The Bishop Tuff

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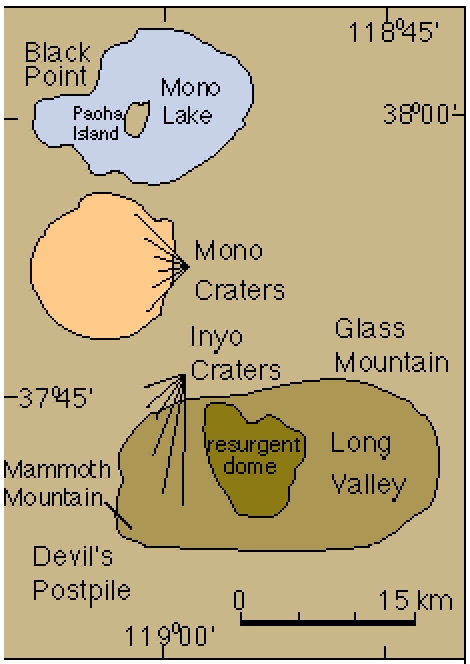
COAS E105: Volcanoes of the Sierra Nevada

Photo by Leah French (Michael Hamburger and Adam Schau walk through the Bishop Tuff in the Owens River Gorge)
Location: 37.6N, 118.8W

California's Sierra Nevada is filled with many fascinating geological mysteries, more than one lifetime can reveal. Though each geological phenomena is within a very close proximity of each other, they are actually strikingly different from one another. Sierra Nevada is filled with rivers, sand dunes, basins, ranges, earthquakes, volcanoes, and the list goes on. However, one paper cannot begin to investigate all the geologic happenings and this paper will mainly focus only on the formation of the Long Valley Caldera and the subsequent tefra, named Bishop Tuff.

The word caldera refers to a large basin, usually a circular or cirque shaped volcanic depression, with a diameter many times greater than that of the included volcanic vents (Dictionary of Geologic terms). The Long Valley Caldera is an elliptical depression two to three km deep. It extends east to west about 32 km, and 17 km north to south with an area of 450 km squared. The western half of the caldera is forested with high relief, and on average reaches 2440 m. The eastern half differs much from the western half, with lower elevations averaging 2070 m, low relief, and covered primarily with grass and sage (Bailey). Bishop Tuff acquired its name from the small town Bishop, which is 50 km south east of the Long Valley Caldera. Tuff refers to rocks that are formed from compacted volcanic fragments, generally smaller than 4 millimeters in diameter (Dictionary of Geological terms).



Location of main features of the Long Valley and Mono-Inyo Craters Volcanic Field. Based on Bailey (1983 and 1989).

http://volcano.und.nodak.edu/vwdocs/volc_images/north_america/california/long_valley.html Volcanic history within the Long Valley region initially began roughly 3.2 million years ago. One method that scientists use to obtain this information about the age and history of Bishop Tuff and other rock formations is through K-Ar dating. The K-Ar dating method requires a compositional measurement of both elemental potassium and the argon isotope in the same sample (Bailey). Most samples were from outcrops in the Long Valley region and had to be tested for purity before use.

