CALIFORNIA GEOLOGY

November 1977

35¢

PLEISTOCENE LAKE YOSEMITE AND
THE WISCONSIN GLACIATION OF YOSEMITE VALLEY

GEOLOGY—Foundation of the present; key to California's future.

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IN THIS ISSUE

NEW EDITOR

William A. Bryant has joined the editorial staff of CALIFORNIA GEOLOGY. Bryant replaces Ralph C. Loyd, who is now assigned to the CDMG Sacramento District working with the surface mining and reclamation act project. Bryant, a geologist, is a graduate of California State University, Los Angeles. He was formerly associated with a consulting geotechnical engineering firm.

FRONT COVER Lake Yosemite once occupied Yosemite Valley. This scene was painted by Herbert A. Collins, Sr., and Herbert A. Collins, Jr., under the direction of François E. Matthes. The painting is in the Yosemite National Park Museum.

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OFFSHORE SEISMIC REFLECTION DATA

The National Geophysical and Solar–Terrestrial Data Center of NOAA publishes multichannel common depth point (CDP) seismic reflection data as they are released by the U.S. Geological Survey. Data are now available for several survey lines in (1) the southeast Bering Sea, Alaska (September 1975) and (2) the Gulf of Alaska (August 1975).

Descriptive fliers and costs available on request to: National Geophysical and Solar–Terrestrial Data Center, NOAA/EDS, Code D621, Boulder CO 80302, (303) 499–1000, Ext. 6542 or 6338.

PLEISTOCENE LAKE YOSEMITE

AND THE

WISCONSIN GLACIATION OF YOSEMITE VALLEY

By

JEFFREY P. SCHAFFER, Geomorphologist
Berkeley, California

The natural beauty of Yosemite Valley is known the world over. To the glacial geomorphologist, the valley represents one of the finest examples in the western United States of glacially related features stemming from the Great Ice Age. Scooped out from solid rock in the path of repeated advancing glaciers, the valley remains much the same in appearance as it did at the end of the Wisconsin Period, the last period of the Great Ice Age.

Because the glacial features present in Yosemite Valley are too sparse to construct the valley's glacial history on their own, no detailed interpretation has been made. François E. Matthes (1930) published a comprehensive paper on the glacial geomorphology of Yosemite Valley. His geomorphic research that was carried out in the 1910 s and 1920 s was recorded on a map of Yosemite Valley he had surveyed during the summers of 1905 and 1906. In his interpretation, Matthes assumed that only one glacier had advanced through Yosemite Valley during the last major glacial period (Wisconsin).

As Matthes was completing his field work, Eliot Blackwelder (1931) was systematically examining the moraines left by glaciers in the Sierra Nevada province and the Basin and Range provinces. Blackwelder believed that there had been two glacial stages in these provinces during the Wisconsin period–an older, larger Tahoe stage and a younger, smaller Tioga stage.

In Yosemite, Blackwelder briefly examined the glacial evidence and concluded that two Tahoe stage glaciers–one down Merced River Canyon and one down Tenaya Creek Canyon–had united at the east end of Yosemite Valley and flowed down–canyon to an area just west of Bridalveil Fall (figure 1). At the east end of the valley is a long linear east–west moraine which Blackwelder interpreted as a medial moraine, formed when the two glaciers merged and flowed as one glacier down through Yosemite Valley. The deposit is still labeled on Yosemite Valley topographic maps as "medial moraine" (figure 1). According to Blackwelder, a Tioga stage glacier later flowed down Merced River Canyon as far as Nevada Fall based on evidence of fresh glacier polish found near the fall's brink. He reasoned the glacier did not reach the valley floor since the "medial" moraine had not been disturbed. Blackwelder did not discuss the extent of the Tioga stage glacier that flowed down Tenaya Creek Canyon.

WISCONSIN GLACIATION

Further research has demonstrated that there were three major Wisconsin glacial stages in the Sierra Nevada, known from oldest to youngest as the Tahoe, Tenaya, and Tioga stages (table 1).

