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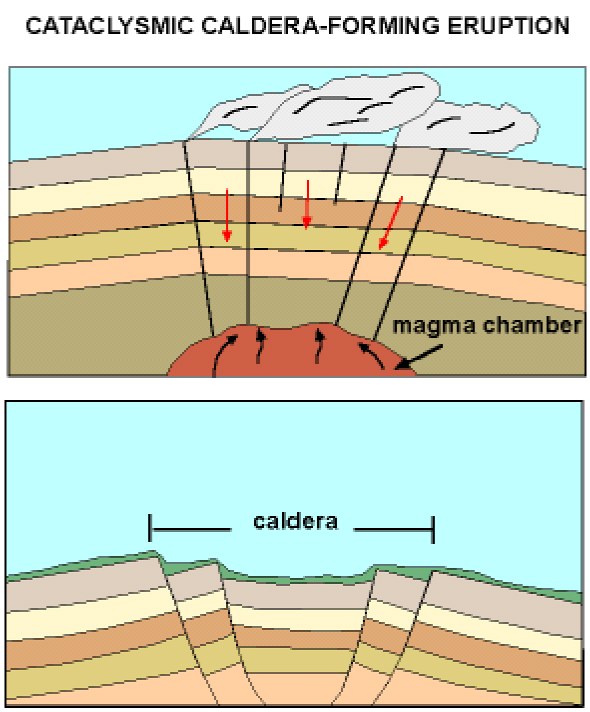
Bishop Tuff and the Long Valley Caldera

Abstract: The formation of the Bishop Tuff ash deposit, and the eruption that was its predecessor occurred nearly 760,000 thousand years ago. This eruption is what caused the elliptical depression that has been measured as a 17-32km across. This depression is known as the Long Valley Caldera, located on the eastern side of the Sierra Nevada Mountain Range. Through the depletion of the magma chamber located under the caldera, as the magma and pyroclastic material was erupted onto the surface the stability of the earth's surface could not support its own weight anymore and caved in. By examining how and where the ash erupted, along with the layering and composition of the ash deposits, such as what type of lithic fragments and crystals present. All helps illustrate the environment in which the material was formed along with the composition of the magma when the eruption occurred.

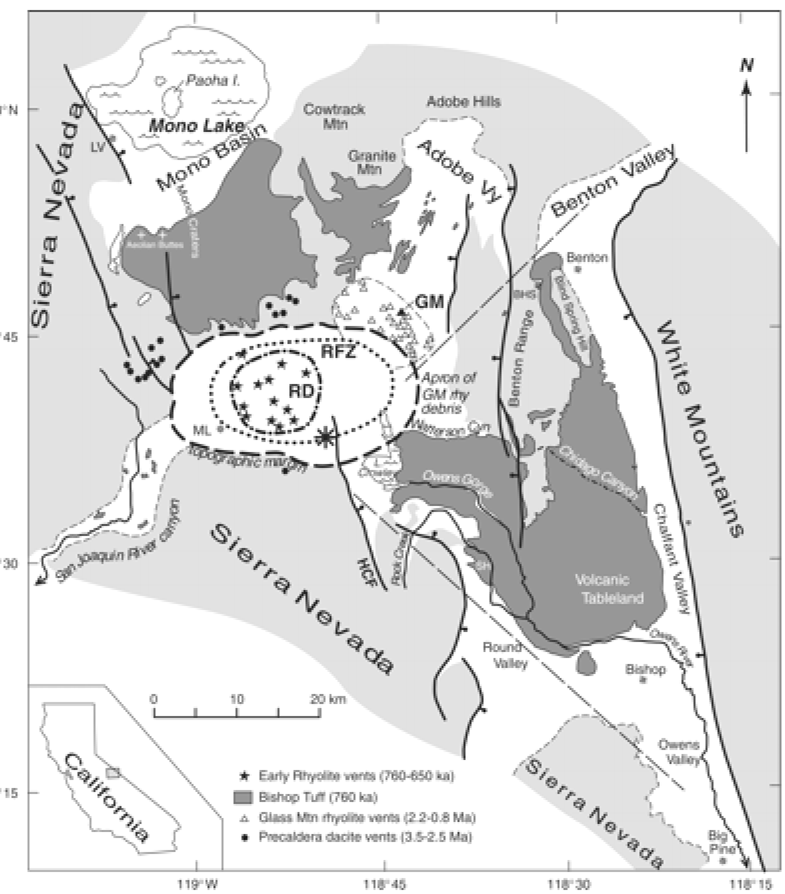


wapi.isu.edu/EnvGeo/EG6_volcano/volcanoes.htm

The Bishop Tuff eruption occurred approximately 760,000 years ago over a 6-7 day period from the Long Valley magma chamber. These eruptions took place through multiple vents, or opened pathways that can no longer be located because of subsequent eruptions and lava flows, in turn burying and erasing all evidence of the exact location of these vent openings, although by looking at ash deposits approximations of the locations have been calculated.(HILDRETH and. MAHOOD 1986)

