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What is a Caldera?

A caldera is a depression in the Earth's surface, caused by the overlying ground collapsing. Typically this collapse is in conjunction with, or fairly directly following a large eruptive explosion of a magmatic mass. Once the magma has evacuated it's chamber, there is an empty space left. This empty space is unsupported. Therefore the pressure of gravity and the weight of the overlying rock eventually causes the chamber to collapse (Brantley, 1994, Wright, 1992).

In some instances the magmatic events associated with the creation of a caldera will cause surface materials to be expelled when they erupt. The extrication of the surface materials enhances the depth and breadth of the caldera formed - while less material creates more negative space. Thus, the magnitude of the eruption, coupled with the volume of magma erupting (and the size of the magma chamber being emptied) , will aid in determining the size and scope of the caldera created there after (Brantley, 1994, Wright, 1992).

How Does a Caldera Form?

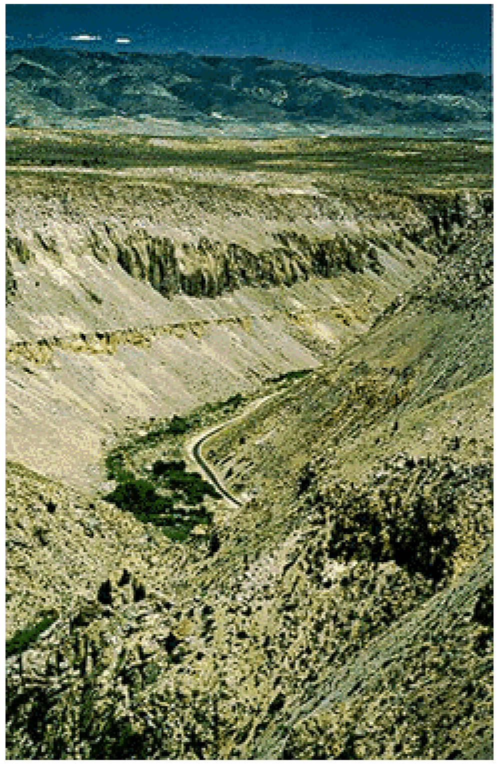
A large, explosive eruption must occur in order to create a caldera. These are eruptions of magma, which are welling up under highly pressurized conditions. Heat and pressure build up in the magma chamber below the Earth's surface. The magma is pushed up toward the surface, by the super-heated magma welling up below it (Brantley, 1994, Wright, 1992).

As it journeys upwards the magma encounters impermeable surfaces. When it comes to one of these impermeable areas it is diverted to paths with less resistance. Eventually the magma finds a weak spot or fissure - it can exploit the weakness to release pressure (Brantley, 1994, Wright, 1992).

If there is enough pressure - as in the instance of a caldera creating eruption - the magma will erupt out with great force. The force of the eruption will spew out lava, ash and tephra. Tephra is a mixture of debri from the ground overlying the eruptive region, and the ash produced by the eruption. The ash will be caught on the wind or travel in a flow, out from the eruptive center (Hill, 1996).

What is the Link Between Calderas and Tuff?

Preceding the formation of a caldera there is a massive explosive eruption. These eruptions produce columns of ash. The ash is ejected high into the air. Then the ash is caught up on the wind, in the atmosphere or creates flows that fan out from the eruptive center. The ash caught on the wind will eventually fall down to Earth in large elliptical "aprons". There the ash will meld or compress to create a unique type of volcanic rock, Tuff (Brantley, 1994, Wright, 1992).



This is a photo of the Bishop Tuff, about 250 miles North of Los Angeles. Photo by R. Forrest Hopson (University of North Dakota, 2002).

Caldera forming eruptions of great magnitude form a tuff of a special nature - Welded-tuff. The high levels of heat and pressure necessary to create an eruption like that of the Long Valley Caldera make Welded-tuff possible. In these cases the heat created by the eruption is so intense that the ash is still slightly molten (or plastic) when it hits the ground (as in the case of Long Valley). The weight of the overlying ash compresses the ash fragments. The plastic nature of the still partially molten ash enables it to "weld" together into a more sold rock - Welded-tuff (Brantley, 1994, Wright, 1992, Pers. Comm. May 2002).

