

Geologic History of the Sierra Nevada

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Sevehah Cliff, near [Convict Lake](#), shows severely deformed [Devonian](#) rock^[14]



[Yosemite Valley](#) in Yosemite National Park was carved by glaciers

For central Sierra Nevada geology, see [Geology of the Yosemite area](#).

The earliest rocks in the Sierra Nevada are metamorphic [roof pendants](#) of [Paleozoic](#) age, the oldest rocks being [metasedimentary](#) rocks from the [Cambrian](#) in the [Mount Morrison](#) region.^[14] They are dark colored [hornfels](#), [slates](#), [marbles](#), and [schists](#), and are found in the western foothills (notably around [Coarsegold](#) and west of the [Tehachapi Pass](#)) and also east of the Sierra Crest.^[15] The earliest granite of the Sierra started to form in the [Triassic](#) period. This granite is mostly found east of the crest and north of 37.2°N.^[16] In the Triassic and into the [Jurassic](#), an [island arc](#) collided with the west coast of [North America](#) and raised a chain of volcanoes, in an event called the [Nevadan orogeny](#).^[17] Nearly all [subaerial](#) Sierran Arc volcanoes have since disappeared; their remains were redeposited during the [Great Valley Sequence](#) and the subsequent [Cenozoic](#) filling of the Great Valley, which is the source of much of the sedimentary rock in California.

In the [Cretaceous](#), a [subduction zone](#) formed at the edge of the continent.^[18] This means that an [oceanic plate](#) started to dive beneath the [North American plate](#). Magma formed through the subduction of the ancient [Farallon Plate](#) rose in plumes (plutons) deep underground, their combined mass forming what is called the [Sierra Nevada batholith](#). These plutons formed at various times, from 115 [Ma](#) to 87 Ma.^[19] The earlier plutons formed in the western half of the Sierra, while the later plutons formed in the eastern half of the Sierra.^[16] By 66 Ma, the proto-Sierra Nevada had been worn down to a range of rolling low mountains, a few thousand feet high.

Twenty million years ago, crustal extension associated with the [Basin and Range Province](#) caused extensive volcanism in the Sierra.^[20] About 10 Ma, the Sierra Nevada started to form: a [block of crust](#) between the Coast Range and the [Basin and Range Province](#) started to tilt to the west.^[21] Rivers started cutting deep canyons on both sides of the range. Lava filled some of these canyons, which have subsequently eroded leaving [table mountains](#) that follow the old river channels.^[22]

About 2.5 Ma, the Earth's climate cooled, and [ice ages](#) started. [Glaciers](#) carved out characteristic U-shaped canyons throughout the Sierra. The combination of river and glacier erosion exposed the uppermost portions of the plutons emplaced millions of years before, leaving only a remnant of [metamorphic rock](#) on top of some Sierra peaks.

Uplift of the Sierra Nevada continues today, especially along its eastern side. This uplift causes large earthquakes, such as the [Lone Pine earthquake](#) of 1872.^[23]



Sierra Escarpment viewed from the east. In the foreground is [Tinemaha Reservoir](#) in the [Owens Valley](#).

From <[https://en.wikipedia.org/wiki/Sierra_Nevada_\(U.S.\)](https://en.wikipedia.org/wiki/Sierra_Nevada_(U.S.))>

Formation of exposed rocks

Passive to active margin

The area of the park was astride a [passive continental margin](#) (similar to the east coast of present-day [United States](#)) during the Precambrian and early Paleozoic. Sediment was derived from continental sources and was deposited in shallow water. The [limestones](#), [sandstones](#), and [shales](#) thus created have since been metamorphosed into [marble](#), [quartzite](#), and [slate](#). These rocks are now exposed on isolated pendants in the northern and central parts of the park (Snow Lake Pendant in the [Emigrant Wilderness](#) is a good example).

Starting in the mid-Paleozoic and lasting into the early [Mesozoic](#), a [Convergent Plate Boundary](#) transported many of the above-mentioned seabed sediments into the area of the park (possibly during the [Antler orogeny](#)). Heat generated from the [subduction](#) led to the creation of an [island arc](#) of volcanoes on the west coast of [Laurentia](#) (proto-North America) between the late [Devonian](#) and [Permian](#) periods. These rocks were incorporated into proto-North America by the middle of the [Triassic](#), some of them finding their way to the area of the park. Most of these igneous and sedimentary rocks have since been heavily metamorphosed, [uplifted](#) and eroded away. Outcrops of the resulting Shoo Fly Complex (made of [schists](#) and [gneisses](#)) and younger Calaveras Complex (a [mélange](#) of shale, [siltstone](#), and [chert](#) with [mafic](#) inclusions) are now found in the western side of the park.

