BEDROCK GEOLOGY OF THE YOSEMITE VALLEY AREA
YOSEMITE NATIONAL PARK, CALIFORNIA
Prepared by
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From the writings of Frank C. Calkins and other sources

PREFACE

Frank Calkins' work in Yosemite was preceded by Henry W. Turner, also of the U.S. Geological Survey, who began mapping the Yosemite and Mount Lyell 30-minute quadrangles in 1897 and laid the foundation that Calkins' work was built on. Although Turner never completed this sizable assignment, he recognized the differing types of plutonic rocks and, for example, named the El Capitan Granite.

Calkins mapped the valley and adjacent areas of Yosemite National Park during the period 1913 through 1916, at the same time that Francois Matthes was studying the glacial geology of Yosemite. Calkins summarized the bedrock geology of part of Yosemite in the appendix of Matthes' classic volume "Geologic History of the Yosemite Valley" (1930), but his detailed bedrock map of the valley was never published during his lifetime. The ultimate perfectionist, Calkins never was satisfied that he had all the geologic contacts correctly located or that he understood completely enough the relations between all the geologic units. We still do not understand all of those relations, and although his map is being published now as a historical document, it remains the definitive geologic map of Yosemite Valley. Its publication, although belated, is a fitting memorial to his mapping talent.

The map itself remains unchanged but its explanation has been modified to reflect current nomenclature, and the names of some of the geologic units differ slightly from those in Calkins' earlier descriptions. The accompanying text is based in part on Calkins' writings, but also partly from the work of other students of Yosemite geology, notably Frank Dodge, Francois Matthes, Dallas Peck, and Clyde Wahrhaftig.

The topographic base used for this map is the original one Matthes prepared from plane-table surveys made in 1905 and 1906 and is a classic in its own right. Matthes' map is used here because it was the base used by Calkins' to compile his geology, and to avoid the considerable adjustment required to fit the geology to the current topographic map of the Valley prepared by photogrammetric methods. Calkins' desired that this base be used because he believed it had more "character" and gave the "feel" of the cliffs better than the more recent version—that it does, despite the increased geodetic accuracy of the latter. The location of roads and structures on Matthes' map was last revised in 1949, but no new highways have been constructed since then, so the map has not been further revised for this publication.

INTRODUCTION

Yosemite Valley, one of the world's great natural works of rock sculpture, is carved into the west slope of the Sierra Nevada. Immense cliffs, domes, and waterfalls tower over forest, meadows, and a meandering river, creating one of the most scenic natural landscapes in North America (fig. 1). In Yosemite Valley and the adjoining uplands, the forces of erosion have exposed, with exceptional clarity, a highly complex assemblage of granitic rocks. The accompanying geologic map shows the distribution of some of the different rocks that make up this assemblage. This pamphlet briefly describes those rocks and discusses how they differ, both in composition and structure, and the role they played in the evolution of the valley.

MAGMA AND ITS PRODUCTS

The rocks that now form the walls and domes of the Yosemite Valley area, part of the lofty Sierra Nevada, originated from molten material—magma—buried miles below the Earth's surface. Cooling and crystallization of this deep-seated magma required millions of years. The resulting rock, composed of interlocking crystals of several kinds of minerals, is called a plutonic rock, named for Pluto, the Roman god of the underworld. Formation of the plutonic rocks of the Sierra occurred over a long timespan, as magma episodically rose from the Earth's interior, intruding older host rocks, and eventually crystallizing to create one of many individual bodies of rock called plutons. Many of these plutons are today exposed at the Earth's surface due to erosion of the once-overlying older rocks.