Although the Tenaya stage has been recognized as a valid entity since the early 1960s, the three–stage Wisconsin glaciation of Yosemite Valley has not been worked out. This is partly because Yosemite Valley, like many other deeply cut canyon floors of the western slope of the Sierra, lies at a low elevation where weathering occurs at a very slow rate. Hence, all the moraines in Yosemite Valley look alike and therefore lend credence to the erroneous belief that they are all the same age. These moraines contrast strongly with those of higher elevations, particularly on the east slope of the Sierra Nevada, where intense ice (frost) wedging results in relatively rapid weathering,

Table 1. Wisconsin glaciation in the Sierra Nevada (after Hill, 1975, and others).

glacial stage	*began*	*at maximum*	*ended*	*duration*
Tioga	30,000 B.P.	20,000 B.P.	10,000 B.P.	20,000 yrs.
interglacial period	40,000 B.P.	——	30,000 B.P.	10,000 yrs.
Tenaya	50,000 B.P.	45,000 B.P.	40,000 B.P.	10,000 yrs.
interglacial period	60,000 B.P.	——	50,000 B.P.	10,000 yrs.
Tahoe	85,000 B.P.	70,000 B.P.	60,000 B.P.	25,000 yrs.

(B.P. = before present)

in some cases causing a very different appearance between boulders found in Tioga stage moraines and those found in the older Tahoe stage moraines. In Yosemite Valley, snowfall is light and ice wedging is almost nonexistent, at least on valley floor boulders. Morainal boulders are further resistant to weathering because they are situated above the level of ground water and hence are not subject to the ceaseless chemical solution that attacks rocks beneath this level (Wahrhaftig, 1965; Clark, 1968).

LAKE YOSEMITE

Age determination of the moraines is a problem linked directly to the age determination of an ancient lake which once occupied the length of Yosemite Valley during the Wisconsin glaciation period.

In his paper on the glacial geomorphology of Yosemite Valley, Matthes (1930) envisioned "a mountain lake of exceptional beauty–a sheet of water in which the cliffs of El Capitan and Half Dome as well as the sprays of the Yosemite Falls were reflected....Ancient Lake Yosemite occupied the entire length and breadth of the main Yosemite chamber [front cover]. It was 5½ miles long, extending from the moraine dam at the El Capitan Bridge to the great wall at the head of the valley, and its waters lapped the bases of the freshly glaciated walls on each side....the lake owed its existence not to the moraine dam alone; it occupied an elongated basin scooped out in the rock floor of the valley by the ancient Yosemite Glacier, and its depth was merely increased somewhat by the moraine dam, which was situated on a broad rock sill at the lower end of the basin."

The existence of Lake Yosemite ended when sediments eventually filled the lake basin. Since Matthes had assumed that only one glacier had advanced through Yosemite Valley during the last major glacial period, and that this glacier retreated from the valley about 20,000 years ago, he believed Lake Yosemite was completely filled with sediments since that time. However, it is now recognized that the last major glacial episode ended only 10,000 years ago (table 1). Could the Merced River and its tributaries completely fill a deep, 5½–mile–long lake in such a short time?

Depth of Lake Yosemite

Three wells have been drilled in the vicinity of Yosemite Lodge (figure 1), and they indicate that the uppermost level of lake sediments is about the 3870–foot contour, or roughly 100 feet below the average surface elevation of the valley floor. This thick layer of post–lake sediments would in itself take a considerable amount of time to be deposited, but the thickness of sediments in Lake Yosemite is even greater. The well cores in the Yosemite Lodge area indicate that this thickness is, as Matthes estimated, over 300 feet.

In 1935 and 1937 seismic surveys were undertaken to determine the depth and configuration of the bedrock floor beneath Yosemite Valley. This granite bedrock was found to be as much as 2000 feet below the valley floor. More important, however, the surveys showed that there were two discontinuities (A and B in figure 2), which have been interpreted as the lower limit of two large ancient lakes (Gutenberg, 1956). Seismic surveys in the Yosemite Lodge area indicate the variable bottom of the most recent lake was between the 3510- and 3675- foot contours.

Deeper well cores indicate the presence of at least half a dozen glacial lakes and, considering that a large, advancing glacier may obliterate earlier lakebed deposits, then perhaps a number of lakes may have existed in past interglacial periods. Glaciers entered Yosemite Valley as early as 2 million years ago and excavated as much as 3100 feet of granitic bedrock before later glaciers began depositing the 2000 feet of sediments.