Later volcanism in the [Jurassic](#) intruded and covered these rocks in what may have been magmatic activity associated with the early stages of the creation of the [Sierra Nevada Batholith](#). 95% of these rocks were eventually removed by uplifted-accelerated erosion. Most of the remaining rocks are exposed as 'roof pendants' in the eastern metamorphic zone. [Mount Dana](#) and [Mount Gibbs](#) are made of these metavolcanic rocks. Only 5% of the rocks exposed in Yosemite National Park are metamorphic. (*Geology of U.S. Parklands*, page 218)

Pluton emplacement

Further information: [Sierran Arc](#)

The first phase of regional [plutonism](#) started 210 million years ago in the late Triassic and continued throughout the Jurassic to about 150 million years BP. Also starting 150 million years ago was an increase in the westward drift rate of the [North American Plate](#). The resulting [orogeny](#) (mountain-building event) is called the [Nevadan orogeny](#) by geologists. The resulting Nevadan mountain range (also called the Ancestral Sierra Nevada) was 15,000 feet (4500 m) high and was made of sections of seafloor and [mélange](#).

These rocks were later metamorphosed and today can be seen in the [gold](#)-bearing metamorphic belt of [California's Mother Lode](#) country. In the area of the park these rocks are exposed along the [Merced River](#) and [State Route 140](#). This was directly part of the creation of the Sierra Nevada Batholith, and the resulting rocks were mostly granitic in composition and emplaced about 6 miles (10 km) below the surface.

The second, major pluton emplacement phase lasted from about 120 million to 80 million years ago during the [Cretaceous](#). This was part of the [Sevier orogeny](#). All told there have been more than 50

plutons found in the park. A few miles (several km) of material was eroded away, leaving the Nevadan mountains as a long series of hills a few hundred feet (tens of meters) high by 25 million years ago.

Cenozoic activity

Volcanism

Starting 20 million years ago and lasting until 5 million years ago a now-extinct extension of [Cascade Range](#) volcanoes erupted, bringing large amounts of igneous material in the area. These igneous deposits blanketed the region north of the Yosemite area. Some [lava](#) associated with this activity poured into the Grand Canyon of the Tuolumne and formed Little Devils Postpile (a smaller but much older version of the [columnar basalt](#) palisades in nearby [Devils Postpile National Monument](#)).

In the late [Cenozoic](#), extensive volcanism occurred east of the park area. Within the Yosemite region, [andesitic](#) lava flows and [lahars](#) flowed north of the [Grand Canyon of the Tuolumne](#) and volcanic [dikes](#) and plugs developed from [faults](#) on the flanks of Mount Dana. There is also evidence for a great deal of [rhyolitic](#) ash covering the northern part of the Yosemite region 30 million years ago. This and later ash deposits have been almost completely eroded away (especially during the ice ages).

Volcanic activity persisted past 5 million years BP east of the current park borders in the [Mono Lake](#) and [Long Valley](#) areas. The most significant activity was the creation of the [Long Valley Caldera](#) about 700,000 years ago in which about 600 times as much material was erupted than in the [1980 eruption of Mt. Saint Helens](#). The most recent activity was the eruption of the [Mono-Inyo Craters](#) from 40,000 to 600 years ago.

Uplift and erosion

10 million years ago, vertical movement along the Sierra fault started to uplift the Sierra Nevada.^[1] Subsequent tilting of the Sierra block and the resulting accelerated uplift of the Sierra Nevada increased the [gradient](#) of western-flowing streams. The streams consequently ran faster and thus cut their valleys more quickly. Tributary streams ran more-or-less in line with the Sierras, therefore not having their gradients increased. Thus their rate of valley cutting was not significantly affected. The results were [hanging valleys](#) and cascading [waterfalls](#) where the tributaries met the main streams. Additional uplift occurred when major faults developed to the east, especially the creation of [Owens Valley](#) from [Basin and Range](#)-associated extensional forces. Uplift of the Sierra accelerated again about two million years ago during the [Pleistocene](#). However, Yosemite valley was not created by streams or fault lines (to create a [graben valley](#)), such was suggested by geologist Josiah Whitney. [Glaciers](#) shaped the Yosemite Valley, and can easily be confused with a graben valley. (Example of a graben valley is [Death Valley](#) in California)