These older rocks—slate, quartzite, marble, and metavolcanic rocks—formed by alteration, or metamorphism, from their original state—shale, sandstone, limestone, and volcanic rocks—with intense heat and pressure. The metamorphism both preceded and accompanied the intrusion of the plutons. Few remnants of these preplutonic host rocks remain near the present valley, although several small masses occur on the flanks of Sentinel Dome and in Indian Canyon. Great thicknesses of these rocks, however, do crop out a few miles to the west. Tightly folded beds of them are visible from the road turnout on Highway 140, 11 miles downstream from El Portal and about 1 mile west of the bridge crossing the South Fork of the Merced River (outside map area). Ancient metamorphic rocks are also widely exposed along the

crest of the Sierra, notably on Mt. Dana and Mt. Gibbs (outside map area).

The numerous plutons composing the Yosemite Valley area, as well as the entire Sierra Nevada, together are called the Sierra Nevada batholith (from the Greek words bathos, deep, and lithos, rock). In the earliest geologic studies of the Sierra, the composite nature of the batholith was not recognized—the differences in rock types were thought simply to represent variations in one huge rock mass. The complex history of the batholith was only deciphered when individual plutons were recognized as separate units. Calkins' Yosemite study was one of the earliest to assign different names to different plutons yet at the same time recognize the composite nature of the batholith. The plutons exposed in the walls of Yosemite Valley were intruded over a period of about 30 million years (approximately from 120 to 90 million years ago) during part of the Cretaceous Period. The Sierra Nevada batholith, however, is composed of hundreds of individual plutons, and construction of this extensive batholith may have taken as much as 130 million years.
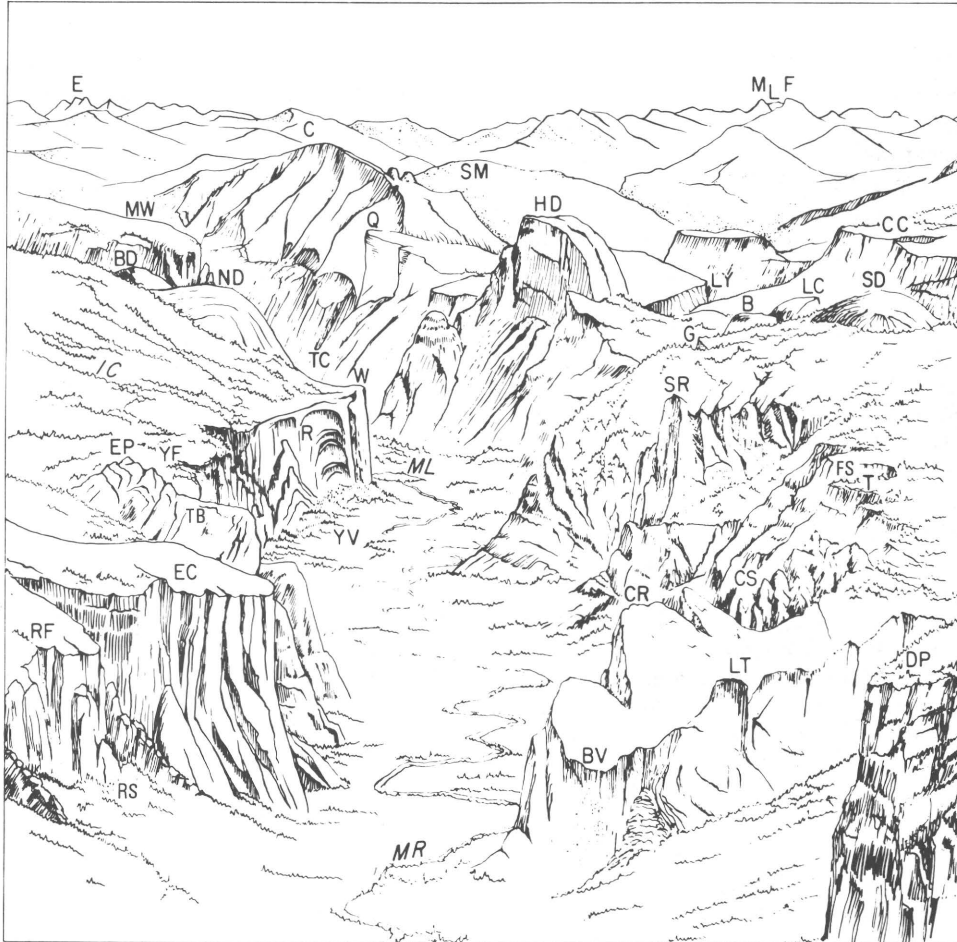

Figure 1.—Bird's-eye view of Yosemite Valley, with identification of selected land forms. Sketch by Natalie Weiskal.