Filling of Lake Yosemite

Based on the well log and seismic data, the volume of sediments deposited in the basin of Lake Yosemite (between discontinuity A, figure 2, and the 3870-foot contour line) was calculated to be about 0.14 cubic miles. The volume of overlying sediments (deposits above the 3870–foot contour line, minus rock fall debris) was calculated to be 0.08 cubic miles.

If Lake Yosemite was formed since the retreat of the Tioga stage glaciers 10,000 years ago, the Merced River and its tributaries would have to deposit roughly 0.22 cubic mile of sediments to fill the lake and lay down the overlying sediments. Was this depositional episode possible in a 10,000–year period?

Based on data from a 14–year discharge record of the Merced River (U.S. Geological Survey, 1961–1974) and tributary discharge estimations, total sediment input into Yosemite Valley is estimated to be about 2830 tons per year.

Of course, the Merced River and its tributaries did not maintain an average discharge over the last 10,000 years. There were three "Little Ice Ages" during which the sediment transport was undoubtedly higher than it is today. On the other hand, there were drier periods too, including a protracted "altithermal" period during which all the Sierra Nevada glaciers melted and disappeared completely. Discharge and transport were probably lower during that time. Therefore, the 2830 tons per year may be fairly close to the actual overall 10,000-year-average figure.

Using the 2830 tons per year figure we can calculate the amount of time required to fill Lake Yosemite and to deposit the layer of sediments above it (figure 2). The amount of time required is staggering: the Merced River fluvial processes alone, without the aid of glaciers, would require about 580,000 years to fill Lake Yosemite and an additional 330,000 years to deposit the layer of sediments above it–910,000 years total!

This overall sedimentation–rate scheme is complicated by the fact that the Merced River had a considerably higher discharge rate at the end of each glacial period when the glaciers were retreating upcanyon. This rate may have been three-

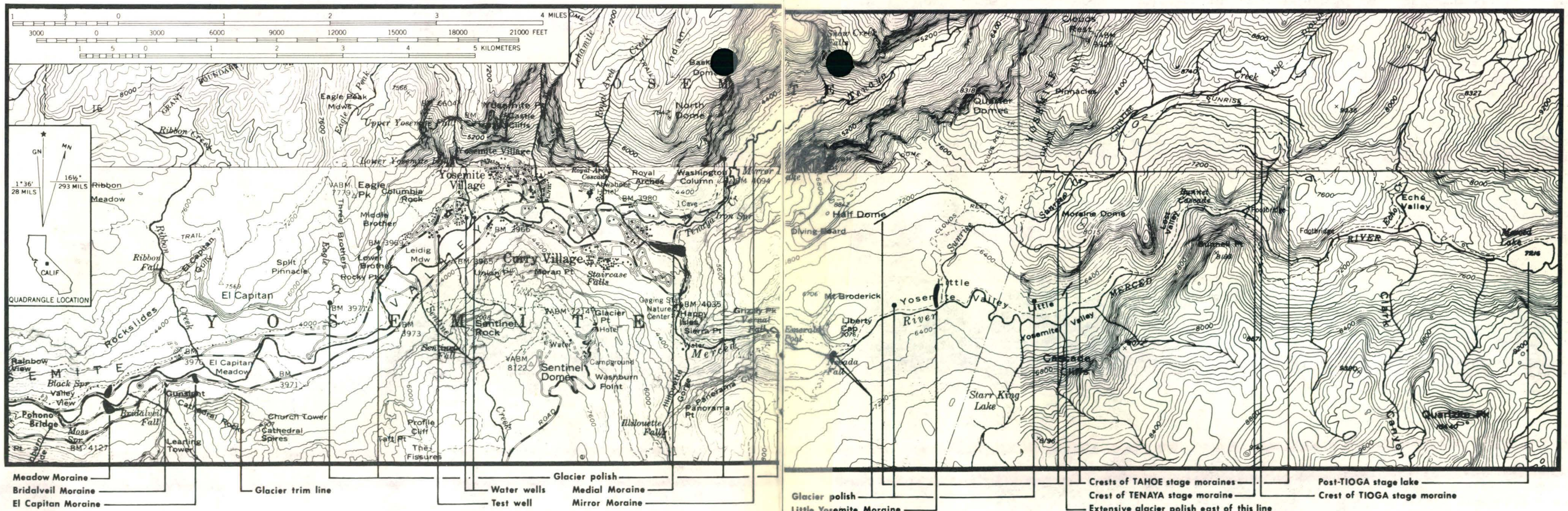

Figure 1. Principal sites of Wisconsin glaciation in Yosemite Valley and vicinity. *JPS*