The Formation of Long Valley, Newberry and Yellowstone Calderas

The Long Valley, Newberry and Yellowstone Calderas are three calderas located along the western half of North America. 3.6 million years ago, basaltic and andesitic lava flows covered the area now known as Long Valley. Relatively soon after, flows of rhyodacite began erupting out of Long Valley (University of North Dakota Website, 2002).

The more silicic nature of rhyodacite (in contrast to basalt and andesite) seems to be indicative of magma accumulation beneath the surface. Meaning, the more mafic magmas were being subjected to fractional crystallization - a process in which heavier, more mafic minerals crystallize and lose their buoyancy. This only occurs when magma is able to stay in one place for a period long enough to allow the mafic minerals to crystalize and settle out. When they have lost their buoyancy the mafic minerals (such as iron and magnesium) separate from the lighter, more felsic minerals and sink. Thus, leaving a lighter, more felsic magma closer to the surface where it erupts in the form of lava flows (University of North Dakota Website, 2002, Pers. Comm., May 2002).

Long Valley Caldera was formed some 2.5 million years later (about 760,000 years ago). At this time there was an eruption, said to be one-thousand times the magnitude of the Mount Saint Helen’s eruption, in modern day Long Valley, California (U.S.G.S. Website, 2002).

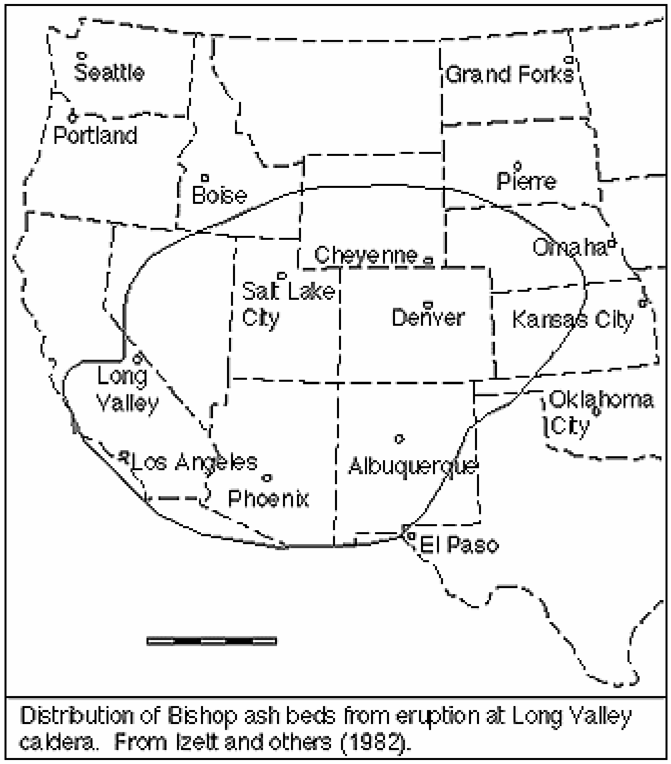


Diagram of travel of Bishop Tuff ash. Courtesy of University of North Dakota, 2002

Molten magma blew it's way up from a depth of approximately 4 miles. About 150 cubic miles of magma was ejected from the magma chamber below Long Valley (Hill, 1996). Plinian ash columns were shot thousands of feet into the air. Pieces of ash from the eruption were caught by and spread on the eastward moving, prevailing winds - blowing as far as Kansas. The red-hot ash fell to earth in eastern-central California. Where it fell most thick the ash melded together. Ash flows, which traveled over the ground added to the mixture of plasticized ash, creating the Bishop Welded-tuff (University of North Dakota Website, 2002).

Some 600,000 years ago Newberry Volcano began to form. Newberry is a shield volcano, formed by thousands of tiny eruptions over about 100,000 years (Sherrod, 1997). After so many tiny eruptions the magma chambers beneath Newberry had begun to grow empty. As the magma evacuated the chambers it no longer supported the volcano. In addition the lava flows were adding weight on top of the volcano. A series of collapses ensued along concentric fractures, forming the Newberry Caldera atop the Newberry Volcano (Deschutes, 2002).