RS,	Rockslides	BD,	Basket Dome	B,	Mount Broderick
RF,	Ribbon Fall	MW,	Mount Watkins	SD,	Sentinel Dome
EC,	El Capitan	E,	Echo Peaks	G,	Glacier Point
TB,	Three Brothers	C,	Clouds Rest	SR,	Sentinel Rock
EP,	Eagle Peak	SM,	Sunrise Mountain	FS,	Fissures
YF,	Top of Yosemite Falls	Q,	Quarter Domes	T,	Taft Point
YV,	Yosemite Village	HD,	Half Dome	CS,	Cathedral Spires
IC,	Indian Creek	M,	Mount Maclure	CR,	Cathedral Rocks
R,	Royal Arches	L,	Mount Lyell	BV,	Bridalveil Fall
W,	Washington Column	F,	Mount Florence	LT,	Leaning Tower
TC,	Tenaya Canyon	CC,	Cascade Cliffs	DP,	Dewey Point
ML,	Mirror Lake	LY,	Little Yosemite	MR,	Merced River
ND,	North Dome	LC,	Liberty Cap		

The plutonic rocks of the valley and adjacent uplands are composed of a variety of minerals. Five of these minerals make up most of each rock variety; quartz, two varieties of feldspar (potassium feldspar and plagioclase), bitotie, and hornblende. These minerals mainly comprise the elements silicon and oxygen, and all except quartz include aluminum as well. Other constituents of the feldspar include potassium, sodium, and calcium; biotite and hornblende also include magnesium and iron.

Feldspar and quartz are translucent and appear light gray on fresh surfaces. On a weathered surface, the feldspars turn chalky white, but the quartz remains light gray. Feldspar crystals have good cleavage—a property of breaking along planar surfaces that reflect light when properly oriented; quartz has no cleavage, so it breaks along curved, or conchoidal, surfaces. Biotite, black mica, commonly appears as hexagonal crystals that can be split with a knife into thin flakes along one perfect cleavage direction. Hornblende is much harder than biotite and commonly occurs as greenish-black elongate rod-shaped crystals; it has good cleavage in two directions that intersect to form fine striations along the length of the rods, making them look like bits of charcoal. Other minerals are present in minor amounts; the most distinctive is sphene, which occurs in small amber wedge-shaped crystals. With a little practice, all of these minerals can be readily identified with a small magnifying glass.

Plutonic rocks consisting chiefly of the light-colored minerals quartz and feldspar and only a minor amount of dark minerals are loosely called granitic rocks. Granitic rocks, such as granite, granodiorite, and tonalite, differ primarily in the relative proportions of these minerals (see fig. 2). For example, granite, in the technical sense of the

term, contains much quartz, both potassium feldspar and calcium-rich feldspar (plagioclase), is generally light colored with only a small percent of dark minerals. Granodiorite is similar but has about twice as much plagioclase as potassium feldspar and has more dark minerals. Tonalite has even less potassium feldspar and more dark minerals. Additional compositional data indicate that rocks previously called quartz monzonite by Calkins (1930) are granodiorite under the rock classification currently in use. In contrast to granitic rocks, diorite and gabbro contain mostly plagioclase and dark minerals with little or no quartz or potassium feldspar; the plagioclase in gabbro has more calcium than it does in diorite.

