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Young Explosive Eruptions from the Clear Lake Volcanic Field

Millions of years ago, the San Andreas Fault began to form as three tectonic plates converged at a triple junction in southern California. At this site, now called the Mendocino triple junction, heat from the mantle was easily transferred to the crust, forming magma. Volcanic fields (clusters of volcanoes and volcanic rocks) erupted as the triple junction migrated northward along the California coast. Eight fields are found near the California-Mexico border to north of the San Francisco Bay area. The youngest volcanic rocks in western California are found in the Clear Lake volcanic field, to the north, and another field near the Salton Sea to the south.

Regional tectonic map showing plate movement around the San Andreas Fault in the area surrounding Clear Lake volcanic field in California.

The Clear Lake volcanic field contains at least 11 maars, or volcanic craters created by the interaction of water and magma, in and around Clear Lake. This photograph taken from Mount Konocti shows maar craters on and around peninsula below Buckingham Peak. Photograph by J. Ball, U.S. Geological Survey.

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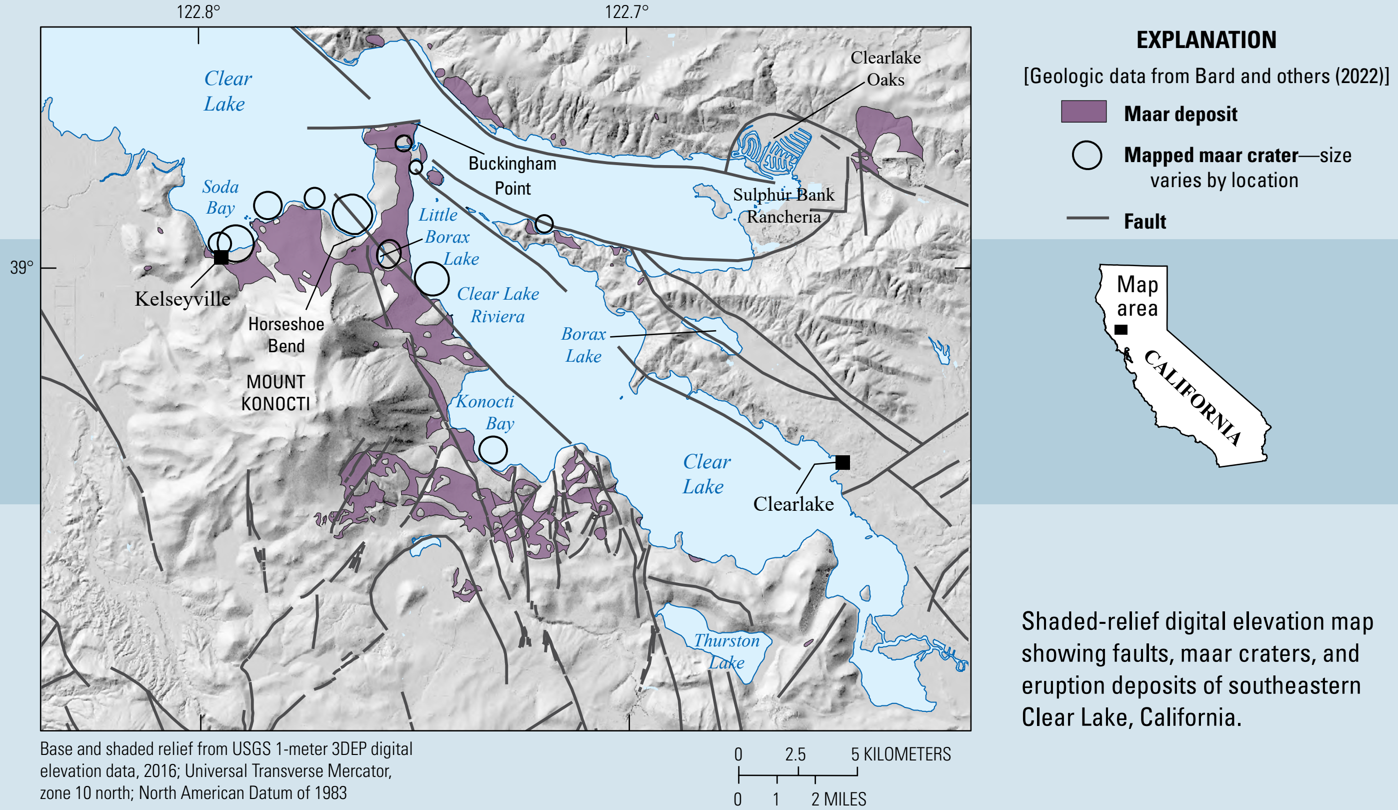
For 2 million years, numerous eruptions have happened around (and through) Clear Lake. The most recent period of activity in the Clear Lake volcanic field probably started around 40,000 years ago and was mainly explosive eruptions concentrated on and near faults in and around the lake. The combination of hot magma and groundwater created explosive releases of hot steam. These excavated craters, called maars, and threw out volcanic ash, pumice, and lava fragments, which fell back to the ground and draped the surrounding landscape. The deposits are visible in many places around the southeast end of the lake (particularly in roadcuts, see photograph on far right page) as repetitive layers of ash and popcorn-sized pumice and rocks. In some places, eruptions were energetic enough to throw football-sized lava bombs well beyond the craters—as far as 2.5 miles (4 kilometers)!