to–four times the normal discharge rate (Broecker and others, 1958). If a four-fold rate increase is assumed, then the annual discharge would be about 33,000 tons per year. Further, assuming a lengthy glacier–waning period of 2000 years (12,000 to 10,000 B.P.), the total amount of sediments deposited in this period can be estimated to be 66,000,000 tons. This figure, combined with the 28,300,000 tons of the following 10,000 years, gives a total of 94,300,000 tons–a seemingly large figure. Yet, this figure amounts to only 10% of the total sediments that lie *above* the 3870–foot contour (layer 1). Therefore, Lake Yosemite could not have formed 12,000 years ago at the beginning of the retreat of the Tioga stage glaciers. How old, then, is Lake Yosemite?

THE AGES OF GLACIAL MORAINES AND LAKE YOSEMITE

The last Lake Yosemite undoubtedly was created during or just after the retreat of a Wisconsin age glacier. Since the lake most likely did not form at the end of the Tioga stage (10,000 years ago) it must have formed at the end of the Tenaya stage or the older Tahoe stage.

If Tahoe stage glaciers entered Yosemite Valley and scooped out a basin from the valley sediments, then Lake Yosemite could be late Tahoe stage, or about 60,000 years old (table 1). If Tenaya stage glaciers extended westward into the valley all the way to Lower Cathedral Rock, then the lake's age would have to be late Tenaya stage, or about 40,000 years old.

Glacial Moraines

In a number of localities on the eastern slopes of the Sierra Nevada, all three Wisconsin glacier stages are easily discernible by their moraines. The Tenaya stage terminal moraines–intermediate in age–are always found to extend down–canyon almost as far as do the Tahoe stage terminal moraines and they extend considerably farther down–canyon than do those of the Tioga stage (Birman, 1964; Sharp, 1972). By analogy we can see the same proportion of space between moraines in Yosemite Valley if (1) the westernmost moraine deposits (Meadow Moraine and Bridalveil Moraine; figure 1) represent remnants of Tahoe stage terminal moraine, (2) the El Capitan Moraine represents Tenaya stage terminal moraine, and (3) the easternmost moraine deposits, the "medial" moraine of Blackwelder (1931) and Little Yosemite Moraine, represent Tioga stage terminal moraines. Therefore, it appears by the position of the speculated Tenaya stage terminal moraine (El Capitan Moraine) that the glacier which formed the moraine entered Yosemite Valley, scooped out a basin in the valley sediments, and formed Lake Yosemite upon its retreat–roughly 40,000 years ago.

Extent of Glaciers

Matthes, in delimiting the maximum height of what he thought was the single Wisconsin age glacier which entered Yosemite Valley, placed the trimline (boundary of maximum height of glacier) at about the 4800–foot contour on Middle Cathedral Rock. This estimate is probably correct even though no trace of this trimline is seen today–time has removed all trace of glacial polish on the face of this steep, monolithic rock.

Yet there is a lower trimline at about the 4450–foot contour, which is about 250 feet above the talus ledge that runs along the base of the northeast face of Middle Cathedral Rock (photo 1). Extrapolated westward, it would terminate no farther west than Bridalveil Moraine (figure 1). However, because the valley widens immediately beyond this face (and the nose of El Capitan north of it), the glacier probably thinned more rapidly, ending at the El Capitan moraine. This low–elevation trimline and the moraine deposits to the west indicate that two Wisconsin glaciers–a large Tahoe stage glacier and a slightly smaller Tenaya stage glacier (figure 3)–plowed their way through Yosemite Valley. As this second glacier was retreating, roughly 40,000 years ago, the latest Lake Yosemite came into existence.

If the Tioga stage glaciers had joined and flowed to the west end of Yosemite Valley, the lake formed after their retreat would be only about 12,000 years old. As discussed previously, this would be far too short a time interval for Lake Yosemite to be filled in with waning glacier outwash and river sediments. Therefore, these glaciers could have advanced only to the east end of the valley (figure 4).