Because most granitic rocks contain minerals of about equal size, they are said to have a granular texture. But some granitic rocks have crystals of one mineral considerably larger than the others; these oversized crystals are called phenocrysts (from the Greek words meaning "to appear" and "crystal") and the texture of such a rock is described as porphyritic. In Sierran granites the mineral that most commonly occurs as phenocrysts is potassium feldspar, with crystals sometimes as much as 2 or 3 inches long.

Certain field relations help determine the relative ages of individual plutons. For example, hot magma associated with younger plutons commonly intrudes older plutons along cracks, or fractures, and solidifies to form sheets, or dikes, along those fractures in the older rocks. Additionally, younger plutons commonly contain inclusions, or fragments, of the older rock, which became embedded in the still-molten magma. Determining the specific age of a given rock in million of years requires measurement of the amount of radioactive decay of certain elements such as uranium, thorium, potassium, and rubidium. From these measurements and the known rates of decay, one can approximate the amount of time elasped since the rock crystallized or cooled below a temperature that permitted the radiometric decay to start.

ROCKS OF THE YOSEMITE VALLEY AREA

Brief descriptions are given below of the plutonic rocks exposed in Yosemite Valley, the Merced Gorge, and the adjacent uplands. Individual plutonic-rock units are generally named for major geographic features situated within the area of the particular rock type; they are listed with brief descriptions on the map explanation.

The oldest plutonic rocks of the region compose the walls of the Merced Gorge and the west end of the valley. They include the diorite of the Rockslides, the granodiorite of Arch Rock, and the tonalite of the Gateway. The largest outcrop of diorite is just west of the Rockslides, but the talus slopes below, composed of broken blocks of diotite, are more accessible. A good exposure of the granodiorite of Arch Rock lies immediately east of the Arch Rock Entrance Station on Highway 140 where the road passes under two large fallen blocks of the granodiorite. The tonalite of the Gateway can be seen on Highway 140 across from the first turnout after the road starts climbing up the Merced Gorge from El Portal. These last two locations are west of the map area. Studies of radioactive decay indicate that the tonalite of the Gateway
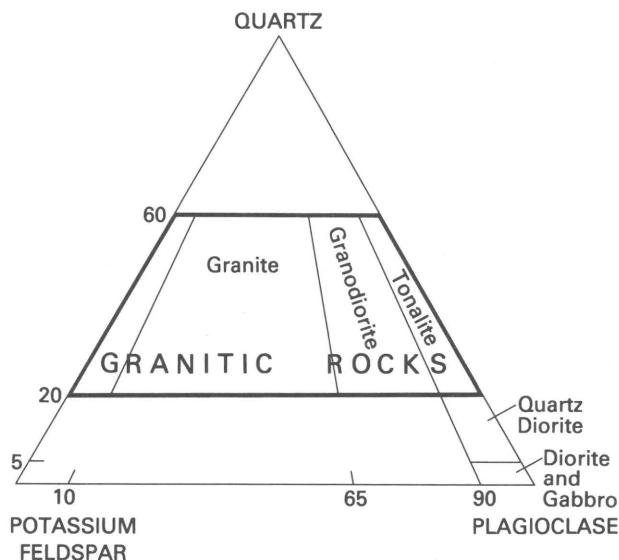

Figure 2.—Classification used for plutonic rock names, based on relative percentages of quartz, potassium feldspar, and plagioclase (Streckisen, 1973). "Granitic rocks" are those that lie within the heavy-line boundary and contain between 20 and 60 percent quartz. Only rock names used in accompanying text are shown.

is about 117 million years old. The age of the granodiorite of Arch Rock has not been radiometrically determined, but it probably is only a little younger than the Gateway.

The El Capitan Granite subsequently intruded these older plutonic rocks about 103 million years ago and now makes up most of the west half of the map area. Just west of the junction of the old Coulterville Road and Highway 140 (Allyear Highway), the roadway passes between blocks of El Capitan Granite dislodged in a 1982 rockfall. These blocks, some the size of a large truck, display fresh surfaces of the granite plus numerous inclusions of an older, dark-colored rock. The imposing monoliths of Turtleback Dome, El Capitan, Three Brothers, and Cathedral Rocks also are hewn from the massive El Capitan Granite.