The uplifting and increased erosion exposed granitic rocks in the area to surface pressures, resulting in exfoliation (responsible for the rounded shape of the many [granite domes](#) in the park) and mass wasting following the numerous fracture joint planes (cracks; especially vertical ones) in the now solidified plutons. Pleistocene glaciers further accelerated this process and the larger ones transported the resulting [talus](#) and [till](#) from valley floors.

Numerous vertical joint planes controlled where and how fast erosion took place. Most of these long, linear and very deep cracks trend northeast or northwest and form parallel, often regularly spaced sets. They were created by uplift-associated pressure release and by the unloading of overlying rock via erosion. The great majority of Yosemite Valley's widening, for example, was due to joint-controlled rockfall. In fact, only 10% of its widening and 12% of its excavation are thought to be the result of glaciation (*Yosemite: A Visitors Companion*, pgs 75-76). Large, relatively unjointed volumes of granite form domes such as Half Dome and [monoliths](#) like the 3604 feet (1098 m) high [El Capitan](#). Closely spaced joints lead to the creation of columns, pillars, and pinnacles such as Washington Column, Cathedral Spires, and Split Pinnacle.

Glaciations



The valley from an airplane

Starting about 2 to 3 million years ago a series of glaciations further modified the area by accelerating [mass wasting](#) through [ice-wedging](#), [glacial plucking](#), [scouring/abrasion](#) and the release of pressure after the retreat of each glaciation. Severe glaciations formed very large glaciers that tended to strip and transport [top soil](#) and [talus](#) piles far down glacial valleys, while less-severe glaciations deposited a great deal of [glacial till](#) further up in the valleys.

At least 4 major glaciations have occurred in the Sierra Nevada; locally called the Sherwin (also called the pre-Tahoe), Tahoe, Tenaya, and Tioga. The Sherwin glaciers were the largest, filling Yosemite and other valleys, while later stages produced much smaller glaciers. The Sherwin may have lasted almost 300 thousand 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 and other canyons in the area. The Tahoe, Tenaya, and Tioga stages were part of the [Wisconsinan glaciation](#). The Tahoe glacial stage is thought to have reached its maximum extent around 70,000 to 130,000 years ago; little is known about the more recent Tenaya. Evidence also suggests that the most recent local glacial stage, the Tioga, started about 28,000 cal (calibrated [Radiocarbon dating#Measurements and scales](#)) years ago, reached its maximum extent 20,000 to 25,000 cal yr ago, and ended by ~15,000 cal yr ago. Glaciers reformed in the highest cirques during a minor late-glacial readvance, the Recess Peak event, between about 14,200 and 13,100 yr ago.

After that, glaciers appear to have been absent from the range until about 3200 cal yr ago, when small glaciers reappeared in the highest cirques. This readvance records the onset of Neoglaciation in the Sierra Nevada. Neoglaciation in the range culminated during the "[Little Ice Age](#)," a term originally coined by [François E. Matthes](#) in the Sierra Nevada, but now widely accepted as referring to a period of global glacial expansion between about AD 1250 to 1900. Moraines in the Sierra Nevada related to the Little Ice Age event are termed Matthes deposits. They are common in north-facing cirques and below modern glaciers in the High Sierra and are typically fresh, unstable, and often ice-cored. Good examples of Matthes moraines can be found below the Palisade Glacier (the largest glacier in the range), Lyell and Maclure glaciers in southern Yosemite N.P., and the smaller glaciers below [Mount Dana](#), [Kuna Peak](#), Mount Conness, and [Matterhorn Peak](#).



[Play media](#)

Animation: Retreating glaciers feed Lake Yosemite and open today's valley

Glacial systems reached depths of up to 4000 feet (1200 m) and left their marks in the Yosemite area.