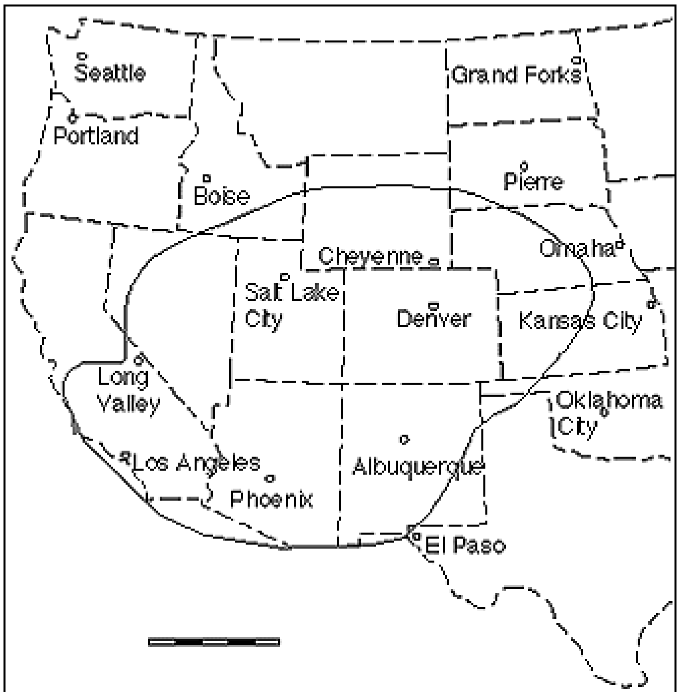
While the obsidian was crushed between 2 and 4 mm before testing, the basalt and andesite samples were examined in small sections to make sure that the rock samples were homogeneous. Large amounts of basalt and andesite inclusions found in postsubsidence intracaldera rocks support the common idea that trachybasalt and trachyandesite lavas dominated the early igneous formations in this area. Basalt from an Old Mammoth mine and andesite from San Joaquin ridge both dated back to 3.1 million years ago (Bailey). However, these igneous formations are not directly related to the Long Valley magma chamber, but conceivably signify an early part of the volcanic cycle. The first volcanic rocks that can be traced back to the Long Valley magma chamber were the ryholites of Glass Mountain. The vents of Glass Mountain are arranged parallel to the Long Valley magma chamber which suggest that the rhyolites were construed from the Long Valley magma chamber through caldera ring fractures. The ring fractures related to the Glass Mountain are the earliest detected in the Long Valley Caldera.

Approximately 730,000 years ago the catastrophic rhyolitic eruption of Bishop Tuff produced an unimaginable amount of ash and tefra, which made up 80% of the total erupted rhyolitic magma throughout the last 2.1 million years (Wilson and Hildreth). The Long Valley Caldera eruption had a force 2,000 times greater then Mt. Saint Helen's eruption. Initially the extremely powerful Pilinian eruption was coming from a single vent. However, after only 20% of the total magma had erupted, the roof of the volcano could no longer support itself and it collapsed to produce a caldera. While the caldera collapsed and subsided, it produced several ring fractures, which allowed Bishop Tuff to surface in enormous volumes. It forced 150 cubic miles of rhyolitic magma to the surface in the form of Plinian ash columns as well as air falls and ash flows.

Photo by Leah French: An Example of an actual Bishop Tuff ash fall deposit.

The arrangement of Bishop Tuff occurred in a very short amount of time, most likely within a couple of hours or days (Hildtreth and Mahood). Many of the ring-fault vents that were active during the eruption were thought to be fissures with openings hundreds of meters wide. Such large openings caused a colossal discharge rate of Bishop Tuff. Many of the ring-fault fissures collapsed from no structural support immediately after the initial Bishop Tuff erupted, trapping the remaining Bishop Tuff underground. This explains why two-thirds of the magma never erupted and stayed within the caldera. Inside the caldera Bishop Tuff was discovered to be over 1000 meters thick with an estimated volume of 350 km cubed. The vents were then buried within the caldera's perimeter under layers of caldera fill and Bishop Tuff making it difficult to trace any fault lines. However, one fault along the east wall of the caldera can still be traced as far as 12 km and has a maximum displacement of 250 m (Bailey).

Spewing from these enormous vents, the Bishop Tuff spread out radially and the volume of magma projected from the Long Valley Caldera is estimated to be some where around 600 km cubed. The ash covered an area between 1040-1150 km squared. Some Bishop Tuff traveled down wind in Plinian ash clouds, thousands of km as far as Kansas and Nebraska.



Distribution of Bishop ash beds from eruption at Long Valley caldera. From Izett and others (1982).