After the El Capitan Granite solidified, the Taft Granite welled up and intruded the older pluton. In addition to younger radiometric dates for the Taft, dikes of the Taft Granite invading the El Capitan Granite and inclusions of the El Capitan in the Taft also establish the Taft as younger. The Taft Granite is lighter in color and slightly finer grained than the El Capitan Granite and, unlike the El Capitan Granite, generally does not contain phenocrysts; otherwise the two rocks are similar. The Taft Granite forms the brow of El Capitan and part of the upland between El Capitan and Fireplace Bluffs. On the south side of the valley, Taft Granite can be seen at Dewey Point and near The Fissures, just east of Taft Point.

In the vicinity of Leaning Tower and Cathedral Rocks, dikes and irregular masses of several fine-grained rocks cut the Taft and El Capitan Granites. Examples of these fine-grained rocks can be seen in talus blocks near the base of Bridalveil Fall. The Leaning Tower Granodiorite characteristically has rounded clots of dark minerals that give it a spotted appearance. The Bridalveil Granodiorite, with fine evenly-distributed dark and light minerals, has a salt-and-pepper appearance; field evidence shows that it intruded nearly all the rocks with which it is now in contact.

Dark fine-grained diorite also intrudes the El Capitan and Taft Granites. A striking example is exposed on the east face of El Capitan where dikes of diorite form an irregular pattern that, in part, very crudely resembles a map of North America (fig. 3).

The Sentinel Granodiorite forms a north-south band that crosses the valley between Taft Point and Glacier Point. The rock varies in appearance, but is generally medium dark gray and medium grained, although along the eastern margin of the Sentinel Granodiorite it is darker and has a streaky appearance because of the parallel orientation of flakes of biotite and crystals of hornblende. This darker rock, which can be seen at Washburn and Glacier Points, probably should be assigned to a separate plutonic unit, but Calkins (1930) included it with the Sentinel so it is shown as such on the accompanying map.

Giant inclusions of the El Capitan Granite are embedded within the Sentinel Granodiorite in a zone that extends along Yosemite Creek and down the face of the cliff near Yosemite Falls. It reappears on the south valley wall west of Union Point and then extends south through Sentinel Dome to Illilouette Ridge. Dikes of the Sentinel

Granodiorite that cut inclusions of the El Capitan Granite can be seen in the roadcut along the Glacier Point Road near the Taft Point trailhead.

Half Dome Granodiorite dominates the map area east of the Royal Arches and Glacier Point. It is medium to coarse grained and contains well-formed plates of biotite and crystals of hornblende. At Church Bowl and in the cliff west of Royal Arches, horizontal dikes of the Half Dome Granodiorite cut the older Sentinel Granodiorite. The Half Dome Granodiorite supports the sheer cliffs to the north of the trail between the Ahwahnee Hotel and Mirror Lake. The Trail to Vernal and Nevada Falls also crosses through the Half Dome Granodiorite. Except for minor dikes, the Half Dome, about 87 million years old, is the youngest plutonic rock in the map area.

RELATION OF LANDFORMS TO ROCK COMPOSITION AND STRUCTURE

The major landforms of the Yosemite Valley area are due to erosion—first by streams and later by glaciers. These processes were described at length in Francois Matthes' classic report "Geologic History of the Yosemite Valley" (1930) and in his book "The Incomparable Valley" (1950). Visitors struck by the varied style of sculptural features on the Valley walls may wonder why Yosemite stands unrivaled in the Sierra Nevada for the magnificence of its falls, cliffs, and domes, Sculptural detail depends to a large extent on the material that erosional forces had to deal with—on what rocks they encountered as they worked downward. The great diversity of erosional features seen today as the magnificent walls, promintories and domes of the valley has resulted from the varied composition and structure of rocks from which they were carved.

