

Plate Tectonics and Volcanism in Western California

Western California is home to a variety of volcanic rocks. The locations, ages, and chemical compositions of these volcanic rocks help tell part of the fascinating story of California's plate tectonic evolution over the past 40 million years. These volcanic rocks are a product of multiple tectonic processes, including subduction of divergent and transform plate boundaries beneath continental North America, opening of a slab window, creation and migration of a tectonic triple junction, and the birth and growth of the San Andreas Fault. This fact sheet explains these tectonic processes and discusses their role in shaping the volcanic history of western California over the past 40 million years.

By studying the volcanic rock record in western California, geologists are able to piece together how regional volcanism and plate tectonics are linked in space and time. Recognizing this linkage helps scientists to understand possible future volcanism in the region, potential hazards associated with this volcanism, and the impacts these hazards may have on population and infrastructure. The U.S. Geological Survey California Volcano Observatory (CalVO) closely monitors the parts of western California with the greatest potential for volcanism.

Western California Volcanic Fields and Volcanic Rocks

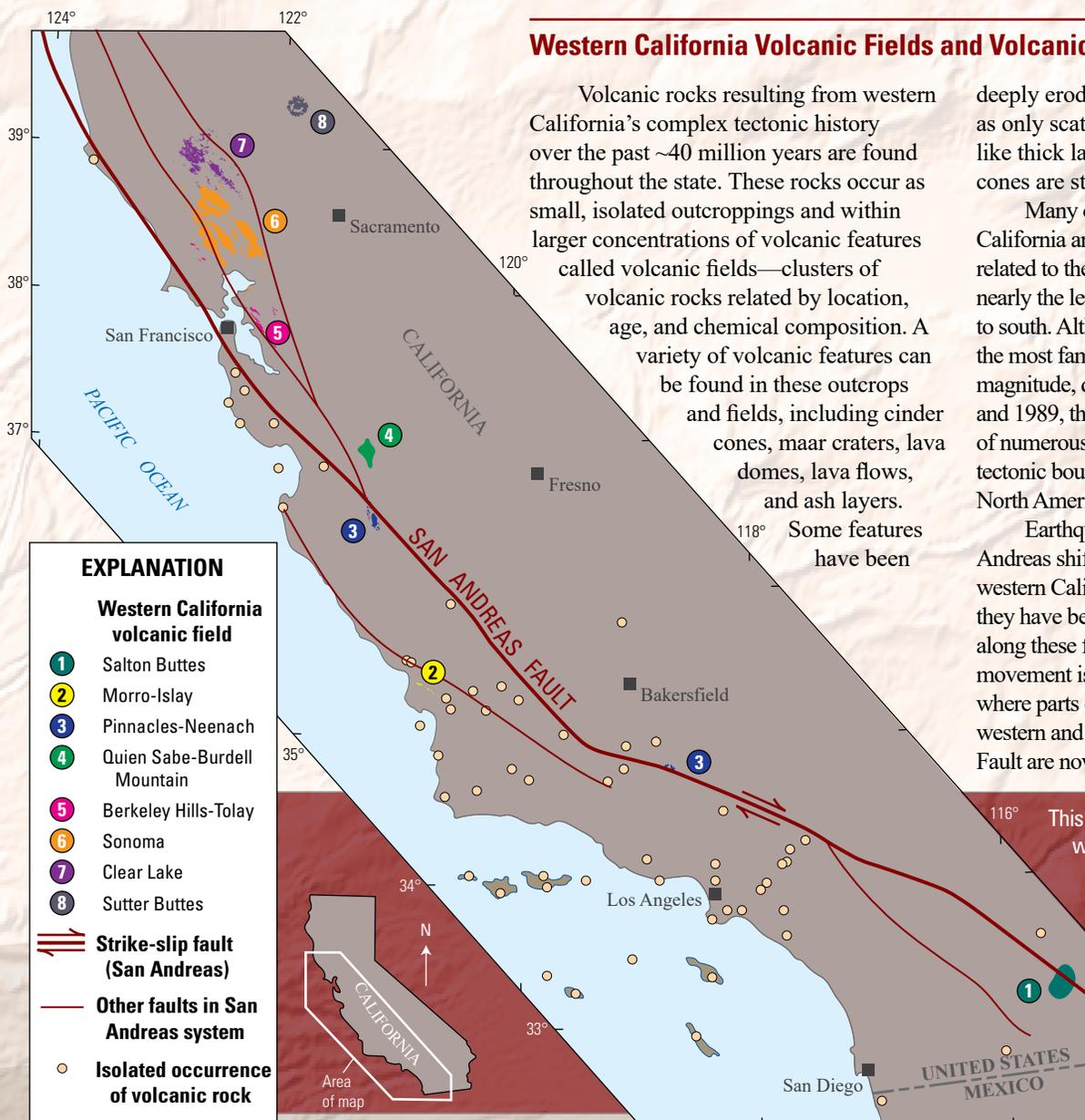
Volcanic rocks resulting from western California's complex tectonic history over the past ~40 million years are found throughout the state. These rocks occur as small, isolated outcroppings and within larger concentrations of volcanic features called volcanic fields—clusters of volcanic rocks related by location, age, and chemical composition. A variety of volcanic features can be found in these outcrops and fields, including cinder cones, maar craters, lava domes, lava flows, and ash layers. Some features have been

