Pyroclastic Flows with Emphasis on The Bishop Tuff

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Abstract:

The Bishop Tuff is a deposit of a huge pyroclastic flow. This ignimbrite covers nearly 2,200 square kilometers(Bailey 1976). It is primarily rhyolitic in composition, and is welded throughout most it. An ignimbrite of this size had to have come from a huge eruption, a super eruption. To understand the size of the eruption, it would help to better understand the Bishop Tuff itself, a product of the eruption. The Bishop Tuff has several different structures within it. Along the Owen River Gorge fiamme structures, rosette jointing, and fumarolic mounds can all be observed. The rosette jointing and fumarolic mounds are evidence for that the Owens River used to flow there before the super eruption, because when the pyroclastic flows came in and went over the river, the river flashed to steam creating these structures(G. A. Izett, Ray E. Wilcox, H. A. Powers, and G. A. Desborough).

Intro:

There are two basic types of volcanoes: red and grey. A red volcano freely spews out lava, or molten rock, which flows out at a very slow pace, one type of this volcano can be found at Hawaii. The lava is destructive in its own way, by destroying roads, buildings and land, but can easily be outpaced. The products of red volcanoes primarily consist of lava flows. A red volcano cannot produce a pyroclastic flow.

A grey volcano is far more destructive and dangerous. The magma is usually very viscous and gaseous, pressure builds and builds in the magma chamber until the volcano cannot hold it in anymore, then it explodes. Tephra is shot sometimes as high as 20 km, and into the stratosphere, the cloud then collapses and falls back to the earth creating a pyroclastic flow(Long Valley Observatory). Pyroclastic flows and surges are a common result from grey eruptions, and are very deadly. They are very hot ash and rock flows that travel hundreds of km an hour. These flows will level any standing building or forest as well as incinerate them(give Mt. St. Helens forest example here). Once the flow is done, the product that is left behind is called a pyroclastic deposit and can vary significantly. There are several different “types” of pyroclastic flows and with that come several different names. Ash flows and ash clouds are flows that consist of primarily ash-sized particles, while block and ash flows consist primarily of ahs and large lava fragments(Pyroclastic-Flow Terminology). A base surge is a low-density flow of rock debris and water and (or) steam, a directed blast is a volcanic explosion of rocks or magma (or both) with a low-angle component(Pyroclastic-Flow Terminology). Nuee ardente (or “glowing cloud“) is a description of what a pyroclastic flow may look like at night or in low light situations(Pyroclastic-Flow Terminology). A pumice flow is a flow consisting of predominantly pumice fragments(Pyroclastic-Flow Terminology). A pyroclastic surge is much like a pyroclastic flow, only it is less dense and contains more gases(Pyroclastic-Flow Terminology), these surges may spread over large areas and cross ridges(Long Valley Observatory).

The size of a grey eruption depends on two main variables: one, the nature of the magma, and two, how much magma is there. If there is over 1000 cubic km of eruptible magma, then it is called a super volcano(Wikipedia 2006). When a super volcano eruption occurs, it can last days or even weeks at a time(Wikipedia 2006). The batholith will empty its eruptible magma out of several different vents, once the emptied batholith is unable to support the ground above, it will collapse and form what is called a caldera(Volcanoes 2003). Eruptions of this size will kill everything within 100 km from pyroclastic flows, as well as blanket entire continents with ash(Wikipedia 2006). In a super eruption pyroclastic flows can travel up to 100 km and deposit volcanic material hundreds of meters thick(Wikipedia 2006).