Matthes (1930) speculated about the "medial" moraine deposited at the east end of Yosemite Valley and concluded that it was likely the "frontal" (this term could mean terminal or recessional) moraine of a glacier from Tenaya Canyon, for its tip curves slightly north toward a smaller moraine at the foot of Royal Arches. This moraine is probably the medial moraine of the Tenaya stage glacier that advanced down Tenaya canyon. Fresh glacial polish can be seen on steep slopes above the north shore of Mirror Lake, about one mile up–canyon from the moraine, and this polish has long been interpreted as Tioga stage polish. However, the polish could be Tenaya stage; it is difficult to tell. During the study, a previously unmapped small moraine was discovered about ⅓ mile above Mirror Lake and interpreted to be a Tenaya stage recessional moraine (Mirror Moraine, figure 1).

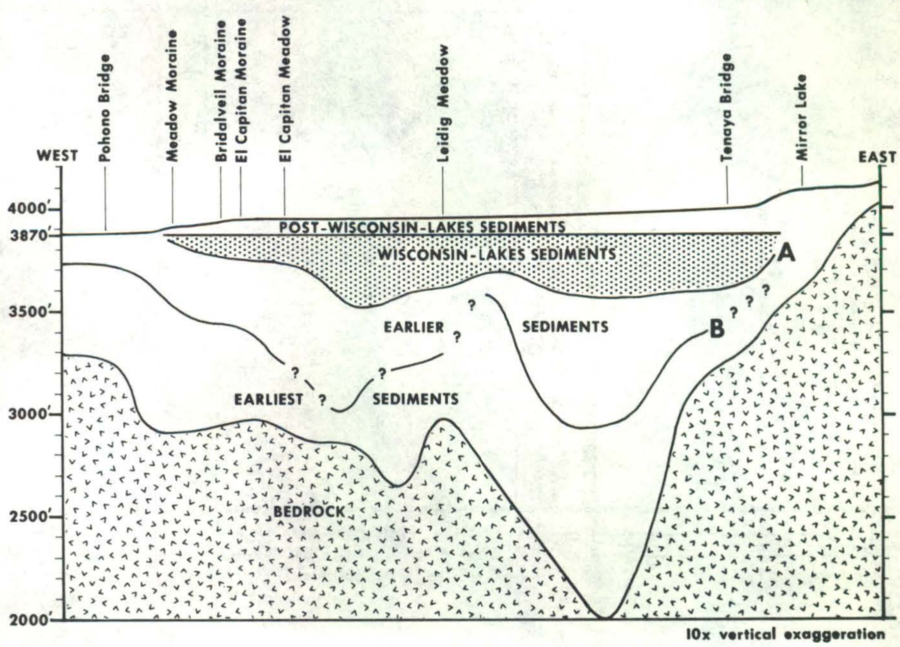

Figure 2. Longitudinal section of Yosemite Valley. *From Gutenberg and others, 1956.*

It is doubtful that the Tioga stage Merced Canyon glacier advanced beyond Little Yosemite Valley. On the north slopes of Merced Canyon opposite Bunnell Point is a conspicuous, westward–descending lateral moraine (figure 1). Other lateral moraines, such as the lateral moraine on Moraine Dome, are found above and west of it, but these are at high elevation and most are probably Tenaya and Tahoe in age. The descending moraine can be extrapolated westward and, in conjunction with the trimline delineated by the maximum height of fresh glacier polish above the canyon floor, indicate that the glacier terminated in Little Yosemite Valley. It may have extended as far west as the moraine found near the west end of Little Yosemite Valley.

Also, the quantity of glacier polish east of Little Yosemite Valley is significantly higher than that to the west (figure 1). It seems to be found almost everywhere on the lower slopes of Moraine Dome and the domes east of it, whereas at Nevada Fall and around Liberty Gap it is restricted. When glacier polish is found, it is usually on very resistant dikes rather than on the bedrock surface. The deep weathering of the glacier polish found on the steeper slopes of the Nevada Fall area and on the low ridge that extends east from Liberty Gap into Little Yosemite Valley indicates that it is pre–Tioga in age (photo 2). If the Tioga stage glacier originating from Merced Canyon had advanced over the polish, it most likely would have obliterated or repolished the features left by previous glaciers.