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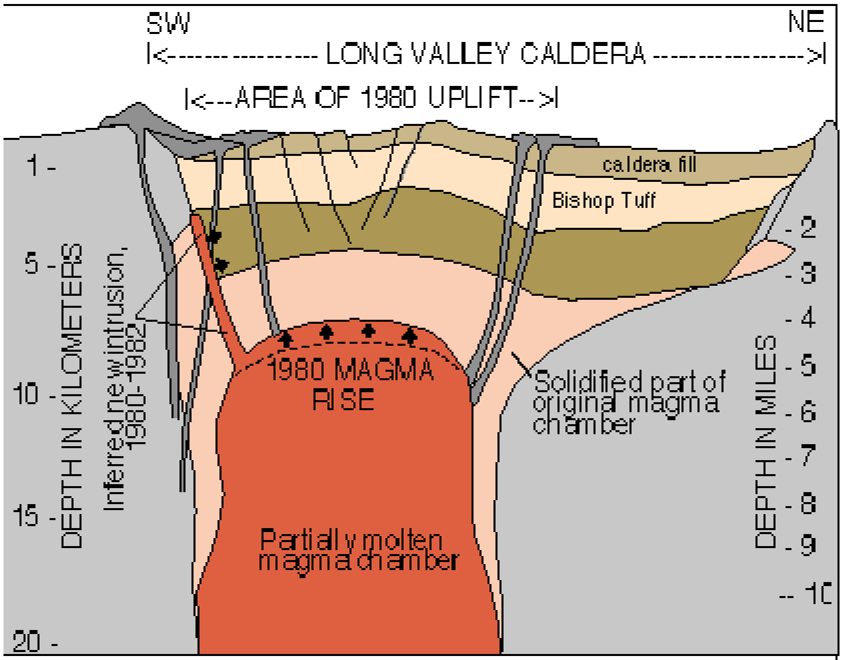
Temperatures of the erupted initial ash falls were estimated at 745 degrees Celsius and under less than 2 kbar of pressure. The initial ash flow eruption temperature is estimated at 800 degrees Celsius under 3 kbar of pressure. The roof of the magma chamber was 6 km below the surface and after the initial eruption the last ash falls were coming from a depth of 10 km. This means that the caldera roof collapsed approximately 3 km (Bailey). K-Ar dating has shown Bishop Tuff samples that range from 0.68-0.74 million years.

This information correlates with the interpretation that it took no longer than a few centuries for the Bishop Tuff ash flow to be placed in its current position (Bailey).

Water filled the Long Valley depression and formed a Pleistocene Long Valley Lake. The lake filled quickly when the normal runoff from the Sierras was greatly increased due to the hot blanket of Bishop Tuff covering and melting the glaciers more rapidly. By studying the terraces on the east wall of the caldera, one can conclude that the level of the lake rose to at least 2,320 m (Bailey). This lake occupied the Long Valley Caldera for most of its history, and it started draining when the resurgent dome began to uplift the west central part of the caldera floor. Upward pressure caused this uplift due to the intrusion of molten rock into the magma chamber underneath the caldera floor. The resurgent dome pushed upward within 100,000 years or less of the caldera-forming eruption 730,000 years ago. Layers of lava flows, tephra, and pyroclastic flows make up the composition of the resurgent dome. The volcanic tephra was erupted onto the caldera floor soon after the caldera formed. The dome, 10 km in diameter, consisted of 500 m of fault-bounded blocks.



Cross-section through the Long Valley caldera showing inferred subsurface relations of the magma chamber and 1980-1982 new intrusion of magma along the south wall of the caldera. Based on Bailey (1983).

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The resurgent dome was an island in the caldera lake for most of its history. As the resurgent dome grew, the lake's waters climbed too high for the caldera walls to contain, and the water overflowed at the southeast rim. The water cut into the nonwelded Bishop Tuff until it reached welded Bishop Tuff where the water was temporarily stabilized. The lake eventually drained fully about 0.1 million years ago (Bailey).

Volcanic activity persisted almost immediately after the eruption and subsidence of the Long Valley Caldera. Crystal-poor rhyolite tuffs and domes accumulated on the caldera's floor rose to at least 500 m (Bailey). These rhyolite tuffs contained great amounts of Bishop Tuff inclusions and a few fragments of granite and metamorphic rock, Indicating that all of these rock types must be within the cauldron block. These rocks did not show ripple marks, however, they are believed to have at least partly formed in the caldera lake. A minimum of 12 vents near the center of the caldera erupted in a span of no more than 100,000 years, and could have occurred within 40,000 years after the Bishop Tuff eruption. These vents produced what is known as the early rhyolites. Additional vents were most likely buried in the caldera itself.