Because these small but highly explosive eruptions probably happened between 40,000 and 8,000 years before present, they may have overlapped with ancient human occupation in the area. Archaeological evidence and indigenous oral histories show that human beings may have observed some of the eruptions in progress!

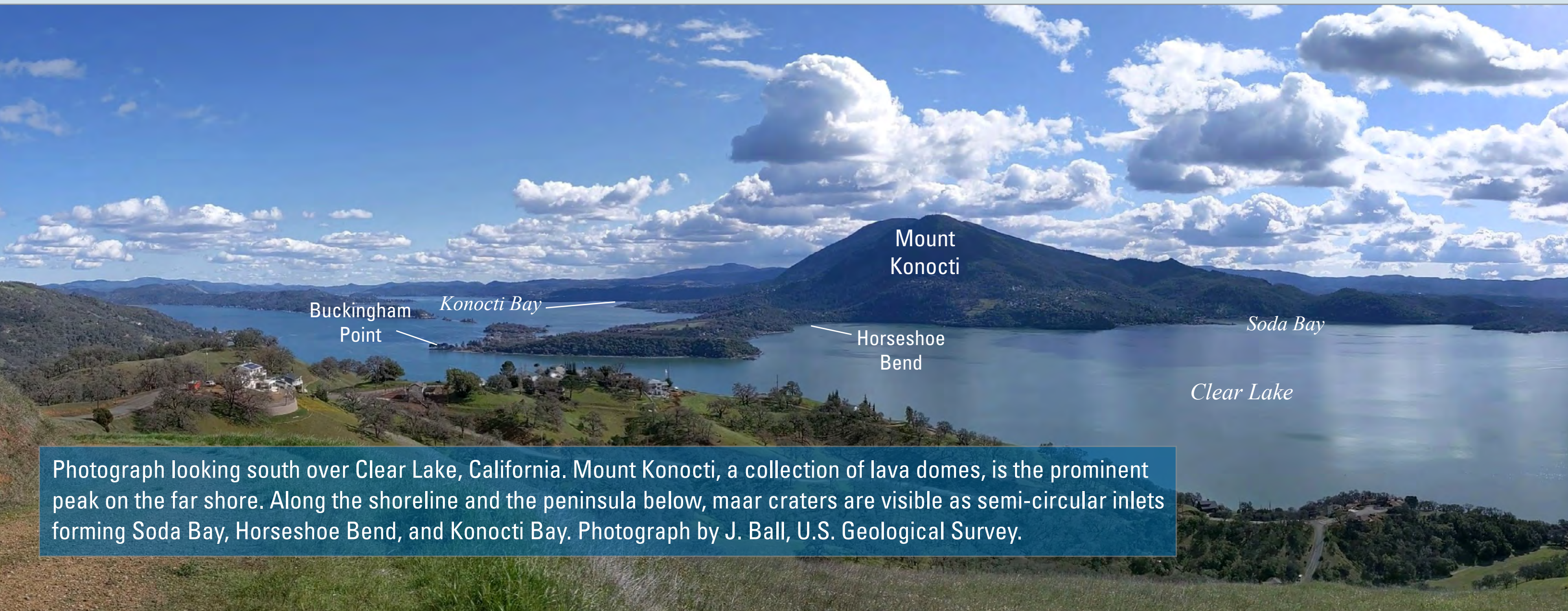
Where are Clear Lake's Maars?