GLACIAL HISTORY OF YOSEMITE VALLEY

The Wisconsin period history of Yosemite Valley now appears to be as follows. The Tahoe stage glacier advanced down the valley to the edge of Bridalveil Meadow about 85,000 years ago before it eventually retreated, leaving a deep basin that was quickly filled with a 7.7 mile–long lake. Sedimentation by the Merced River and its tributaries had just begun to accumulate when the valley was invaded by the Tenaya stage glacier about 50,000 years ago. This glacier excavated these miniscule sediments and probably deepened the lake basin. This shorter–lived glacier then retreated about 40,000 years ago, leaving the most recent Lake Yosemite. During this retreat, the Merced River poured a considerable amount of sediments derived from the melting glacier into this enormous lake. Afterward, the Merced River again began to trickle sediments into it. Then glaciers once again advanced down the Merced River and Tenaya Creek Canyons about 30,000 years ago, transporting much of the glacial debris left behind by earlier glaciers as well as grinding and transporting new material. These glaciers, however, did not reach Yosemite Valley as did glaciers of the Tahoe and Tenaya glacial stages. In fact, sedimentation of Lake Yosemite and some post–lake deposition was completed during the existence of the Tioga stage glaciers.

In the Merced Canyon, Merced and Washburn Lakes were formed at the end of the Tioga stage about 10,000 years ago. Since they have only received geologically recent fluvial sediments, they still exist today. Little Yosemite Valley, in an intermediate location, between these lakes and Yosemite Valley, was partly covered by a glacier during Tioga times; hence, it was receiving some of the glacier's sediments although some sediments undoubtedly reached Lake Yosemite. However, Lake Yosemite was principally filled by sediments from the larger Tioga stage glacier which flowed down Tenaya Canyon.

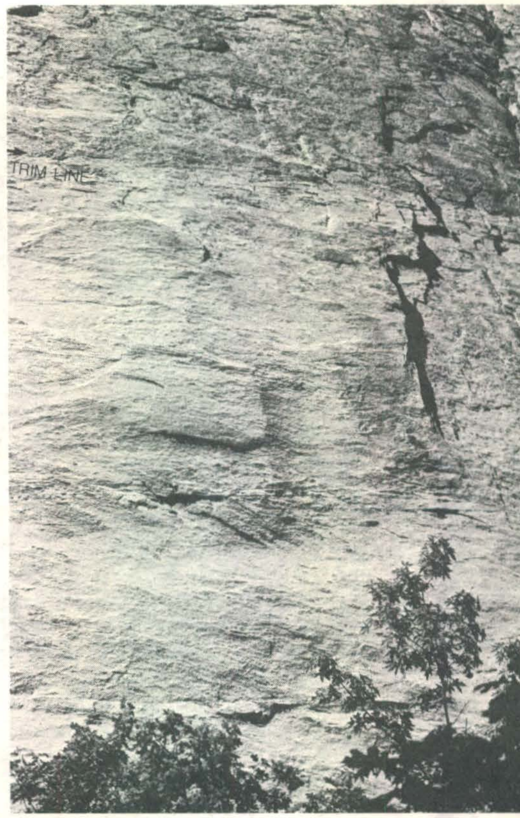

Photo 1. Tenaya stage glacier trimline on the lower part of Middle Cathedral Rock, northeast face.

Finally, it should be noted that rockfall deposits lying on the floor of Yosemite Valley were deposited since the Tenaya stage glacier retreated and *not* after the Tioga stage glacier, as many have supposed. Thus, they may be up to 40,000 or more years old and estimates of rock fall rates in the valley should be based on this approximate time span.

This new interpretation through correlation of glacier moraine deposits may aid in the identification of other Wisconsin glacial stages in other canyons of the western Sierra Nevada.