Characteristics of Pyroclastic flows:

A pyroclastic flow is a high-speed avalanche of hot ash, rock fragments, and gas moving down the sides of a volcano and away from the vent during an explosive eruption. A pyroclastic flow can be between 100 to 800 degrees Celsius and move up to 150 km/hr(Myers and Brantley 1995). Many pyroclastic flows consist of two parts: a basal flow, the lowest part of the flow, consisting of coarse fragments that moves along the ground, and a turbulent cloud of ash that rises above the basal flow(Myers and Brantley 1995). These flows will incinerate and destroy almost everything in its path. With rock fragments ranging from ash to boulders traveling across the ground at speeds usually greater than 80 km per hour, pyroclastic flows knock down, obliterate, bury, or carry away nearly all objects and structures in their path(Myers and Brantley 1995). The extreme temperatures of rocks and gases inside the pyroclastic flows can cause combustible materials to burn. Pyroclastic flows can vary in size and speed, but even the smallest ones can do considerable damage, and are still very lethal. Pyroclastic flows generally follow valleys or other low-lying areas and, depending on the volume of rock debris carried, they can deposit layers of loose rock fragments to depths less than 1 m to more than hundreds of meters(Myers and Brantley 1995). Although, pyroclastic surges, which are less dense and contain more gases than rock, may easily move up and over ridges(Myers and Brantley 1995).

The most common way to produce a pyroclastic flow is an explosive eruption of magma, whether it be a directed blast, which is where the eruption took place on the side of a volcano and that created a flow, the 1980 eruption of Mt. St. Helens is a good example, or a collapse of a vertical column of ash and larger rock fragments, where the vertical ash and rock fragment column begin to fall down on itself due to gravity(Myers and Brantley 1995). Pyroclastic flows can also be formed from a collapse of a lava flow, this only occurs with lava domes and other viscous magmas(Myers and Brantley 1995).

Pyroclastic deposits:

Pyroclastic flow deposits can be hundreds of meters thick, the general term for the rock unit deposit is ignimbrite. Silicic ignimbrites are most common, although ryholite to basaltic ignimbrites also occur(Kanen). The length and depth of the ignimbrite often depends on the topography, as they are usually deposited in low lying areas. Ignimbrites usually consist of three layers. The lowest layer, or sillar layer, generally doesn't have any large fragments, which are probably expelled due to frictional forces. It is a smaller grain size with small glass and pumice fragments and is usually white or gray in color. The middle layer is often welded and very poorly sorted. An ignimbrite becomes welded because the fragments were still hot enough and partially molten to fuse together creating a single layer, this layer is called a cooling unit. Often the middle layer shows a reverse grading of pumice and normal grading of larger lithic fragments. It varies in color from light brown to black. The middle layer merges into the top layer which consists of unwelded ash tuff(Kanen).

Poor sorting, subtle or no grading, and poor or no bedding are all characteristics of pyroclastic flow deposits, although usually a crude layering can be found. Some differences in size of fragments in different layers give an irregular and indistinct stratification to some deposits. Flat fragments within the deposit near their basal parts are commonly strongly oriented parallel to depositional surfaces or are imbricated, which is just a fancy way of saying dipping up the flow(Richard V. Fisher 1997). Pumice fragments tend to show inverse grading, the largest occurring at the top of a flow, this can be observed at the Pumice Quarry near Bishop California. The denser lithic fragments concentrate toward the base. The inverse grading of pumice is caused by buoyant rise during the flow, because pumice is less dense than most other fragments of rock. Maximum sizes of lithic and pumice fragments decrease with distance from source, in a similar way that grading occurs in streams, as the pyroclastic flow moves away from its origin, its strength, force and momentum decrease with distance, as well as its ability to carrier larger rock fragments. Multiple grading and bedding may develop from separate flows of the same composition repeated at relatively short time intervals(Richard V. Fisher 1997). And by topographic splitting of the flow front which advances around obstacles and reunites on the opposite side, and mechanical segregation of different fragments sizes due to shearing within a high concentration flow(Richard V. Fisher 1997).