In the case of plutonic rocks, the most significant structure that affects their erosional form consists of joints. Joints usually occur as sets of parallel fractures or cracks in the rock. In the 80 million or more years since these rocks crystallized, were cooled, uplifted and eroded into mountains, they have been subjected to many disruptive forces and are now broken by a variety of joints. Landforms in and near the valley reflect the influence of several types of joints, which occur at both outcrop and regional scale.

At the outcrop scale, two nearly vertical joint sets perpendicular to each other combine with nearly horizontal joints to create roughly rectangular blocks several feet on a side. Generally the more siliceous, or quartz-rich, rocks (granite and granodiorite) have more widely spaced joints than the less siliceous rocks (tonalite and diorite). Also, the finer grained rocks generally have more closely spaced joints than the coarser grained ones. Thus, both composition and texture influence the spacing of joints in a given rock mass.

The diorite of the Rockslides is the least siliceous of the plutonic rocks in the valley and is the most closely jointed rock in the valley. Because of this extensive jointing, enormous talus piles of joint-derived blocks of diorite have accumulated throughout the area of the Rockslides and at the base of Bridalveil Fall.
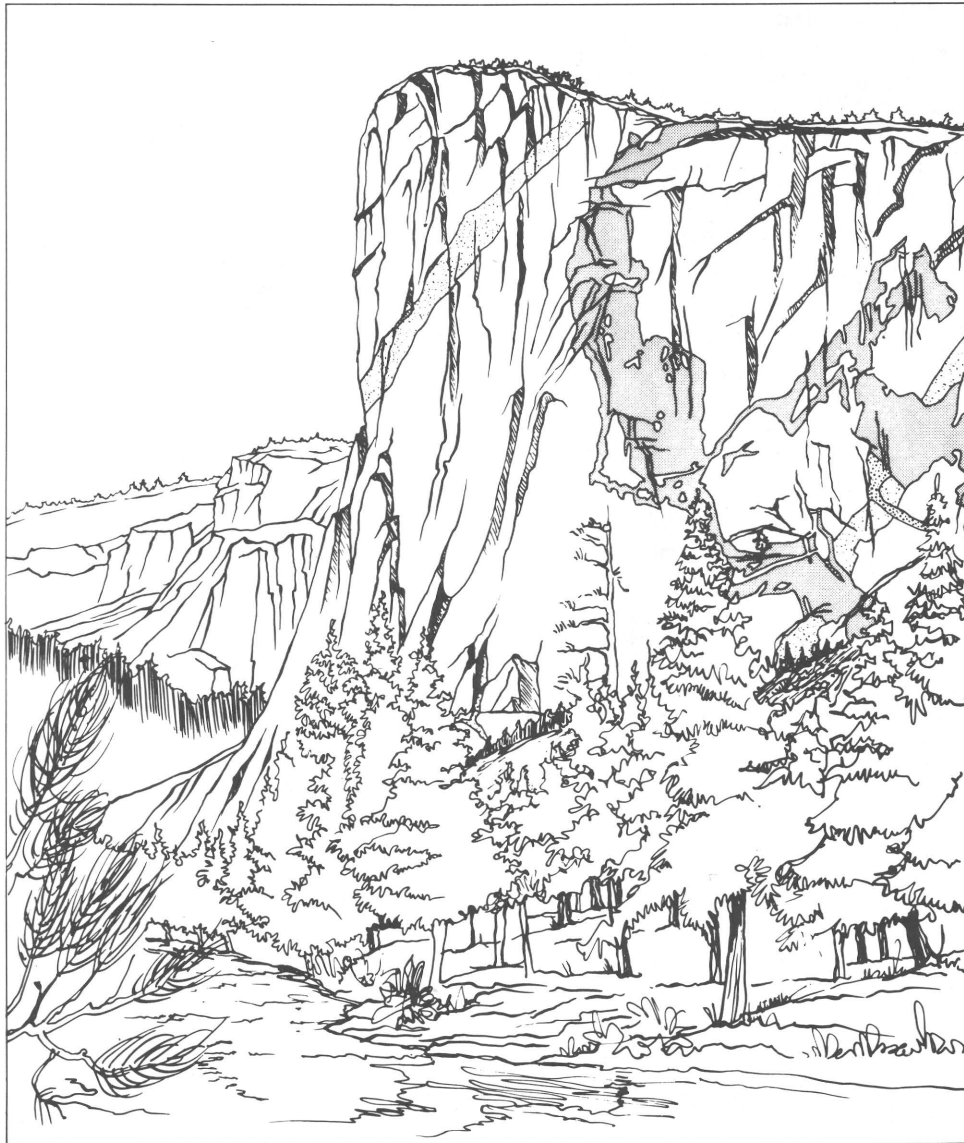
Figure 3.—Sketch of diorite dikes exposed on the east face of El Capitan that crudely form a "map of North America." Sketch by Natalie Weiskal.