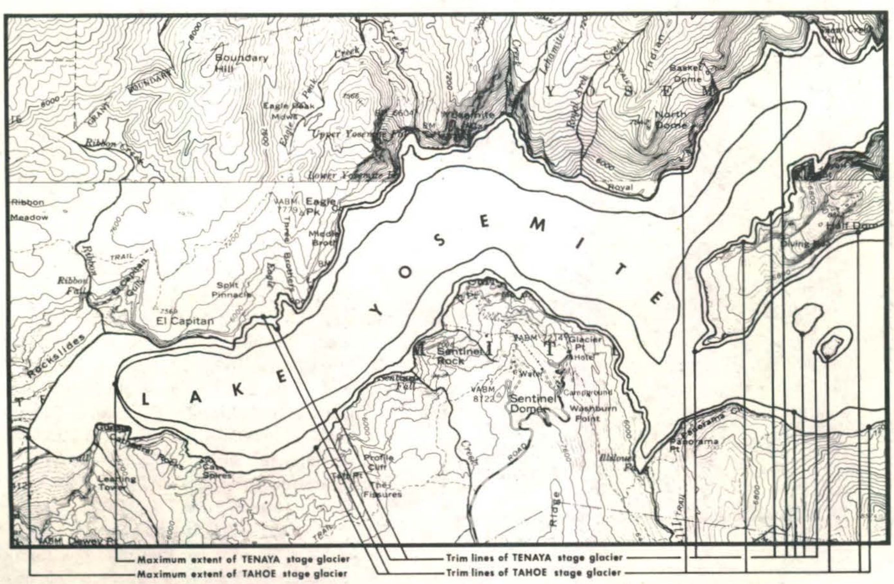

Figure 3. Extents of the Tahoe and Tenaya stage glaciers in Yosemite Valley. *JPS*

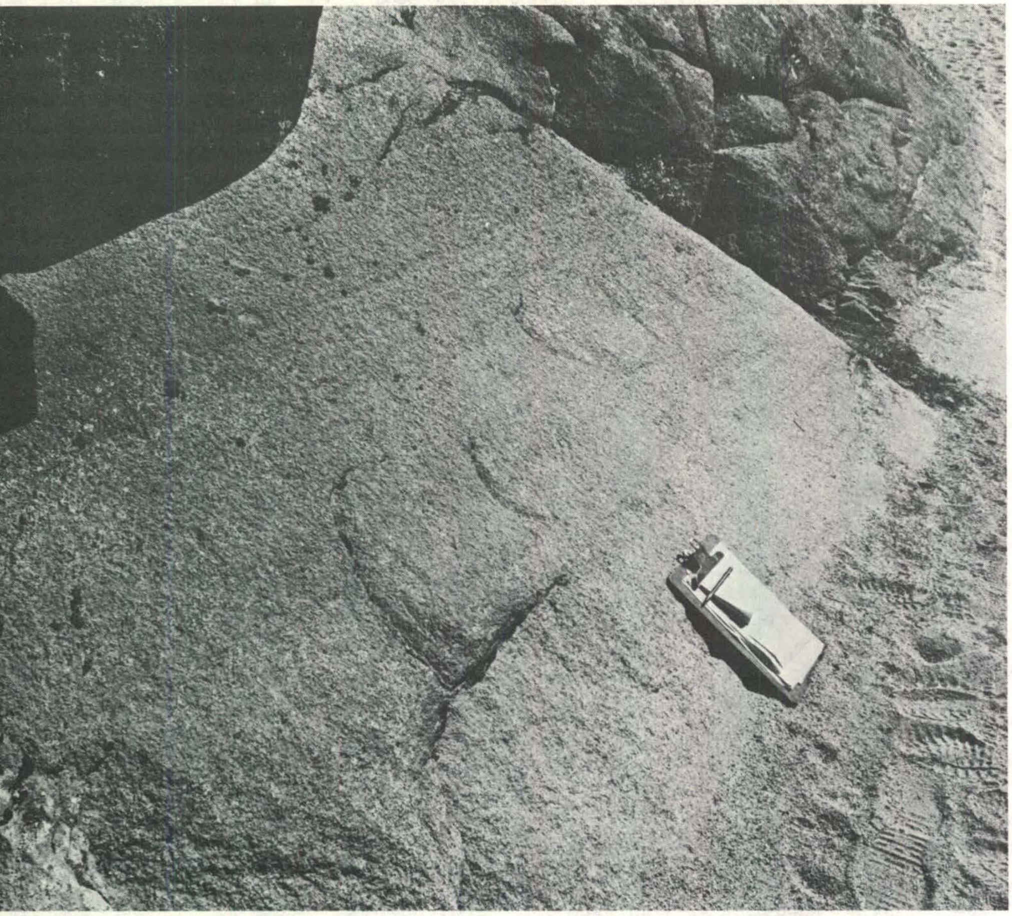

Photo 2. Weathered, weakly–striated Tenaya stage glacier polish located along trail about 100 yards northeast of Nevada Fall's brink.