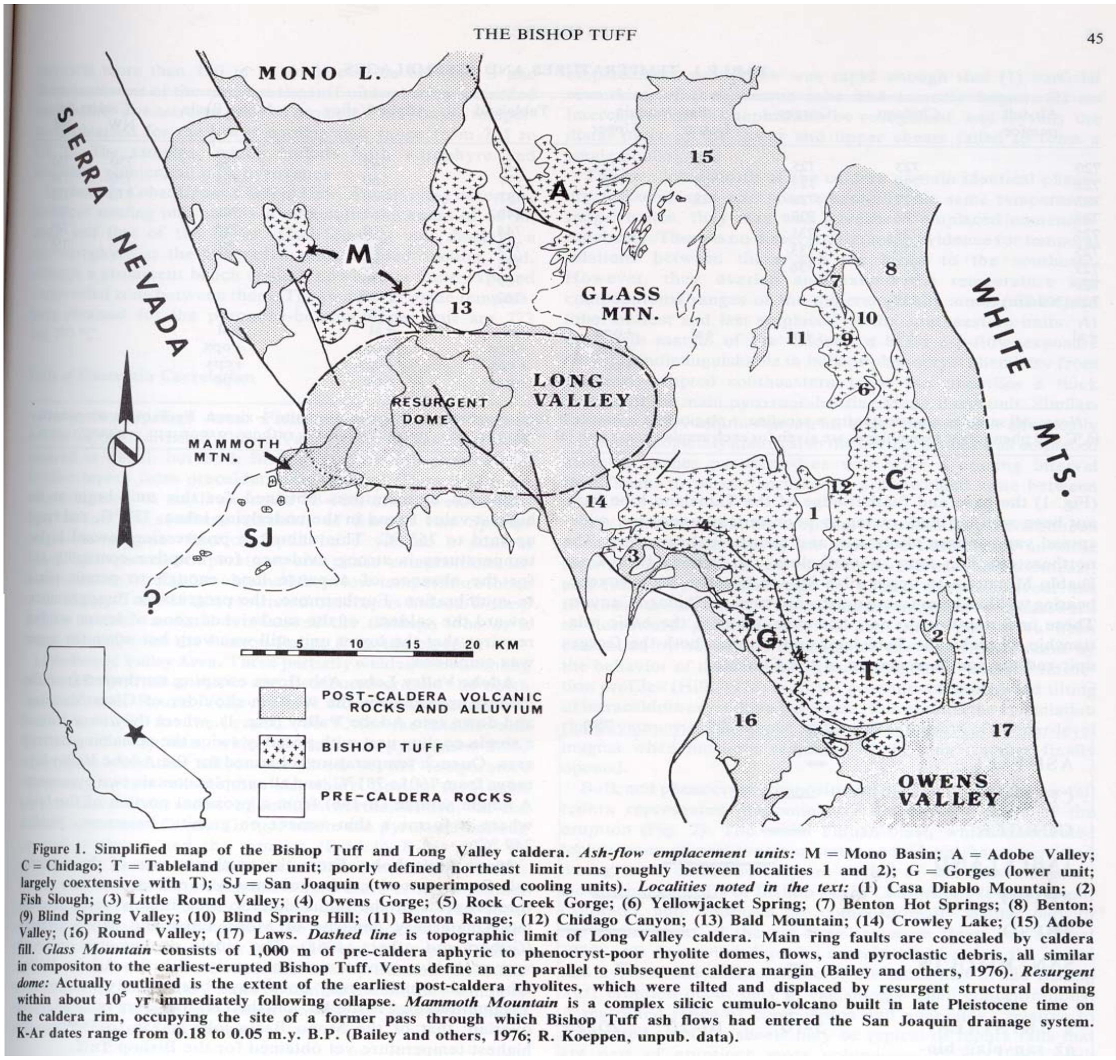

Figure 1: This photo shows the Long Valley Caldera and The Bishop Tuff

Long Valley Caldera and the Bishop Tuff:

The Long Valley Caldera is a large depression that is about 32 km (east-west) long and 17 km (north-south) wide (Figure 1)(Bailey 1976). It is located in eastern California adjacent to Mammoth Mountain. Long Valley is one of the largest calderas in the world, and was formed 760,000 years ago when a super eruption occurred, creating huge pyroclastic flows that cooled and formed the now called Bishop Tuff. The eruption was so huge that it emptied out the magma chamber beneath the now destroyed volcano to the point of collapse. This collapse caused a secondary pyroclastic flow to occur, which burned and buried thousands of square miles(Bailey 1976). Ash from this eruption covered much of the western part of the United States(Colin J. N. Wilson and Wes Hildreth 2000). The depression made from the collapse is called a caldera. Because the caldera was formed by volcanism, radiometric dating can be used, the formation of the Bishop Tuff is about .76 million years old, and we then know that the eruption and the formation of the caldera must also be around that age as well(Colin J. N. Wilson and Wes Hildreth 2000).

A fine grained lake bed deposit inside of the caldera suggests that a lake used to be there about 600,000 years ago(David Alt and Donald Hyndman 2000). Observations can be made on the sides of the caldera where erosion has occurred from the lake. The lake then overtopped the southern rim of the caldera, eroded the sill, and created the Owens River Gorge(David Alt and Donald Hyndman 2000). The lake then completely drained in the last 100,000 years(David Alt and Donald Hyndman 2000). Since all of this occurred inside and through the caldera and into the Bishop Tuff, it is obvious that the eruption would have to have occurred some time before the lake(David Alt and Donald Hyndman 2000).