Since Newberry was formed by thousands of small eruptions, it has many layers of composite tuff, which are not as easily distinguishable as the Bishop Tuff (Deschutes, 2002).

Soon after the formation of the Newberry Caldera snow melt and rain filled the depression, forming a lake. Over time continued volcanic activity divided the lake into two separate lakes, East and West (Deschutes, 2002).

Photo of Newberry Caldera Lake (to the left) and Big Obsidian Flow (to the right). Courtesy of U.S.G.S.

Yellowstone Caldera is a unique example of repeated caldera formation in relatively the same geographic region. Approximately two-million years ago rhyolitic magma pooled beneath the surface of Yellowstone (Newhall, 1988). Pressure and heat grew as it pushed up from beneath the surface, resulting in a cataclysmic eruption. Subsequently, with the magma chamber emptied, the surrounding area was involved in a series of collapses. This created a caldera greater than 45 miles in length (U.S. National, 2002). That's over two times as long as the Long Valley Caldera!

Another product of the initial caldera forming eruption was the Huckleberry Ridge Tuff. Ash spewed out of the eruptive center. As it fell back to Earth the ash blanketed Oregon. When the Huckleberry Ridge Tuff solidified it covered some 2,500 cubic kilometers! The boundaries of the Huckleberry Ridge Tuff extend from Yellowstone Park in the east to Island park in the west (Newhall, 1988).

As time passed in the Yellowstone area the cycle of Caldera and Tuff formation continued. Circa 1.3 million years ago a second (smaller) eruption occurred, forming the Island Park Caldera, located just west of modern day Yellowstone park. The catalyzing eruption also produced the Mesa Falls Tuff, much smaller than the Huckleberry Ridge Tuff, it only covers about 280 cubic kilometers (Brantley, 1994, U.S. National, 2000).

Map of Yellowstone Caldera. Courtesy of www.yellowstone-park.net.

Finally, about 600,000 years ago the Yellowstone area again became volcanically active (Brantley, 1994). This time the eruption created Yellowstone Caldera, which is among the largest and most volcanically, geologically active Calderas in the world (Wood, 1990)! At the time of the eruption (as seems to be the case with all Caldera formation) a Tuff was formed, this one is known as the Lava Creek Tuff, which covers approximately 1,000 cubic kilometers (Newhall, 1988).

<u>The Physical Attributes of Long Valley, Newberry and Yellowstone</u>

The Long Valley Caldera is an oval like depression approximately 10 miles by 20 miles. The floor of the Long Valley Caldera has an elevation of about 8,500 feet in the west and 6,500 feet in the east. The walls of the caldera have elevations ranging from 11, 500 feet to 9, 800 feet. Near the center of the caldera is what is known as a resurgent dome (University of North Dakota Website, 2002, U.S.G.S. Website, 2002).

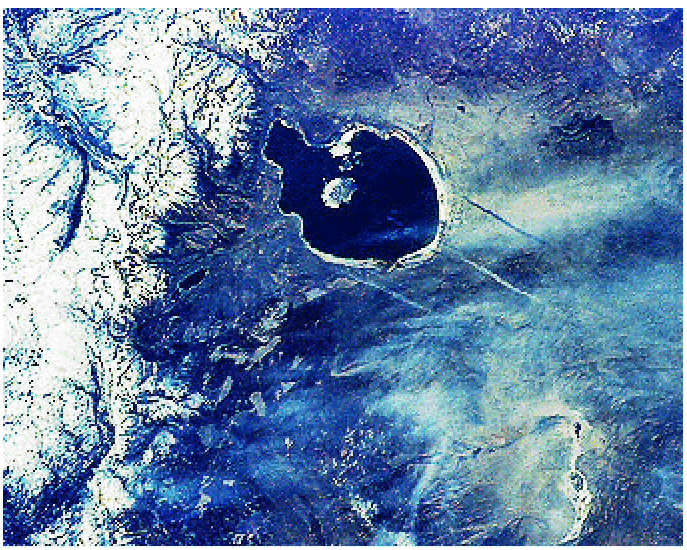


Photo of Mono Lake and Long Valley region. Courtesy of University of North Dakota, 2002 .