There are two main types of ash deposits that took place during the Bishop Tuff eruption, ash fallout and ash flow. Exposed south and southeast of the caldera are deposits of approximately 5m of plinian ash fall that accumulated before the first of the ash flows were laid down on top. There is evidence of partial cooling between the layers of the ash flow found in the southeastern area and the southwestern section. The layers or sheets of ash flow have been divided into 9 unique units each laid down within hours of each other this is where the partial cooling evidence can be found.(HILDRETH and MAHOOD 1986)

When looking at an outcrop of Bishop Tuff there is a line separating two distinct layers of ash, the lower and upper deposits. On the lower section of the deposit the ash tuff is very consolidated and dense which is caused as the ash flows build upon themselves compressing the layers below. The upper layers are unconsolidated pumice and ash fall. (Hildreth and Wilson 2007) There has been fallout evidence that covers areas from the Pacific Ocean all the way to Nebraska. While the ash flows has been documented as traveling more than 70 km down Owens valley 40-50km N into Mono Basin Adobe Valley (Hildreth and Wilson 2007).



The long valley caldera has been filling in since the initial eruption 760,000 years ago; it is now thought that there is a layer somewhere between 100-500m thick composed primarily of layers of tephra and lava flow that formed within the first 100,000 years after the initial explosion Of Bishop Tuff. This thick layer of volcanic material is now covering part of Bishop Tuff deposit which was laid down beforehand. (***http://lvo.wr.usgs.gov/gallery/CalderaFlows_1.html***) **.** Intracaldera tuff cannot be found exposed anywhere within the confines of the caldera, researchers have attempted to use geothermal drilling to measure and try to calculate the entire depth of the Bishop tuff deposit ,but to date they have only been able to reach into the layer of Bishop tuff BUT not to the bottom into the precaldera material. Researchers were only able to reach depths of 2,100m which is not deep enough to calculate the entire depth of the Bishop Tuff deposit. (Hildreth 1986) There can be found toward the center of the crater densely tufted rhyolitic intrusions that have reached the surface as the ground has uplifted. This evidence of densely compacted tuff along with the core samples lead us to the conclusion that there are large layers of rhyolitic bishop tuff underlying the entire caldera. While much of the deposit has been covered by newer eruption there are still areas that exposed at the surface. The most extensive area of exposed Bishop Tuff accumulation can be found within the southeast area known as the volcanic tablelands near the caldera (Gilbert 1938)

The magma chamber that fed the eruption of Bishop tuff is thought to be a long lived mafic rhyolitic magma chamber. This chamber is described as very large and shallow, forming from basaltic intrusions rising and evolving from the middle and upper crust of the earth . While the chamber is slow in forming, many eruptions previous to Bishop Tuff occurred up to 4mya. The recent timeline for the Bishop Tuff eruption shows that the chamber had been forming and filling approximately 100-160 kya before the Bishop Tuff eruption. (Hildreth and Wilson 2007)

Ash flow tuff: pyroclastic material deposited in large volumetric quantities that are composed of ash and small rock particles that are no larger than 4mm. The formation of the bishop tuff occurred at the time of the eruption 760,000 years ago, as the rhyolitic ash flow deposit settles onto the ground in sheets, as this is occurring the deformation process has already began. The main processes that must occur for the ash to be formed into welded tuff all have to do with the removal of pore space, in doing so creating a compact dense ash tuff. The processes involved deal with this type of deformation, include deflation, compaction, welding compaction, and equal volume deformation with or without shear (Sheridan and Ragan, 1976).

One of the first processes that occur after the ash sheets are laid down is the expulsion of gases from within the pore space in the particles. Researchers Sheridan and Ragan have come to the conclusion that as the pyroclastic material is being erupted from the vents volatile gases are trapped within the pores of the particles. So that when the depression of the gasses occur they are released into the atmosphere. Scientist believes that is this release of gasses that causes the formation of subsurface fumarolic pipes, which allow gasses to escape from the ground. Mechanical compaction occurs from the movement, rotation and compression of particles without a real change in shape this process only has a minor affecting the total outcome of the sheet bed and has to do with settling. Finally there is Welding Compaction. This process plays one of the largest roles in controlling the outcome of the tuff and the compaction textures. Welding compaction depends on the rate of viscous deformation of glass particles in the ash. This deformation rate depends largely on the temperature and pressure distribution that can be found throughout the ash sheet. The location of the particles within the sheet determines their fate. As the tuff slowly cools the deformation of the particles also slows until there is unique density profile that becomes solidified in the tuff. (Sheridan and Wang 2005) Throughout the sheet there are areas that have different density profiles, since they were formed under different pressure and temperature conditions. The area that becomes the densest, the most compacted is located in the central lower area of the ash sheet. This occurs because this area is the most insulated and is therefore able to hold in its heat the longest, this in turn allowing the deformation process to continue for a longer period of time creating a very dense compacted ash tuff.