The longest glacier in the Yosemite area ran down the Grand Canyon of the [Tuolumne River](#) for 60 miles

(95 km), passing well beyond [Hetch Hetchy Valley](#). Merced Glacier flowed out of Yosemite Valley and into the [Merced River Gorge](#). Lee Vining Glacier carved Lee Vining Canyon and emptied into [Lake Russell](#) (the much enlarged ice age version of [Mono Lake](#)). Only the highest peaks, such as [Mount Dana](#) and [Mount Conness](#), were not covered by glaciers. Retreating glaciers often left recessional [moraines](#) that impounded lakes such as Lake Yosemite (a shallow lake that periodically covered much of the floor of Yosemite Valley).

Some domes in the park were covered by glaciers and modified into [roche moutonnées](#), which are characterized by having a smooth, rounded side and a steep face. The rounded side was where the glacier flowed over the dome and the steep side is where the glacier flowed away from it. The steepness is caused by glacial plucking of rock along fracture joints. Good examples in the park are [Liberty Cap](#), [Lembert Dome](#), and [Mount Broderick](#). [Half Dome](#) was created by a different process, but erosion acting on jointing planes was still the major factor.

Controversy

The origin of the geological landscapes of the park have been under debate since 1865. At that time, [Josiah Whitney](#), then chief geologist of [California](#), proposed that [Yosemite Valley](#) is a [graben](#): a downdropped block of land surrounded by faults. [John Muir](#) proposed that Yosemite Valley and [Hetch Hetchy Valley](#) were formed purely by glacial action. In 1930, [François E. Matthes](#) proposed a hybrid hypothesis, where most of the depth of the valley was gouged by water erosion, the rest by glacial action. The glacial action also claimed to have widened the valley.

More recently, the debate has been reopened by [Jeffrey Schaffer](#), who suggests that the role of glaciers and other erosion processes has been dramatically overstated. Schaffer states that Yosemite Valley above 5600 feet (1700 m), for example, has changed relatively little in the past 30 million years. Other than being slightly larger, if one could look back in time and see them, the major features would be recognizable to the modern eye. Schaffer believes that the numerous joint planes have had the greatest impact on the [geomorphology](#) of the Park's major features. This is in contradiction to the consensus view that huge highly abrasive glaciers acting on joint planes combined with a great deal of uplift over just the past couple million years was the primary shaping force of the features (such rapid uplift would have greatly accelerated all types of erosion).

From https://en.wikipedia.org/wiki/Geology_of_the_Yosemite_area

A [timeline](#) of significant geological events in the evolution of western [North America](#). Dates are approximate. ("Ma" = millions of years ago)

Date	Period/Epoch	Event
350 Ma	Devonian	An unnamed terrane collides and accretes to the North American Plate , along a line roughly coinciding with the Nevada–Utah border and called the Carlin Unconformity .
250 Ma	Permian	The Sonomia Terrane collides and accretes to the North American Plate, along a line called the Golconda Thrust (also the name of the event) which runs through central Nevada.
200 Ma	Triassic	Sierra Nevada batholith first develops.
180 Ma	Jurassic	The Intermontane Plate collides with the Pacific Northwest, the remnants of which form the Intermontane Belt today.
165 Ma	Jurassic	The Smartville Block , an island arc terrane, collides and accretes to the North American Plate, along a line which coincides with the Mother Lode country of California.
140 Ma	Jurassic	Second wave of plutons added to Sierra batholith.
115 Ma	Cretaceous	The Insular Plate collides with the Pacific Northwest. The remnants of that

		terrane comprise the Insular Belt today, of which Vancouver Island is a part.
90 Ma	Cretaceous	Third and last wave of plutons added to Sierra batholith.
43 Ma	Eocene	The Pacific Plate changes its direction of motion from north to northwest.
35 Ma	Eocene	Rio Grande Rift begins to form.
20 Ma	Miocene	San Andreas Fault comes into being as the North American Plate begins splitting the Farallon Plate in two.
17 Ma - 14 Ma	Miocene	Columbia River Basalt Group Forms.
8 Ma	Miocene	Onset of faulting creating the Basin and Range geologic province.
5 Ma	Miocene - Pliocene	Northward propagation of the East Pacific Rise into the North American Plate initiates rifting off of the Baja California peninsula .
4 Ma	Pliocene	Sierra Nevada begins to rise.
3.5 Ma	Pliocene	The Pacific Plate changes its direction of motion about 11 degrees east of its previous heading, from northwest to the present northwest by north.

From <https://en.wikipedia.org/wiki/Geologic_timeline_of_Western_North_America>