The Long Valley Resurgent Dome is actually a series of small uplifted areas on the floor of the caldera. The dome is located along fault lines, which comprise the eastern edge of the Sierra

Nevada mountain range. Movement along fault lines is partially responsible for the uplift of the dome (U.S.G.S. Website, 2002). However, other forces are at work.

It is thought that a magma chamber remains under the floor of the Long Valley Caldera. Heat and pressure are building in the magma chamber, below the granite bedrock. As the magma becomes more pressurized it attempts to rise. The rising magma displaces the surface above, resulting in the formation of a resurgent dome (U.S.G.S. Website, 2002).

While the Newberry Caldera does not seem to have a resurgent dome. It does, however, exhibit extrusive lava flows. Small eruptions have continued beneath the Newberry Caldera Lake, fueled by a magma chamber thought to be located some 2 miles below the Caldera floor. The most obvious clue as to the continuation of volcanic activity in this area, are the composite flows that bisect the lake (Deschutes, 2002). The fact that these flows are above the caldera floor tell us they are more recent then the formation of the Caldera.

Before lava flows bisected the Newberry Caldera it had a diameter of 4 miles from north to south and 5.5 miles from east to west - not even half the size of the Long Valley Caldera. The lowest point on the floor of the Newberry Caldera measures in at an elevation of 6,330 feet. The highest point on the rim of the caldera is just shy of 8,000. feet (Deschutes, 2002, Hoblitt, 1987).

The Yellowstone Caldera, largest of the three mentioned in this paper, has dimensions of 28 miles by 47 miles. What we see of the Yellowstone Caldera today, is only the latest (and largest) in a series of calderas that have existed in the Yellowstone region. The Caldera’s relatively recent birth is indicative of the magmatic mechanisms still at work there (U.S. National, 2000).

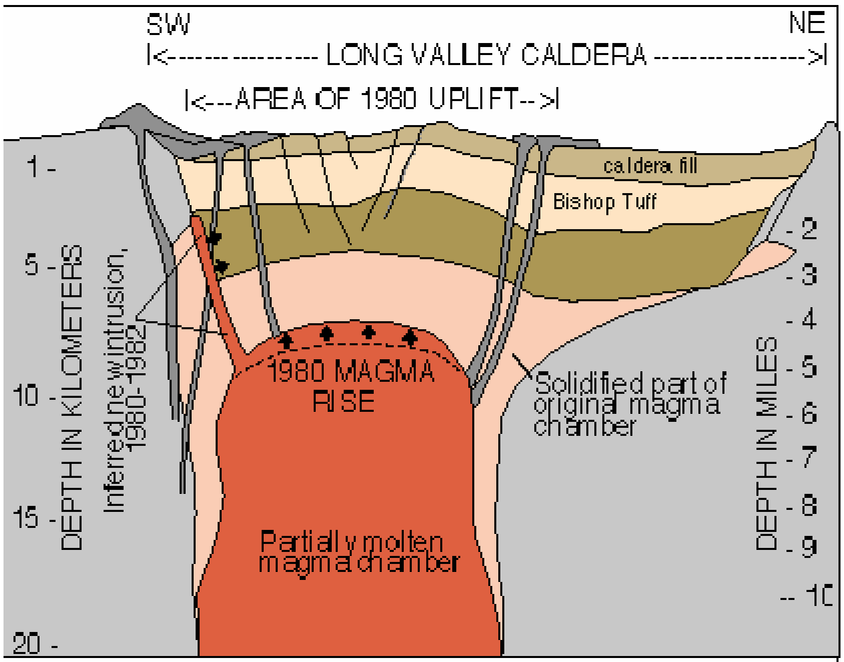
Mud pot in Yellowstone park. Courtesy of www.yellowstoneparknet.com.