At least 11 maar craters have been mapped at Clear Lake, mostly located at or very near the lakeshore. Many of these craters are responsible for the lake's scalloped shorelines, and several even host their own bodies of water. At least seven of these craters formed on or near faults, which suggests that the faults provided a pathway for magma to rise to the surface.

The location of maar deposits, shown in purple, and the shape of the lake's shorelines suggest that even more craters may be hidden beneath the water in places like Konocti Bay, Clearlake Oaks, and along the northern shore of Clear Lake.



Shaded-relief digital elevation map showing faults, maar craters, and eruption deposits of southeastern Clear Lake, California.



Photograph looking south over Clear Lake, California. Mount Konocti, a collection of lava domes, is the prominent peak on the far shore. Along the shoreline and the peninsula below, maar craters are visible as semi-circular inlets forming Soda Bay, Horseshoe Bend, and Konocti Bay. Photograph by J. Ball, U.S. Geological Survey.

What is a Maar Eruption?

Maar eruptions occur when rising magma meets groundwater. Heat from the magma heats the confined water above its boiling point, and if the pressure in the rock holding the groundwater is suddenly relieved or the water breaks its confinement, it will flash into steam. The steam expands explosively, fragmenting magma and excavating a circular crater at or below the ground surface. The word maar comes from a 19th-century German dialect and was originally used to describe circular lakes.

This phreatomagmatic (interacting magma and water) activity happens where groundwater is abundant. Lava, pumice, and ash create tuff rings or tuff cones around the edges of maar craters as erupted material falls back to the ground around the vent. Maar eruptions are also known for producing angled jets of material that look like rooster tails, together with lava bombs and pyroclastic density currents, which are violently turbulent ground-hugging clouds of volcanic ash, gas, and lava fragments.