The formation of tuff depends entirely on the conditions if the formation temperature is too low or the hot ash sheet cools too quickly before compaction and welding can occur the tuff will not become welded. (Sheridan and Wang 2004) The Bishop Tuff ash fall is composed of two main types of deposits ash fall and ash flow. But within those two categories the ash sheets have been further divided into 9 distinct layers. There is a sequence of events that occurs creating distinct compositional units. The start of the Bishop Tuff eruption occurred in a south central area of land that after the eruption will from the caldera. A column of ash and debris formed and was thought to be as large as 18km-45km tall, being blown in an easterly direction (Hildreth and Wilson 2007). By calculating how long it took for each sheet or layer of ash to be deposited researchers are able to calculate how long it took for the entire eruption to take place, these calculations came to the conclusion that if was not years or months but only hours between the layers being deposited, when the time for each sheet to be formed is added together the numbers show that it took only 6 days for the entire eruption to take place.

Photograph by R.A. Bailey on October 29, 1987

(section of Bishop Tuff)

Pumice clasts in relationship to phenocryst content, range throughout the layers of the Bishop tuff from <1%-25%, these percentages are determined by the mineral separations in heavy liquids. (Hildreth and Wilson 2007) So depending on the mineral content and the amount of lithic fragment present in the pumice the different normal dominate categories of pumice can be created. Researchers Hildreth and Wilson have found that the percentage of juvenile pumice clasts in the deposits are composed of normal pumice ranging from crystal deficient to crystal rich (0-<12%).These are the major type of pumice in almost 93-99% of all of the deposits found in the Bishop tuff . There are other forms of pumice deposits present throughout but they compose only a very small percentage of overall deposits. Swirly type of pumice has the second highest percentage present, but still at the most it can be found at 28%. Swirly pumice is described as normally found in a light grey color, but there have then been oxidation that has altered the appearance of the pumice to include colors such as yellow, tan or pale orange. The other types of pumice such as, glistening, dark grey, recycled, banded, reassembled, dactite, are very rare and most often only have a percentage recovered of less than 1%. The mineralogy of the pumice clasts are as researched by (ANDERSON and DAVIS and QIONG LU 2000) have found that in bishop tuff that erupted early to mid timeframe that there was found to be phenocryst of quartz sanidine and plagioclase and that they occur in proportions 3:3:1. As the Bishop Tuff eruptions become younger there is a range in those proportions and it becomes closer to 2:3:1 and we find that biotite and magnetite make up approximately 4% volume of the bishop tuff phenocryst.

Not only does the mineralogy differ throughout the layers the deposits of the Bishop Tuff there is also a large variance in the size of the phenocryst crystals in the pumice clasts. Once again researchers (ANDERSON and DAVIS and QIONG LU 2000) have found that the crystals of quartz and sanidine can be found in a range that includes 0.3 mm to 3mm, these ranges are the maximum dimensions that can be found in early to mid erupted pumice. While in the late erupted pumice there are also found phenocryst of quartz and sanidine range to approximately 5mm.

(Variant Pumice Clasts)

Throughout their research they also found that polycrystalline aggregates of feldspar and quartz are very difficult to find, very rare. While there has been evidence of crystal fragments lining vesicles in the bishop tuff it seems that the crystals are all much fractured, and all of these fragments are part of the same mineral, not multiple types of minerals forming in the same location under the same conditions. It has been found that more than half of all of quartz and plagioclase phenocryst found in the Bishop tuff are composed of crystals that are fragmented and irregular these types of crystals are called phenoclasts. It is thought that these fragments are caused by melt inclusions. The fragment where once part of a large crystal that when the melt inclusion ruptured and vesiculated, the crystal shattered. (Best & Christiansen, 1997) So it seems that the phenocryst of feldspar and quartz present throughout the Bishop Tuff are composed of only singular crystals, and it is common to find inclusions of glass in these crystals more often than not in large whole crystals.