deeply eroded since eruption, present today as only scattered remnants. Other features like thick lava flows and steep-sided cinder cones are still remarkably fresh.

Many of the volcanic rocks in western California are geographically and geologically related to the San Andreas Fault, which runs nearly the length of California from north to south. Although the San Andreas Fault is the most famous California fault due to large magnitude, damaging earthquakes in 1906 and 1989, the San Andreas Fault is only one of numerous faults that together define the tectonic boundary between the Pacific and North American tectonic plates.

Earthquakes along faults like the San Andreas shift the Earth's crust. Since some of western California's volcanic fields erupted, they have been ripped apart by movement along these faults. An example of this movement is the Pinnacles-Neenach field (3), where parts of the same volcanic field on the western and eastern side of the San Andreas Fault are now ~300 kilometers apart.

This map highlights the locations of western California volcanic outcrops and volcanic fields, the San Andreas Fault, and other major faults in the state. Each volcanic field is numbered and is a different color. More information about each volcanic field, keyed by color and number, can be found on the back page.



EXPLANATION

Western California volcanic field

- ① Salton Buttes
- ② Morro-Islay
- ③ Pinnacles-Neenach
- ④ Quien Sabe-Burdell Mountain
- ⑤ Berkeley Hills-Tolay
- ⑥ Sonoma
- ⑦ Clear Lake
- ⑧ Sutter Buttes

⇄ Strike-slip fault (San Andreas)

