pinnacles and spires are found there.

Hetch Hetchy Valley on the Tuolumne River, otherwise similar to Yosemite Valley, has comparatively smooth walls and an absence of pinnacles and spires (fig. 9). In this valley, the Tioga glacier was also less extensive than the Sherwin but, unlike the glacier in Yosemite Valley, the Tioga glacier filled Hetch Hetchy to the rim. Hetch Hetchy Valley's walls were scraped smooth and debris was removed from the valley with each glaciation, including the last. The greater extent of the glaciation in Hetch Hetchy can be attributed to the drainage basin of the Tuolumne River above Hetch Hetchy being more than three times as large as that of the Merced River above Yosemite Valley. As a result, the much larger ice field feeding the Tuolumne glacier was able to provide the necessary volume of ice to fill Hetch Hetchy, even though the Tioga glaciation was regionally less extensive than the Sherwin. The smaller Merced ice field was unable to provide sufficient ice to fill Yosemite Valley, even though supplemented by ice from a part of the Tuolumne drainage that flowed southwest over a low pass into Tenaya Canyon.

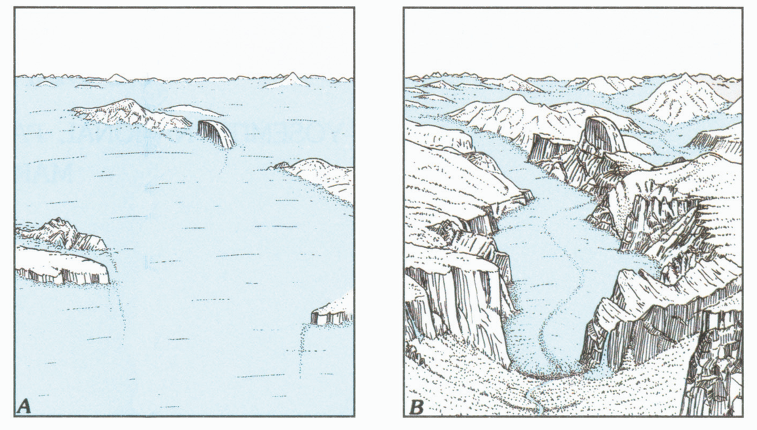

Figure 10. GLACIERS LARGE AND SMALL. Sketches of Yosemite Valley area, showing extent of valley-filling glaciers (blue): Sherwin-age glacier ***(A)*** and less extent of Tioga-age glacier ***(B)***.

LEAPING FALLS AND HANGING VALLEYS

Waterfalls leaping out from a valley's walls far above the valley floor have long been considered evidence of a glaciated valley. The enormous Sherwin-age glacier that shaped Yosemite Valley was able to excavate the central chasm to a greater depth than smaller glaciers in side-entering tributaries, which resulted in some of the side valleys being left "hanging" with waterfalls at their brinks. Since Sherwin time, most of the tributaries have eroded their channels back into the walls to leave little more than steep ravines containing minor falls interrupted by chains of cascades, such as those at Sentinel Fall. Bridalveil Fall is an exception, although it also has receded back into an alcove from its original position farther out on the valley wall (fig. 2).

In contrast to Bridalveil Fall, Upper Yosemite Fall, although now leaping from a hanging valley, had a very different origin. Yosemite Creek is the largest stream flowing into the north side of Yosemite Valley and probably entered the Merced River canyon through a steep side canyon before glaciation. After the Sherwin glacier deepened Yosemite Valley, Yosemite Creek continued to enter the main valley through this ravine, which lies just west of the present falls and contains Yosemite Falls Trail (fig. 6). Matthes recognized this and noted that just west of Yosemite Creek's present channel is "what appears to be an old stream channel leading to the notch [of the ravine]" (fig. 11). A half-mile stretch of the Yosemite Creek Trail presently follows this old channel north of the notch.

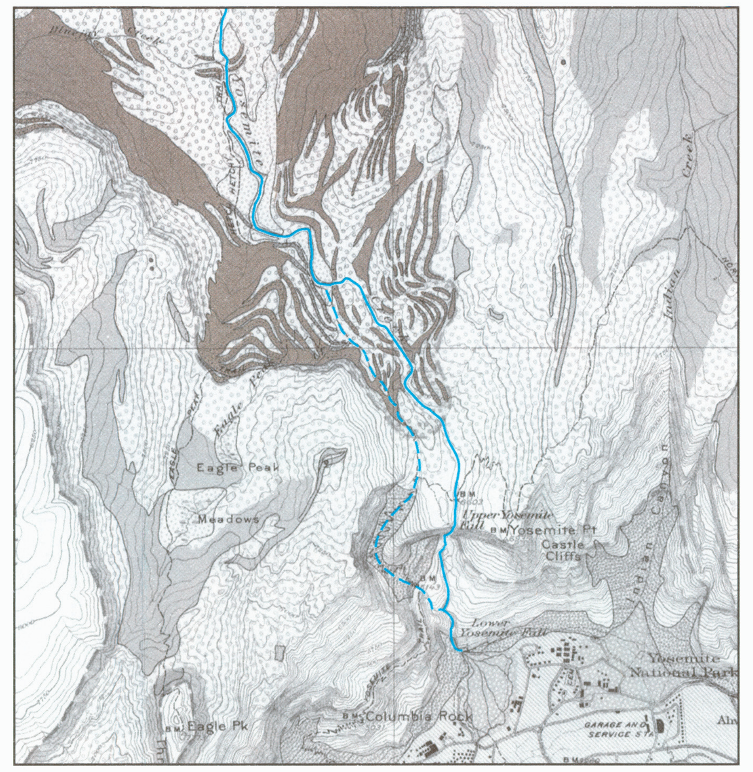

Figure 11. YOSEMITE CREEK, PAST AND PRESENT. Today Yosemite Creek (solid blue line) flows over the valley rim to create Upper Yosemite Fall. Before its diversion about 130,000 years ago, Yosemite Creek flowed down an older channel just to the west (dashed blue line) and cascaded down through the steep ravine that is now the route of the Yosemite Falls Trail. A complex of glacial moraines mapped by Matthes (1930) are shaded brown.