A particularly striking contrast to the jumbled piles of debris at the Rockslides is the largely unbroken face of El Capitan, a short distance to the east—one of the sheerest cliffs in the world. It consists chiefly of the El Capitan and Taft Granites, two of the most siliceous plutonic rocks in this area. The character of these rocks determines the character of El Capitan itself—massive and resistant. Because El Capitan is largely unjointed, the talus pile at its foot is small. Cathedral Rocks and the Leaning Tower are composed of the El Capitan Granite, complexly intruded by the Bridalveil Granite; these pinnacles stand out as they do because of their siliceous composition. The lower part of the cliff east of Glacier Point consists of unjointed Half Dome Granodiorite capped by well-jointed Sentinel Granodiorite; from a viewpoint near the Ahwahnee Hotel, the eye can trace the contact between the two rock types quite closely by noting this difference in structure.

At the regional level, widely spaced master joints have split the rocks of Yosemite Valley to create large-scale features. Many of these joints, which tend to be near vertical, persist for miles, crossing boundaries between different rock types as if such boundaries did not exist. Moreover, some fault movement probably took place on these joints after they formed, creating zones of broken rock; deep weathering and erosion along these zones is

responsible for many straight and narrow canyons, perhaps Tenaya Canyon, and for notches such as the Gunsight in the Cathedral Rocks. Steep master joints have also determined the location of many of the cliffs bordering the valley. The near-vertical north face of Sentinel Rock was formed when masses of rock split off the cliff along steep joints that trend nearly east-west. The sheer cliff below Glacier Point developed along vertical joints that trend almost due east-west.

Such a bulky feature as Half Dome could only have been carved from a great mass of unjointed rock. A major joint system bounds Half Dome on the northwest, however, and is responsible for its smooth vertical 2,000-foot cliff. This cliff probably is the southeasternmost exposure of the joint system that determined the course of Tenaya Canyon. Yosemite Valley itself may have been eroded along a complex joint system now concealed by alluvium.

Although vertical master joints prevail, inclined joint sets have added to the diversity of Yosemite Valley's landforms. The western faces of Three Brothers were largely determined by a series of master joints that slope about 45° westward. The slope between Cathedral Rocks and Bridalveil Creek also follows a set of westwardly inclined joints.