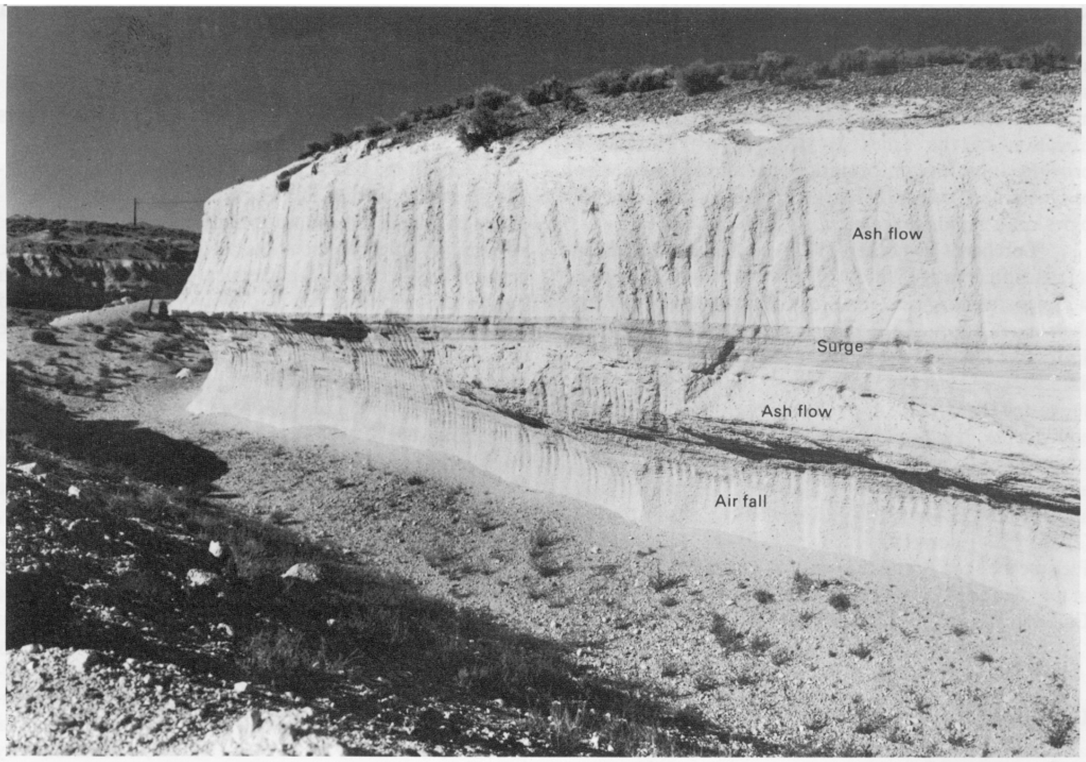

Figure 2. Lower part of the Bishop Tuff at the Insulating Aggregates Co. quarry about 10 km north of Bishop, Calif. A basal air-fall pumice unit is overlain by a thin, lenticular ash flow, which in turn is overlain by a thin, pumice-rich surge deposit followed by a thick ash flow. Pyroxene microphenocrysts were found in a few pumice lumps in the surge deposit. Air-fall unit is about 4 m thick (base not exposed); surge deposit is about 1 m thick.

Figure 2: This is a photo of the Pumice Quarry, 10 miles north of Bishop California.

The Bishop Tuff is an ignimbrite (welded tuff), a cooled deposit of a huge rhyolitic pyroclastic flow(Bailey 1976). It formed .76 million years ago and covers nearly 2,200 square kilometers of area, with deposits ranging from 150 to 200 meters in thickness(Roy A. Bailey, C. Dan Miller, and Kerry Sieh 1989). At the most southern edge of the Tableland(Bishop Tuff south of caldera) the Bishop Tuff is the least welded, one location for this observation would be the Bishop Pumice Quarry. At the Bishop Pumice Quarry (Figure 2) there is 4-6 m of distal Bishop Tuff flow. The flows were massive and are generally poorly sorted, noting the size of the single layers, but the few basal centimeters consists almost entirely of fine ash, suggestive of a pyroclastic surge(Roy A. Bailey, C. Dan Miller, and Kerry Sieh 1989). The lowest 2 m of ash flows contain many discontinuous swarms of relatively coarse pumice lapilli and blocks, indicating that pyroclastic flows must have overlapped each other and other sporadic movement must have occurred with in the flows(Roy A. Bailey, C. Dan Miller, and Kerry Sieh 1989). At Chalk Bluffs (southern most edge of the observed Bishop Tuff) the top of the cliffs are partially welded by the Bishop ash flows. What lies beneath the ash flow deposits are pre-caldera eruptions, from Glass Mountain eruption(Roy A. Bailey, C. Dan Miller, and Kerry Sieh 1989). In the middle of the Bishop Tuff, inside the Owens River Gorge, 150 m deep is visible of the Bishop Tuff. Here the Bishop Tuff is far more welded than Chalk Bluffs. The upper half of the Bishop Tuff is pinkish, porous, and poorly to moderately welded. The lower half of the Bishop Tuff is dark grey in color and becomes more densely welded and less porous(Roy A. Bailey, C. Dan Miller, and Kerry Sieh 1989).

Distal ahs fall deposits can be found as far north as Idaho, as far east as Nebraska, and as far south as New Mexico(Glen A. Izett, John D. Obradovich, and Harald H. Mehnert 1988). The ash was erupted high into the atmosphere and blown by winds to cover more than 1 million square miles of the Western United States(Glen A. Izett, John D. Obradovich, and Harald H. Mehnert 1988). By 1988 over 40 different locations of the Bishop Ash had been found. These deposits are very fine grains of rhyolite ash, another name for this deposit is bentonite clays(Glen A. Izett, John D. Obradovich, and Harald H. Mehnert 1988).

Geochemistry and Structures within the Bishop Tuff:

The entire Bishop Tuff is high-silica rhyolite, but virtually all the elements vary with temperature. The most common minerals in the Bishop Tuff is as follows, usually in the this order of abundance: quartz, sanidine, plagioclase, biotite, pyroxenes, allanite, zircon, apatite, and pyrrhotite. The Bishop Tuff has about 25% phenocryst content at about 790 degrees Celsius, or in other words, the Bishop Tuff has about one quarter of actual mineral crystals, and the rest of the Bishop Tuff formed too rapidly to make crystals and it cooled at about 790 degrees Celsius(Wes Hildreth 1979).