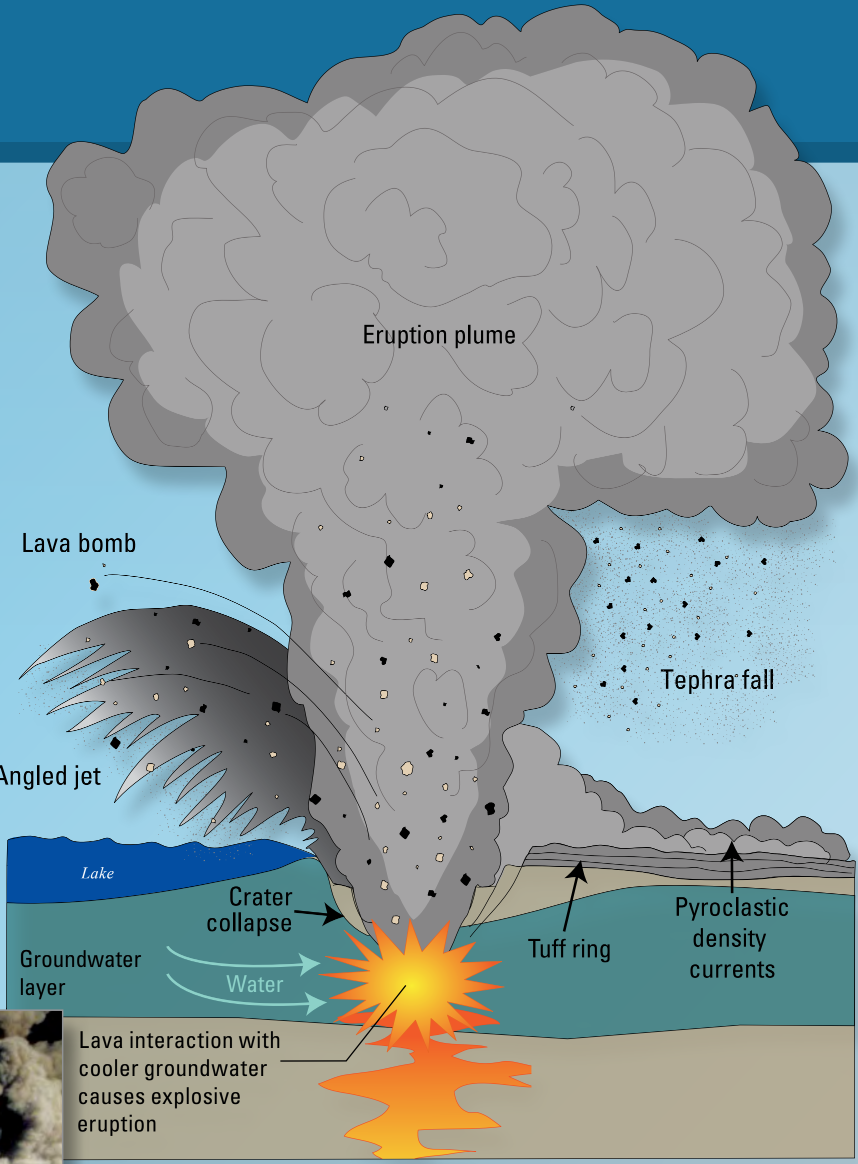


Diagram of a maar eruption, labeled with different types of volcanic processes, features, and hazards. The material involved in maar eruptions is a combination of fresh magma and surrounding rocks disrupted by explosions.

While maar eruptions are violent, they are usually not large. The tallest plumes in the April 1977 eruptions of Ukinrek Maars in Alaska rose only 3.7 miles (6 kilometers) above sea level, and pyroclastic density currents and bombs reached <2 miles (~3 kilometers) from the vent. For comparison, the first eruption cloud of Mount St. Helens in May 1980 rose more than 13.7 miles (22 kilometers) into the air, and pyroclastic density currents reached at least 5.6 miles (9 kilometers) from the vent.

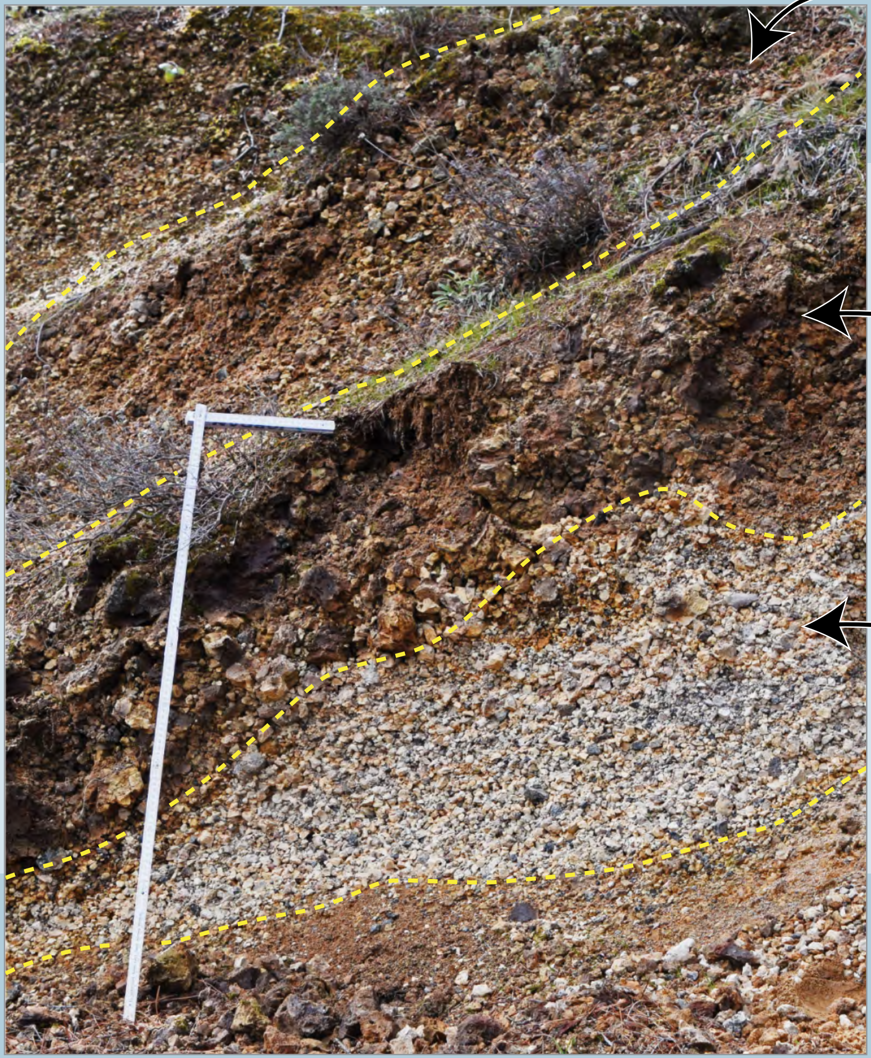
Phreatomagmatic eruption cloud rising from the east Ukinrek Maars crater, Alaska, April 6, 1977. Photograph by R. Russell, U.S. Geological Survey.