Matthes did not speculate on how or when Yosemite Creek was diverted from that old channel into its present channel to create Upper Yosemite Fall. He did, however, map a morainal complex that he attributed to his Wisconsin-age glacier that flowed down Yosemite Creek but stopped about one-half mile short of the rim of Yosemite Valley. A plausible explanation for the diversion of Yosemite Creek into its present channel is that the stream was temporarily blocked by glacial deposits and had to find a new way through the intricate complex of nested moraines. Because the Wisconsin glacial stage includes both Tahoe and Tioga glaciations, Upper Yosemite Fall and its relatively new hanging valley can be little more than 130,000 years old. And what a spectacular addition to Yosemite Valley's architectural wonders it is!

YOSEMITE VALLEY'S GLACIAL FINALE

While the Tioga glacier was constructing its terminal moraine at Bridalveil Meadow, the climate apparently warmed slightly. The ice at the front of the glacier began to melt faster than the ice was moving forward, and the ice front, or snout, of the still-flowing glacier began to retreat up the valley. When the climate cooled again, the ice front paused and temporarily stabilized just west of El Capitan Meadow, where the glacier began to construct a new moraine, known as a recessional moraine because the glacier had receded from its terminal position. The snout remained at this location longer than it had at Bridalveil Meadow, and the resulting El Capitan Moraine is larger in both volume and height. Eventually, the climate warmed abruptly, and the Tioga glacier's snout retreated toward the head of the valley with no more recessional pauses, probably leaving Yosemite Valley by 15,000 years ago.

When the Tioga-age glacier receded from Yosemite Valley, it left behind a lake that Matthes christened *Lake Yosemite* (fig. 12). It is likely that the advancing Tioga glacier had excavated some of the pre-existing valley fill east of the El Capitan Moraine, creating a shallow basin that filled with glacial meltwater. The lake was, in part, dammed by this moraine and the Merced River flowed over a low spillway through the moraine near the south valley wall. As the separate arms of the Tioga glacier retreated up the Merced and Tenaya canyons, the melt-water-swollen, debris-laden rivers issuing from their snouts delivered large quantities of sediment to the lake basin. The lake was soon filled with this sediment, creating the relatively level valley floor we see today. The resulting gentle slope allowed the Merced River to develop a sinuous, meander path across this broad flood plain. A low-gradient, meandering stream is particularly susceptible to overbank flow during high water, and its flood plain is naturally destined for periodic flooding.

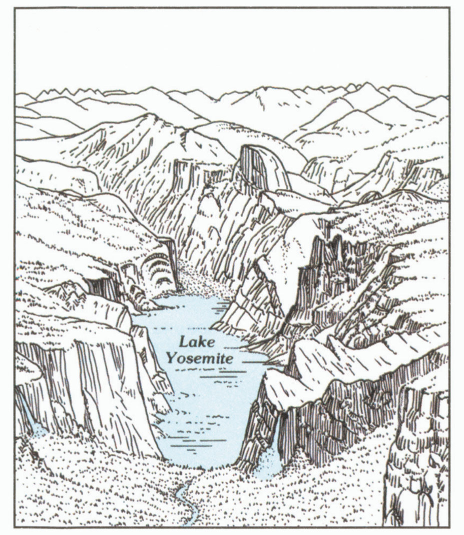

Figure 12. GLACIAL LAKE YOSEMITE filled the basin remaining upstream from El Capitan Moraine after the retreat of Tioga-age ice from Yosemite Valley.

THE ROCKS COME TUMBLING DOWN

The Tioga-age glacier did little to modify Yosemite Valley except to remove pre-existing talus at the base of cliffs east of Bridalveil Meadow; present talus has accumulated in the last 15,000 years or more since the Tioga glacier receded. In contrast, the enormous talus slope west of El Capitan, known as the Rockslides, escaped the reach of the Tioga glacier. For the past million years, the rock walls of the valley that remained above the ice level of the smaller post-Sherwin glaciers have weathered, joints have been enlarged, and rock has spalled off to form the very irregularly sculptured surface we see today. This geologic history provides the setting for abundant rockfalls. Every significant historical rockfall in Yosemite Valley has originated in vulnerable fractured rock from above the level of the Tioga glacier. Some rockfalls are quite large, but most are relatively small and gradually build a cone of debris below the most active sites. Thus, the size of a debris cone may reflect the volume or the frequency of individual rock falls or a combination of the two. The shattered rock high on the east side of Middle Brother provides material for a debris cone at one of the most active rockfall sites in the valley; it is inevitable that such rockfalls will continue as part of ongoing geologic processes.

EPILOGUE

The geologic story of Yosemite Valley presented here describes our present understanding of the interplay of various geologic processes that contributed to the valley's creation. But this is not the last word. We are still learning about these various processes and their effects on the evolution of the valley. And these geologic processes are far from finished. We are seeing only a brief period in time in the landscape's ongoing history. Dynamic geologic processes will continue to change the many faces of this "Incomparable Valley."

Additional Reading

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