— Other faults in San Andreas system

○ Isolated occurrence of volcanic rock

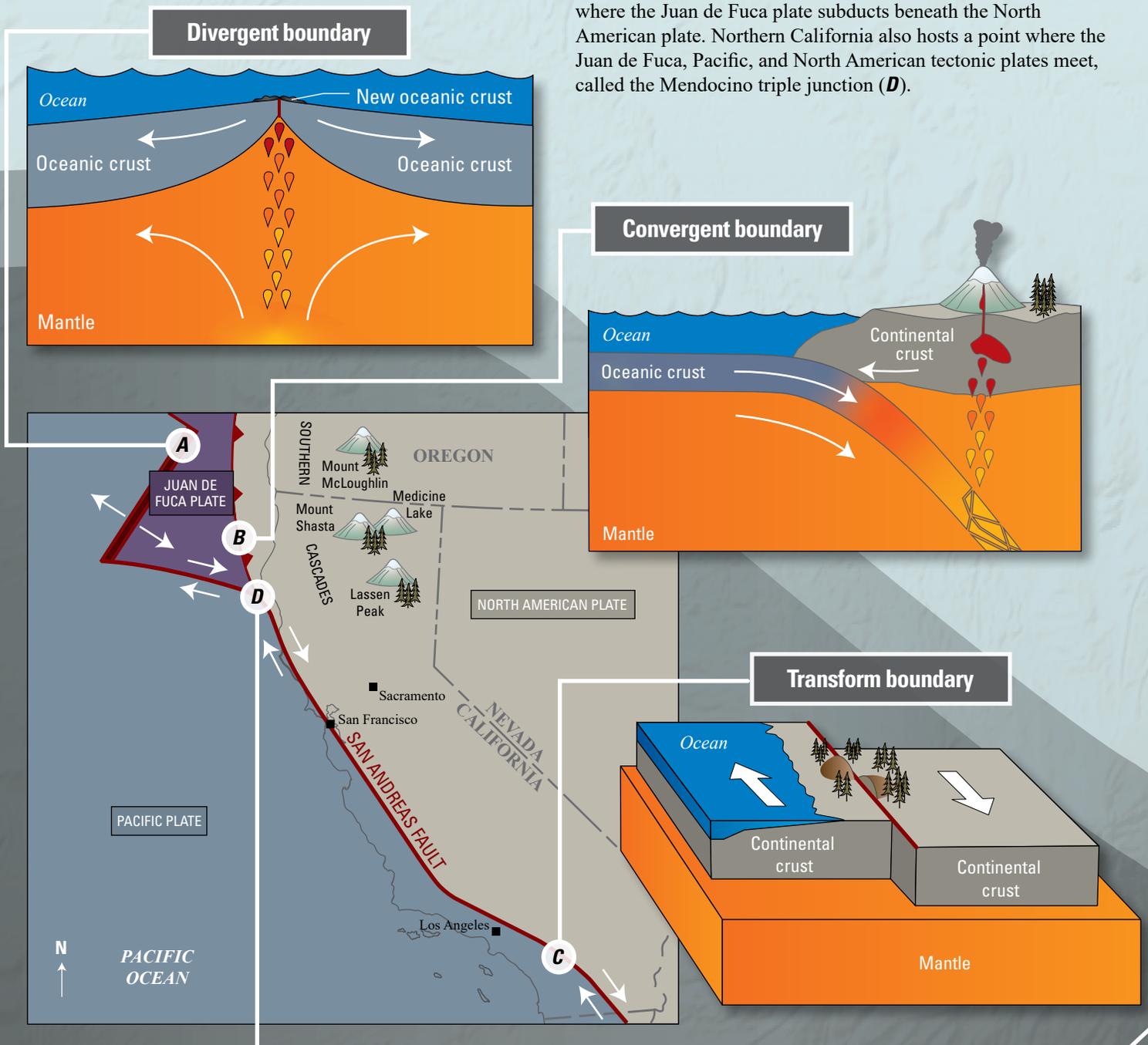
California Plate Tectonics

Earth's crust consists of discrete tectonic plates, which are divided into two types: oceanic crust, which is generally thinner, denser, younger, and rich in elements like iron and magnesium, and continental crust, which is generally thicker, older, less dense, and rich in elements like silicon and potassium. Tectonic plates ride atop the underlying mantle and interact with one another, meeting at various types of plate boundaries where they can move toward, away, and past one another. Each type of boundary produces a characteristic set of geologic features.

A divergent boundary (**A**) is formed when tectonic plates are pulled apart from one another, forming new crust as hot mantle rises and melts due to decreased pressure. This magma fills the space made by the diverging plates. A convergent boundary (**B**) is formed when oceanic and (or) continental plates converge toward

one another, for example at subduction zones, where the denser oceanic plate subducts beneath a continental plate. Subduction of the denser plate adds volatiles, like water, to the mantle, leading to melting in the overriding plate and the formation of volcanoes like those seen in Northern California, the Cascades, and Aleutians. A transform boundary (**C**) is formed when tectonic plates move laterally past one another, which can occur between any combination of oceanic and continental crust. Examples of each boundary type are shown below.