The type of jointing that has most influenced the form of Yosemite's monuments, however, is the broad shell-like unloading joints, or sheeting, also commonly referred to as exfoliation. Granitic rocks crystallized at great depths within the Earth while under extreme pressure from miles of overlying rock. As the still-buried plutonic rocks were uplifted into mountains and the overlying rock eroded, the release, or unloading, of the previously confining pressure caused the rock to expand outward. In jointed rocks such expansion is taken up by adjustments along the numerous partings, but in a massive rock monolith the stresses accumulate until they exceed the tensile strength of the rock and the outer and more rapidly expanding layer bursts loose. In the course of time the process is repeated, and the monolith becomes covered with several layers of shells. The outermost layer, being exposed to the weather, gradually disintegrates, and the pieces fall off. The process of sheeting eliminates projecting corners and angles and replaces them with curves (fig. 4). As succeeding shells drop off the curves become more and more gentle, and thus a smoothly rounded surface evolves.
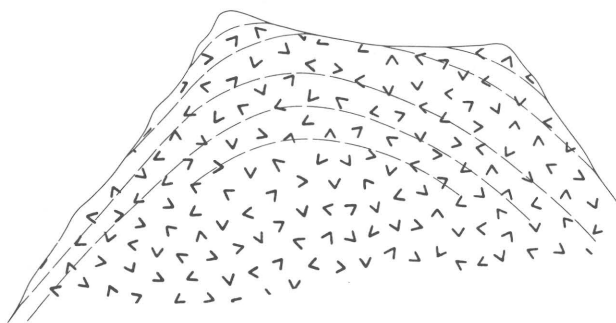

Figure 4.—Diagram illustrating progressive rounding (exfoliation) of massive granite as successive sheets spall off.

Because the expansion that forms sheet jointing takes place perpendicular to the Earth's surface, the shape of sheets generally reflects the topography, although their formation also subtly modifies the topography. If the ground surface is level, the sheets will be horizontal. If the granite underlies a hill, the sheets will curve accordingly, convex upward; beneath a valley, concave upward. Sheeting also tends to parallel the walls of canyons. If a canyon wall slopes toward the river, the sheets do also. If the walls are vertical, the sheets are also vertical; hence the vertical cliffs of Yosemite that appear to be unbroken monoliths may have hidden vertical fractures behind and parallel to the cliff face.

All of the prominent domes that overlook the eastern part of the valley, including Half Dome, North Dome and Liberty Cap, are composed of the Half Dome Granodiorite. This rock characteristically disintegrates by sheet jointing and it forms nearly all the domes of the valley area. An exception is Sentinel Dome, which is composed of El Capitan Granite.

Half Dome Granodiorite is less siliceous than El Capitan Granite, but at Half Dome it is not cut by any rocks that are less siliceous, a fact likely responsible for the almost complete absence of vertical joints at Half Dome itself. Although here it is indeed cut by many narrow dikes of coarse-grained pegmatite and fine-grained aplite, these are more siliceous and even more resistant than the dominant rock, so that many stand out in relief on the dome's southern slope.

The Royal Arches is a gigantic expression of sheet jointing, with sheets as much as 200 feet thick. Too far below the surface to form the tops of domes, the arches reveal a cross-sectional view of sheet jointing in the Half Dome Granodiorite. Similar features can also be seen on the walls behind Upper Yosemite Fall and at the head of Ribbon Fall alcove. The undulating surface of the wall below Clouds Rest is an outstanding example of sheeting that parallels the topographic surface; the sheets are concave in the bowl-shaped basins high on the cliff face and convex on the intervening spurs.

Glaciers greatly modified the original shape of Yosemite Valley. Yet they were effective in removing the rock only to the extent that the rock they encountered was susecptible to their erosive force. Intensely jointed rock of both local and regional scale was easily carried away by the deep rivers of ice, but massive unjointed rock remained in place. The smooth, broadly curved walls of El Capitan, Glacier Point, and similar monuments probably were formed by glacial peeling of the rock along near-vertical master joints. In short, the presence or absence of jointing in the rock determined the effectiveness of the erosive and sculpturing powers of the glaciers.

ADDITIONAL READING

The foregoing paragraphs on the bedrock geology of the Yosemite Valley area are only broadly descriptive and have not dealt with the detailed geologic processes that produced the rocks and landscape that we see today. These more comprehensive geologic aspects are considered in the citations referred to in the text and in other selected items in the bibliography.

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