The glass Matrix of the Bishop Tuff has a compositional makeup that is very similar in both the early and late pumice that has been analyzed; it has been found that the matrix is made up of (77wt% SiO_2) (12.7wt% Al_2O_3) (3.2wt% NaO_2) (Anderson and Davis and Lu 2000) .While there is physical evidence of the constant eruption of the Bishop tuff, in observing and calculating the depth and speed at which the layers of ash were laid down there can also be diverse mineralogical had chemical evidence that supports the theory of a single integrated magma reservoir. There is evidence that the erupted magma had been stored in a differentiated zoned chamber, was richest in gas, lowest in temperature, poorest in the phenocryst crystals that where located at or near the roof when the eruption began and the magma began to leave the chamber. The Bishop eruption was prime example of an eruption that was part of a complex chemically and thermally zoned magma system.   In this system there was an increase in temperature from approximately 720-800 degrees along with a change in crystal content that Rose from 5% to 25%. Along with Temperature and crystal content there was also a large change in the amount of trace elements that accumulated in crystallizing phases as the one moves deeper into the magma chamber these accumulates are Ba,Zr,Sr. (Wark,. Hildreth,. Spear, Cherniak and Watson 2007). There have been many theory's on the pattern of crystallization and the chemicals and zoning involved with it, but there is one general consensus that many scientist have been working toward. Chemical stratification throughout the magma chamber can be partially explained by the fractional melting and the processes that occurs alongside it. In fractional melting as the process occurs there is a cumulate crystal mush that builds up at the bottom of the magma chamber. By the time the crystal that are at the bottom of the chamber erupt they are composed of completely different mineral compositions, along with zoning. (Wark,. Hildreth,. Spear, Cherniak and Watson 2007). Some of the supporting evidence for the crystal sinking, and fractionalization has to do with the compositions of crystals that have been analyzed. There is evidence found in sanidine phenocryst of reversed zoning, this is showing that these crystals formed in a melt that was richer in Ba over time. This process could have occurred as the forming crystals sank deeper into the magma chamber closer toward the bottom where the melt is richer is Ba; crystal sinking is one plausible explanation for this response. In relation to this it was also found that in quartz phenocryst there are CO_2 rich melt inclusions that can be found in the outer rims of the crystal, this is telling us that as the crystallization process ongoing there was a increase of $CO_{2,}$ this has a direct correlation with the occurrence of Ba rims in sanidine. Both the CO_2 in quartz and the Ba in Sanidine are related to late erupted melt inclusions, along with both types of enrichment being compatible with the idea of fractional crystallization. There is also evidence that late erupted CO2 melt inclusions have been found with high gas saturation pressures. This will occur when a crystal is put under an increase in pressure during its growth, trapping melt inclusions; this is what would have happened if during the quartz phenocryst growth it sank lower into the magma chamber causing the pressure exerted onto the crystal to increase. (ANDERSON [and] DAVIS and QIONG LU 2000[)]

Thermal Stratification has its own explanation, there are going to be lower temperatures in the magma towards the top of the magma chamber as this is caused by heat loss associated with being closer to the roof of the chamber. While at the same time toward the bottom of the magma chamber there is an increase in temperature, this is thought to be related to the injections of basaltic melts that are underlying the chamber. It is thought that it is from these melts that are constantly heating the chamber and keeping the magmatism active. This theory also includes the facts that the gradients found in crystalline are because of higher amounts of H_2O in the upper parts of the chamber where the solidus temperatures are lower. (Wark, . Hildreth, Spear, Cherniak and. Watson 2007).

The unique rimming of crystals and the type of thermal and chemical gradients have led researchers Wark, . Hildreth, Spear, Cherniak and. Watson 2007) To create a new pertaining to these formational conditions. They have come to believe that the difference in core to rim compositional changes are unique because growth during cooling should have and opposite effect. These observations seemingly require a unique explanation, because crystal growth during cooling should lead to opposite trends these zoning patterns. While before we discussed that this could have occurred as the crystals sank there is an alternate theory has been proposed. Research has been done with a Ti-in quartz thermometer that shows that the cores of the crystals were formed in lower temperature melts than the rims. The theory has to do with thermal rejuvenation along with CO_2 induced crystallization. This could have occurred from an hot injection of a CO_2 Mafic melt. There is evidence that the rim growth on the quartz which formed under high temperatures was created within 100 years of the Bishop Tuff eruption, there is a belief that it was this recharge, the injection of the hot new material that could have caused the eruption of Bishop Tuff 760,000 years ago.

So in conclusion the Bishop Tuff eruption 760,000 years ago was part of a unique magmatic system that evolved over a very long period of time. From the early erupted Bishop Tuff which was found to be high silica rhyolite, comparatively uniform differentiated crystals and melt. All the way to late erupted magma with zoning found in sanidine and inclusions of quartz which formed under a less differentiated melts. Once the eruption of Bishop Tuff began, the air fall of ash was laid down continuously 10-15 hours in-between at the most. The eruption took place over 6 days from at first from within a single vent transferring over into a ring vent system partially throughout the eruption. There was as much as 600 km^3 of ejected material created the ash fall and flows which created the unique aspects of Bishop welded Tuff.

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