California is currently home to all three types of plate boundaries. A divergent boundary is found offshore of northern California to the northwest, separating the Pacific and Juan de Fuca plates. A transform boundary separates the Pacific and North American plates and includes the famous San Andreas Fault, which spans much of the length of California. A convergent boundary exists just offshore of northern California where the Juan de Fuca plate subducts beneath the North American plate. Northern California also hosts a point where the Juan de Fuca, Pacific, and North American tectonic plates meet, called the Mendocino triple junction (**D**).



40 Million Years of Movement

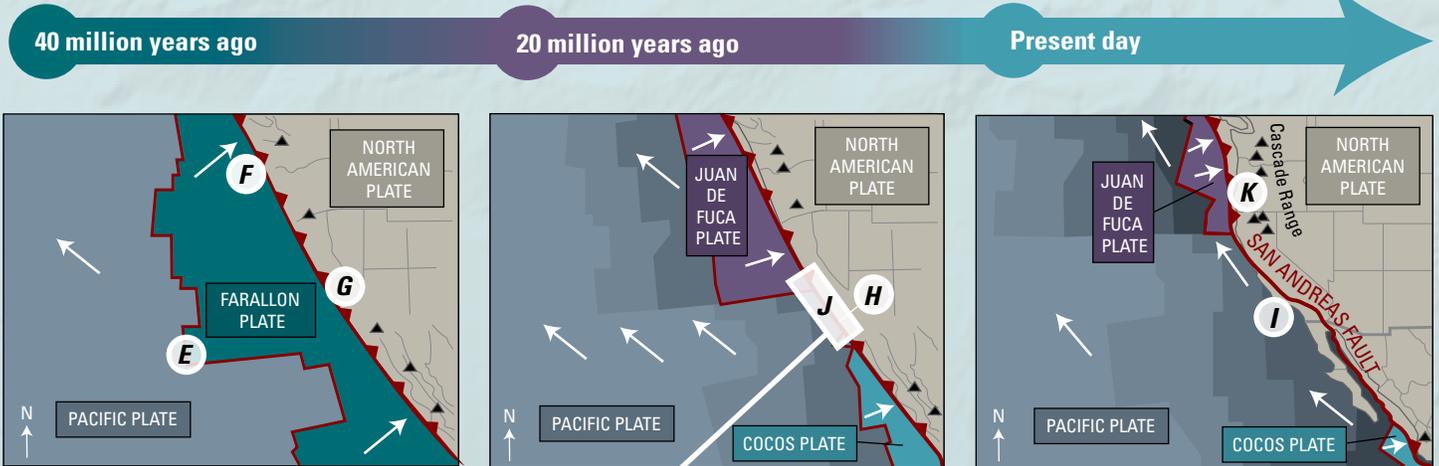
The tectonic geometry of California has evolved continually over the past 40 million years. Roughly 40 million years ago, the divergent boundary separating the Pacific and Farallon tectonic plates was located offshore of the edge of western North America (**E**). Over time, convergent plate motion caused the Farallon plate to subduct (**F**) beneath the North American plate at a long subduction zone (**G**). During and because of Farallon plate subduction, large volcanoes, similar to the modern Cascades (like Mount Shasta and Mount Rainier), but much older, were erupting inland of the subduction zone.

By ~28 million years ago, a segment of the divergent boundary separating the Farallon and Pacific plates had collided with North America and began to subduct beneath the North American plate and consume the Farallon plate (**H**). By 20 million years ago, much of the Farallon plate had been consumed by subduction, leaving the Juan de Fuca and Cocos plates as its modern remnants.