Interpreting Maar Stratigraphy—Size, Sorting, and Structures

The characteristics of maar deposits help us interpret the volcanic processes that produced them. Clast type, size, sorting, and any internal structures of the overall deposit are all clues to questions like: Was the eruption mainly driven by steam explosions or did it involve magma? Were clasts falling from the sky or tumbling along the ground? How much energy did the eruption release?

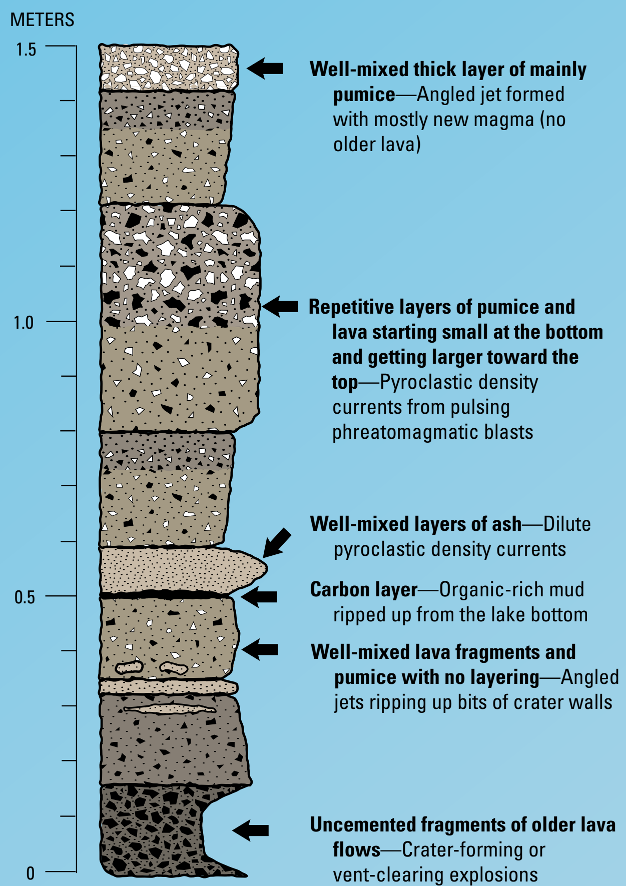
To the right is an example of layers (stratigraphy) in the walls one of the Konocti Bay maar craters. Geologists carefully note variations in size, composition, and the thickness and shape of the layering. They then combine these observations to make conclusions about the eruption.

A 30-foot (9-meter) thick outcrop of layered maar deposits on Kono Tayee Point, on the north side of Clear Lake. Photograph by J. Ball, U.S. Geological Survey.



Layers in a maar deposit contain varying amounts and sizes of ash, pumice, lava, and local rocks, depending on which processes created and deposited them. In this photo, the mostly pumice layer was from eruption(s) of mostly fresh magma, while the layers with local, or country, rocks were probably created during crater-excavating explosions. The measuring stick is 3.3 feet (1 meter) long. Photograph by J. Ball, U.S. Geological Survey.

How Do You Recognize a Maar Deposit?