Magmatism in the Yellowstone Caldera is still very active and present as illustrated by the volcanic phenomena which are common there. Most of these phenomena are associated with hydrothermal processes, particularly the heating of ground water by sub-surface magma. The results of hydrothermal activity are varied even within this locale. Hydrothermal explosions have been recorded in Yellowstone, as well as regularly operating geysers, hot springs, fumeroles and the not so glamorous mud pots - where boiling water has diluted the surface soils to a stew-like mush (Wright, 1992, Brantley, 1994).

Other indications have been made as to the continued volcanism of the Yellowstone Region. Seismicity remains an issue, as repeated small earthquakes persist. Ground deformation is present as well, with the Yellowstone Caldera forming a resurgent dome, like that of the Long Valley Caldera. Scientists have measured an uplift in some areas of nearly 90 cm between 1923 and 1984, after which there was a period of subsidence. These changes in elevation are presumed to be caused by the shifting of sub-surface magma as well as the change in pressure and heat of groundwater (Brantley, 1994, Wright, 1992).

Concerns About Future Volcanism

All of the calderas discussed in this paper are still presumed to be volcanically active. Many similarities can be seen in the illustration of volcanism in all three calderas, Long Valley, Newberry and Yellowstone. All have mechanisms of hydrothermal activity as well as recent extrusive lava flows and ground deformations (University of North Dakota Website, 2002, Foxworthy, 1982, Brantley, 1994).



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).

Diagram of magma intrusion thought to be the cause of 1978-1980 earthquakes in Long Valley. Courtesy of University of North Dakota, 2002.

Long Valley exhibits this with it's resurgent dome. Between 1978 and 1980 a series of earthquakes took place in the Long Valley Caldera. The most notable of these instances was in May 1980, when four magnitude 6 earthquakes were recorded in just two days! These earthquakes were thought to be caused by shifting magma below the surface, though the magma never did surface (Deschutes, 2002).

Also of interest is the volcanism located around the caldera's edge. The Mono Crater chain, which extends northward, ending in Mono Lake is one of the youngest volcanic chains in the world. The youngest volcanoes in the chain being the Mono Lake islands Paoha (circa 270 years old) and Negit (Circa 550 years old) - Negit having erupted less than 250 years ago (Hill, 1996).

In contrast Newberry Volcano last erupted 600 years ago, releasing an obsidian flow (Wright, 1992). The flow covered previous layers of obsidian including the Big Obsidian Flow, which erupted 1,300 years ago (Sherrod, 1997). These two eruptions illustrate the relatively high level of volcanic activity in the Newberry Volcano.

High level volcanic activity has lent the Newberry Caldera to hydrothermal activity as well. This is evident in the upwelling of heated ground water out of springs in the East Newberry Crater Lake (Foxworthy, 1982). Scientists interested in the hydrothermal activity in Newberry have performed drilling. Drilling in the caldera has illuminated the fact that super-heated water, greater than 265 degrees Celsius, has been found at a depth of 932 meters (Hoblitt, 1987).

Hydrothermal systems are no stranger to Yellowstone, in fact that's what Yellowstone is known for - it's geysers, scalding hot springs and mud pots (Brantley, 1994, Wright 1992). These hydrothermal mechanisms cause the average out flow of heat in the Yellowstone caldera to be forty times that of the global average (Wood, 1990)! The existence of such hydrothermal phenomena in Yellowstone are markers for the volcanism hidden beneath the surface.

Yellowstone geysers. Courtesy of www.yellowstone.net.

Further evidence of magmatic activity is present in the seismisity and ground deformation in Yellowstone. As mentioned earlier, in some areas there has been almost 90 cm of differential in elevation of over the last century in the Yellowstone Resurgent Dome.

What will the future hold for these incredibly active volcanoes? It is likely that we will see continued volcanic and hydrothermal activity. It also seems inevitable that there will be more eruptions. Of what scale these eruptions will be, it seems unclear. In the case of Yellowstone perhaps the legacy of eruptions which create paired caldera and tuff formations will continue, adding to the complex, multi-faceted dynamics of these volcanic hot spots.

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