During this time, subduction of the Farallon plate brought the Pacific plate in oblique contact with North America, creating a transform boundary and forming the beginnings of what we know

today as the San Andreas Fault (**H**, **I**). The Mendocino triple junction (**D**), where the Pacific, Juan de Fuca, and North American plates meet, was also created by this oblique subduction. At this triple junction, a “slab window” is opened under the North American plate, which allows heat to move upward and can result in volcanism at the surface (see 3D diagram, **J**). The transform boundary between the Pacific and North American plates causes the triple junction and related slab window to migrate northwest over time.

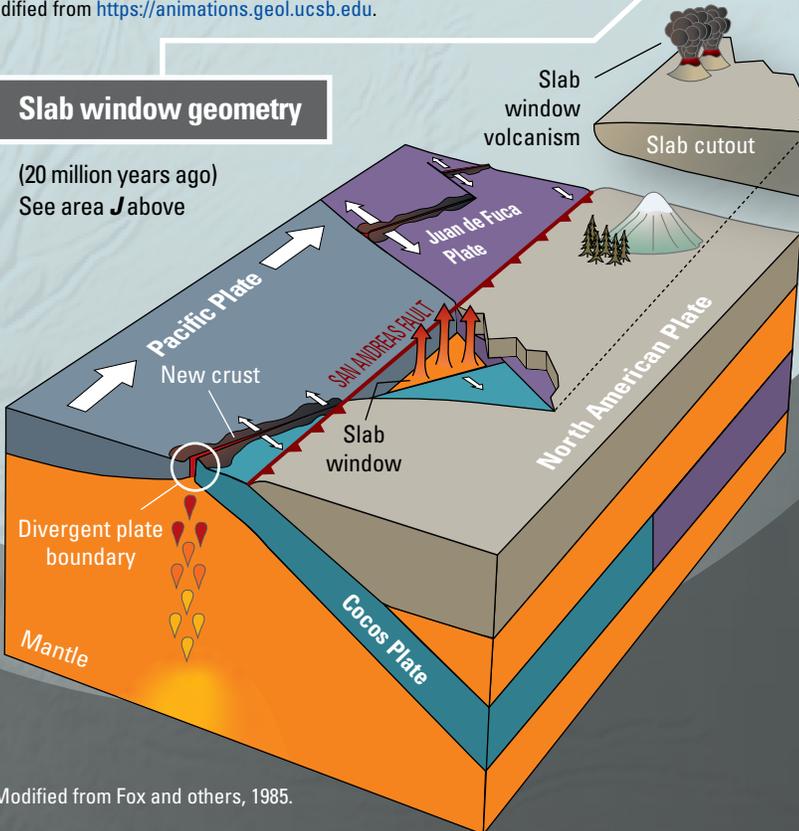
Over the past 20 million years, the Mendocino triple junction has migrated to the northwest, the San Andreas Fault has grown to span nearly the entire length of California, and the Juan de Fuca and Cocos plates have moved north and south, respectively. Subduction of the Juan de Fuca plate (**K**) forms the modern Cascade volcanoes, from Mount Shasta, Medicine Lake, and Lassen Peak in California to the numerous volcanoes in Oregon and Washington. The North American plate is fixed on all panels, and the white arrows show plate movements relative to North America.



Modified from <https://animations.geol.ucsb.edu>.

Slab window geometry

(20 million years ago)
See area **J** above



Modified from Fox and others, 1985.

A Slab Window in Three-Dimensions

This block diagram shows an approximation of the tectonic plate geometry of California as it existed roughly **20 million years ago**. A piece of the North American plate has been cut out to show spreading ridge subduction and the opening of a slab window. As the spreading ridge separating the oceanic crust of the Cocos plate and continental crust of the Pacific plate is subducted, the leading edge falls away, leaving a gap, or window in the subducting oceanic crust beneath North America. Hot mantle material upwells to fill this gap and can partially melt as it rises. This hot mantle material can also melt the edges of the downgoing slab or base of the overlying continental crust. If this magma erupts, its chemistry and location near the transform boundary separating the North American and Pacific plates tells geologists that it wasn't created in a typical subduction zone, but instead is the product of a slab window. The volcanic rocks and fields in western California result from a combination of spreading ridge subduction and melting above a slab window.