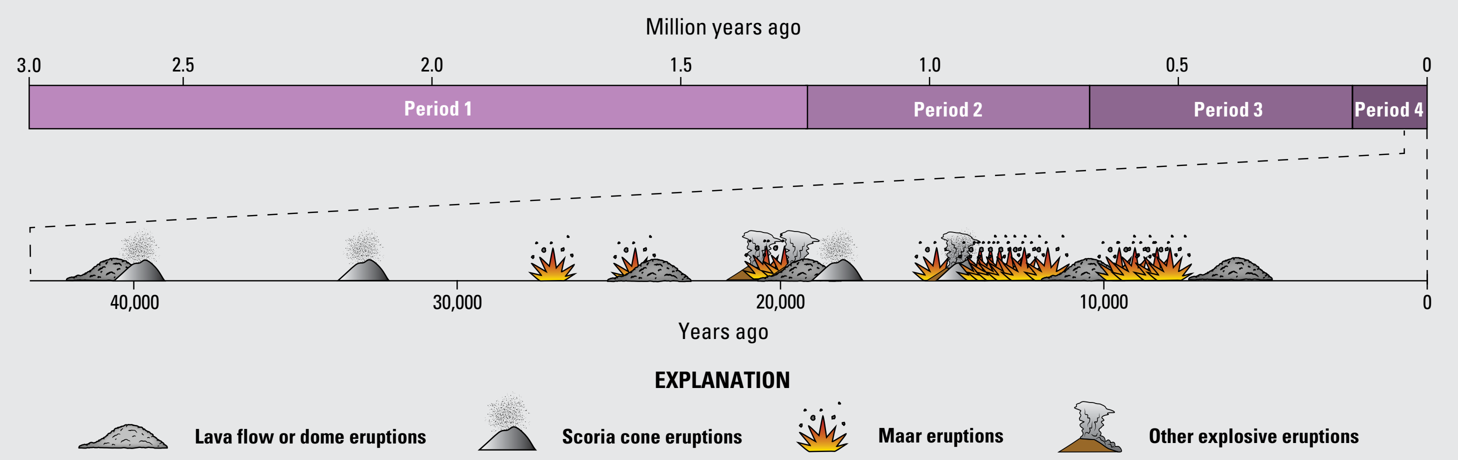
Maar deposits are made up of pebble- to boulder-sized pieces of lava, local (country) rocks, pumice, and volcanic ash which are deposited as layers that drape the ground where they land.

These materials are either thrown out as ballistics, fall from the plume to settle to the ground, or are transported by pyroclastic density currents. The layers pinch and swell depending on their location around a maar crater, showing where angled jets and pyroclastic flows have concentrated debris.

Section of a stratigraphic column from maar deposits bordering Konocti Bay, showing different clast (rock) sizes, types (white, pumice clasts; black, fresh and older lava clasts), and sorting, and the interpretation of what eruptive process produced them, such as angled plumes, vent-clearing explosions, plumes of ash and rock thrown high into the air, and other eruptive processes.

History of Eruptions in the Clear Lake Volcanic Field

Eruptions in the Clear Lake volcanic field fall into four general periods, with the youngest beginning about 40,000 years ago. Eruption styles throughout all of the periods varied from explosive to flowing (effusive), creating small mountains, long lava flows, and towering domes of lava. Radiocarbon dates (that is, dating the isotope carbon-14 [^{14}C]) collected from organic material in the maar deposits show that they occurred mainly in the last 20,000 years. While this seems old from a human point of view, the maars are really quite young compared to the rest of the volcanic field.



Timeline of eruptive periods and eruptions in the Clear Lake volcanic field (upper timeline), showing individual eruptions over the last ~45,000 years (lower timeline). On the lower timeline, radiometrically dated events are shown by their eruption type, with the four main kinds being maar (explosive), other explosive eruptions, scoria cones (minor explosive), and lava flow or dome eruptions (mostly flows, or effusive). The ages from these eruptions are approximate and based on the best data available at the time of publication.

What Could Happen During Future Eruptions in the Clear Lake Volcanic Field?

Radiocarbon dates that place maar eruptions within the last 10,000 years, and the presence of The Geysers geothermal field 15 miles (25 kilometers) to the southeast, means that there is still magma below the region and that the Clear Lake volcanic field is considered ‘active’ by the U.S. Geological Survey. Geophysical surveys suggest that magma is still present at around 3.1 miles (5 kilometers) below parts of the Clear Lake volcanic field, and future magmatic intrusions and eruptions in and around Clear Lake are possible. A maar eruption could prove hazardous to the population of the Clear Lake area if one were to happen again.