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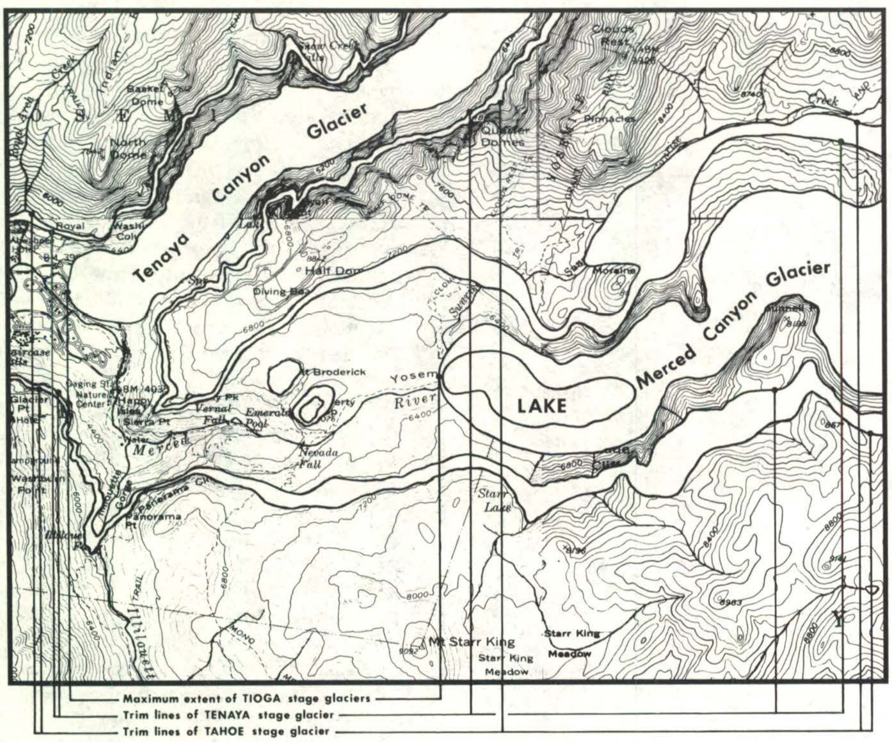

Figure 4. Extents of the Tioga stage glaciers in Tenaya and Merced Canyons. *JPS*

REFERENCES

Birman, J.H., 1964, Glacial geology across the crest of the Sierra Nevada, California: Geological Society of America Special Paper 75, 80 p.

Blackwelder, E., 1931, Pleistocene glaciation in the Sierra Nevada and Basin Ranges: Geological Society of America Bulletin, v. 42, no. 12, p. 865–922.

Broecker, W.S., Turekian, K.K., and Heezen, B.C., 1958, The relation of deep sea sedimentation rates to variations in climate: American Journal of Science, v. 7, p. 503–517.

Clark, M.M., 1968, Role of biotite in the weathering of granitic rocks as observed in the deposits of Pleistocene glaciers of the Sierra Nevada, California (abstract): Geological Society of America Special Paper 115, p. 36–37.

Gutenberg, B., Buwalda, J.P., and Sharp, R.P., 1956, Seismic explorations on the floor of Yosemite Valley, California: Geological Society of America Bulletin, v. 67, no. 8, p. 1051–1078.

Hill, M., 1975, Geology of the Sierra Nevada: University of California, Berkeley, California, 232 p.

Matthes, F.E., 1930, Geologic history of the Yosemite Valley: U.S. Geological Survey Professional Paper 160, 137 p.

Sharp, R.P.,1972, Pleistocene glaciation, Bridgeport Basin, California: Geological Society of America Bulletin, v. 83, no. 8, p. 2233–2260.

U.S. Geological Survey, 1961–1974, Water resources data for California: 855 Oak Grove Avenue, Menlo Park, CA 94025.

Wahrhaftig, C., 1965, Stepped topography of the southern Sierra Nevada, California: Geological Society of American Bulletin, v. 76, no. 10, p. 1165–1189.