A Closer look at Western California's Volcanic Fields

Volcanism resulting from subduction of divergent and transform plate boundaries can be found throughout western California. These volcanic rocks record a wide variety of chemical compositions, ages, eruption styles, and volumes. Some are erupted as small, isolated flows or large lava domes; some are the roots of volcanic systems exposed by erosion; some are the remnants of eruptions that sent volcanic ash across California; some flowed over the ground like Hawaiian lavas; and some are part of volcanic fields. Eight discrete volcanic fields can be found from near the California–Mexico border

to ~90 kilometers north of Sacramento (see map on page 1). The fields are oldest near the center of the state and youngest toward the ends of the San Andreas Fault. The youngest volcanic rocks in western California are found in the Clear Lake and Salton Buttes volcanic fields—with activity in the past 10 thousand years at both locations, these are the most likely locations for future volcanism. By understanding the timing, location, composition, and style of past eruptions, geologists can better understand the potential for future volcanism in western California. A list of the eight volcanic fields within western California is found below.

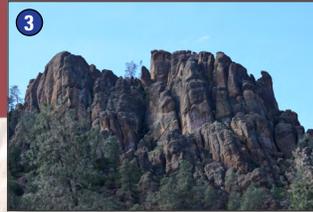
The **Salton Buttes** volcanic field is the youngest and southernmost of the fields associated with the North American and Pacific plate boundary. Five rhyolitic obsidian domes are exposed at the southern end of the San Andreas Fault, where transform motion becomes divergent. All eruptions occurred within the last few thousand years.



The **Morro–Islay** chain is not a typical western California volcanic field as it primarily contains the exposed, unerupted roots of a volcanic field which has eroded away. This chain of rocks is ~27 million years old and primarily composed of dacite, a rock rich in minerals like feldspar and quartz.



The **Pinnacles–Neenach** volcanic field erupted ~23 million years ago. Since eruption, this field has been offset by movement on the San Andreas Fault. The Pinnacles on the west side of the fault has been displaced ~300 kilometers north of the Neenach, on the east side.



The **Quien Sabe–Burdell Mountain** volcanic field contains both erupted volcanic rocks and related igneous rocks exposed by erosion. This field is ~11 million years old and consists of lava flows, volcanic breccias, and plugs—the remnants of magma that crystallized within the plumbing system of a volcano.



The **Berkeley Hills–Tolay** volcanic field is ~10 million years old. Because of movement on faults related to the San Andreas Fault, this volcanic field is found both north and east of San Francisco, California. This field is predominantly composed of andesite, a rock rich in minerals like feldspar and pyroxene.



The **Sonoma** volcanic field was the most explosive of the western California fields. Silicic volcanic ash from multiple Sonoma volcanic field eruptions can be found in sediments along the coast of California and within the California Central Valley. The Sonoma volcanic field erupted between about 8 and 3 million years ago.



The **Clear Lake** volcanic field contains some of the youngest volcanism in western California and has been intermittently active for nearly 3 million years. The youngest known eruptions occurred ~10 thousand years ago when lava erupted through the waters of Clear Lake.



The **Sutter Buttes** volcanic field is further inland, relative to the San Andreas Fault, than any other western California volcanic field. The Sutter Buttes volcanic field is composed primarily of ~1.5 million year old andesite and rhyolite domes.

For more information see or contact:

USGS Volcano Hazards Program: www.usgs.gov/programs/VHP;
 USGS California Volcano Observatory: www.usgs.gov/observatories/calvo;
 USGS Coast Range Volcanic Field project: <https://geography.wr.usgs.gov/science/volcano/ClearLakeVolcanics-web-tool.html>.
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