The youngest volcanic formations of the Long Valley Caldera are within the Inyo Crater chain.

Photo by R. Forrest Hopson
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The Inyo Crater chain consists of a line of domes and craters 10 km long. The Inyo domes consist of five rhyolitic to rhyodacitic lava domes (Bailey). The three youngest domes, Obsidian dome, Glass Creek dome, and Deadman Creek dome, are less than 720 years old and erupted within a few years or even months of each other. These young domes are of significance because the lava is heterogeneous, meaning that the domes consist of two distinctly different rocks. One type is a light, coarsely porphyrtic rock that tends to be pumiceous, and the second is dark rhyolitic obsidian. The composition of the Inyo dome rocks resemble that of the magma bodies of the Long Valley Caldera and the Mono craters. This represents a possibility that a mixing of magmas occurred before eruption through a connecting fissure (Bailey).

The Inyo craters at the south end of the chain were possibly caused by the rise of rhyodacitic magma, similar to Bishop Tuff, and caused the waters to turn to steam (Bailey). The craters could be as young as 550 year old, which leads to the conclusion that the Long Valley magma chamber possibly had remaining magma close to the surface as recent as 550 years ago.

Photo by Leah French: South Inyo Crater

Outside the caldera, the Owens River has cut a deep gorge in the Bishop tuff and revealed some interesting formations. The Bishop Tuff formed columnar-joints as well as rosettes or radial columnar jointing which could have formed in many different ways.

Photo By Leah French: Owens River George with rosettes in upper right corner

Some of the joints are effects of cooling. Joints increase the surface area of the hot tuff, which allows heat to escape more rapidly and the in return the tuff cools at a faster rate. Some joints, called late joins, are effects of stress. Once one crack forms in the tuff it produces more stress on the rest of the tuff, causing another crack. Soon these cracks become deep and form joints. Steam vents or fumarolic activity was yet another reason for these particular joints to develop in the Owen River Gorge. Fumarolic fractures show strong preferred orientation, which differs from late joint, and they are also deeper and longer than cooling joints. The history of fumarolic joints is very complex and hard to understand. It is believed that the Bishop Tuff went through two different phases. One phase included the welding and cooling of the tuff, in between the phases was a dormant period, and the other phase integrated the fumarolic activity. These phases partly contributed to the fact that Bishop Tuff in the Owen Gorge is composed of two separate parts. The lower part consists of strongly welded tuff, which has less jointing, and the upper part consists of nonwelded tuff. The lower, welded region of the Bishop Tuff contains less jointing partly because it erupted with lower energy and did not mix well with the atmosphere, and was able to cool at a slower rate. The upper section of the Bishop Tuff contains columns that range from three to five feet, and the oriented vertically as well as horizontally. It is thought that these columns are arranged along the isothermic (areas with the same temperature) heat line.

Bishop Tuff is an excellent clock which helps to determine other geologic happenings. Geologists can identify the very distinct layer of Bishop Tuff in the crust with the knowledge that it occurred around 730,000 years ago. In one instance, a core of the dry Owen Lake riverbed was taken and the Bishop Tuff was identified. It was a great discovery, which allowed geologists to determine that all the samples taken from the core above the Bishop Tuff occurred before 730,000 years ago. Subsequently the samples taken beneath the Bishop Tuff were older than 730,000 years old. This discovery allowed scientists to understand the region of the Owens River to a much higher degree.

The Long Valley Caldera was created by a massively powerful eruption, which saturated the entire Long Valley region with a huge layer of tefra. The intricate formations that we can see today show the amazing history that this region has endured. Geologists who study the details of Bishop Tuff and the formation of the Long Valley Caldera can use their knowledge and relate it to other geologic happenings around the globe.

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