Work is ongoing to determine just how recent the youngest eruptions were and how violent they might have been. While most of the known Clear Lake volcanic field maar deposits are found immediately adjacent to Clear Lake itself, some pyroclastic density currents and tephra fall may have reached as far as 3.1 miles (5 kilometers) from their vents. Research at Ubehebe Craters (a maar volcano in Death Valley) has revealed that pyroclastic density currents may travel as much as 9.3 miles (15 kilometers) from their origins. Based on observed eruptions such as Ukinrek Maars in Alaska, eruption plume heights of 20,000 feet (6,000+ meters) could not only disrupt regional populations, infrastructure, and transportation but could also affect major airports (such as the airports in Oakland and San Francisco) in northern and central California.

However, these are only potential hazards. As of 2024, there were no clear signs of volcanic unrest in the seismic, gas, or deformation data collected by the California Volcano Observatory. The California Volcano Observatory closely monitors the Clear Lake area with a network of seismometers, satellite data, and frequent on-the-ground observations and sampling of gas vents and springs throughout the volcanic field. The Clear Lake volcanic field remains quiet for now, but ongoing work to understand the history and mechanisms of its eruptions will help scientists assess its potential for future volcanic unrest.

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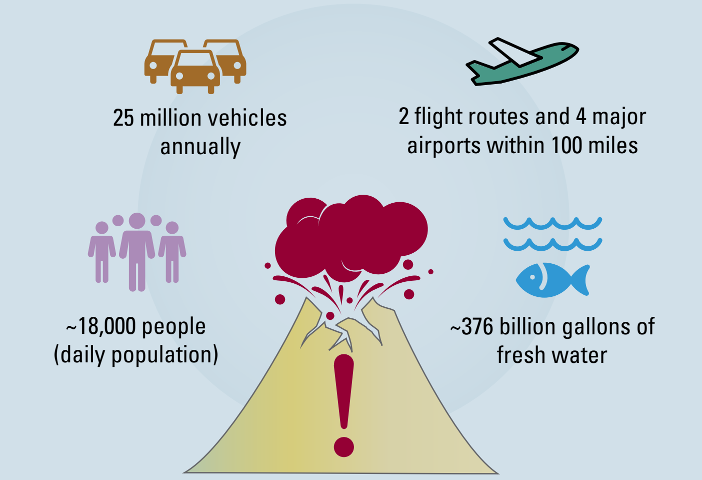
Hazard exposure in the event of an eruption in the Clear Lake Volcanic Field



Estimated people, transportation, and resources that could be affected by a maar eruption in the Clear Lake volcanic field, as of 2018 (Mangan and others, 2019).

See also:

Ball, J.L., 2022, Stratigraphy and eruption history of maars in the Clear Lake volcanic field, California: Frontiers in Earth Science, v. 10, 18 p., https://doi.org/10.3389/-feart.2022.911129.

Bard, J.A., Adhar, R., Robinson, J.E., Stewart, P.K., Ramsey, D.W., Hearn, B.C., Donnelly-Nolan, J.M., and Goff, F.E., 2022, Database for the Geologic Map and Structure Sections of the Clear Lake Volcanics, Northern California: U.S. Geological Survey data release, https://doi.org/10.5066/P9HUYU9P.

Ewert, J.W., Diefenbach, A.K., and Ramsey, D.W., 2018, 2018 update to the U.S. Geological Survey national volcanic threat assessment: U.S. Geological Survey Scientific Investigations Report 2018–5140, 40 p., https://doi.org/10.3133/sir20185140.

Mangan, M., Ball, J., Wood, N., Jones, J.L., Peters, J., Abdollahian, N., Dinitz, L., Blankenheim, S., Fenton, J., and Pridmore, C., 2019, California’s exposure to volcanic hazards (ver. 1.1, December 2019): U.S. Geological Survey Scientific Investigations Report 2018–5159, 49 p., https://doi.org/10.3133/sir20185159.

Background image on cover: Mount Konocti and the southeastern Clear Lake volcanic field viewed from the northern lakeshore near Glenhaven. Photograph by Jessica Ball, U.S. Geological Survey, 2021.

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