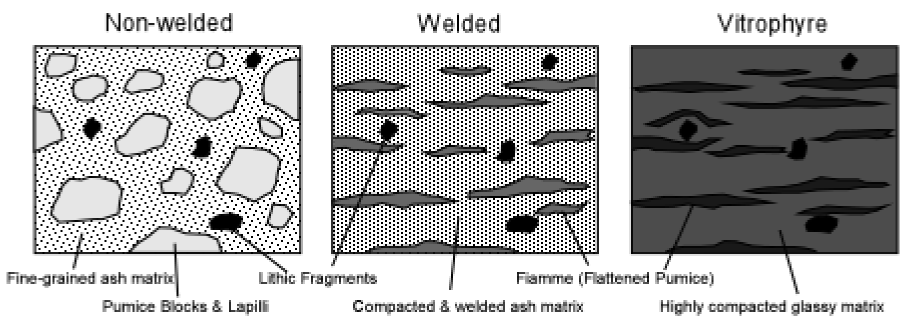

Figure 3: Diagram showing the different levels of welding in an ash-flow deposit and the type of deposit produced.

At the Owens River Gorge many different structures can be seen within the Bishop Tuff. Fiamme structures are common throughout the Gorge (Figure 3), but are less common on the top quarter of the Gorge. Fiamme structures are elongated pumice and obsidian fragments that have been flattened parallel to the direction of the flow by heat and pressure(Roy A. Bailey, C. Dan Miller, and Kerry Sieh 1989). In the upper half of the gorge there are locally columns that point towards a common foci, this formation of columns are rosette joints. These rosette joints are what’s left of large fossil fumaroles. At the top of these rosette joints are indurate fumarolic mounds, exposed by the Owens River cutting through the surface of the Bishop Tuff. The location of these mounds close to the present gorge suggests that the gases and products responsible for their formation were derived in part from the ancestral Owens River, which was overrun by the Bishop ash flows.(Roy A. Bailey, C. Dan Miller, and Kerry Sieh 1989). Giving further evidence that the original Owens River must have flowed near this area 760,000 years ago.

The Bishop Tuff Chronology:

At almost every basal exposure, the ash flow section is underlain with 3 to 5 m of white, angular air-fall pumice, which is poorly sorted from sand-sized to 5 cm fragments(Wes Hildreth 1979). The temperatures of this pumice fall into a narrow range of 720 to 725 degrees Celsius(Wes Hildreth 1979). Next came the Chidago Lobe ash flow, this flow was the eastern expanse of the Bishop Tuff and flowed through the topographic low north of Casa Diablo Mountain and spread out from the present head of Chidago Canyon(Wes Hildreth 1979). This cooling unit had a temperature range of 723 to 737 degrees C(Wes Hildreth 1979). In the Owens River Gorge area there are two discrete cooling units that come together further south(Wes Hildreth 1979). The lowest cooling unit had a temperature of 725 to 736 degrees C, and therefore the flow of the Chidago Lobe must have erupted at the same time and then flowed around opposite sides of Casa Diablo Mountain and may have merged further south(Wes Hildreth 1979). The Tableland, or upper cooling unit, which overlaps the Chidago Lobe and the lower cooling unit has high temperatures of 737 to 763 degrees C(Wes Hildreth 1979). The increasing temperatures show strong evidence for a continuous eruptions and for the lack of long pauses(Wes Hildreth 1979). North of the caldera, is the Adobe Valley Lobe of Bishop Tuff, which has temperatures of 760 to 781 degrees Celsius(Wes Hildreth 1979). In the northwest, the Mono Basin Lobe is ¾ hidden by Mono Lake and the Mono Craters, its temperatures were 756 to 790 degrees Celsius(Wes Hildreth 1979). The mineralogy of this flow is similar to the Adobe Valley Lobe and both of them were probably erupted at the same time. The Mono Basin Lobe is the highest temperature yet to be obtained for the Bishop Tuff(Wes Hildreth 1979).

Conclusion:

The Bishop Tuff is a huge ignimbrite, left behind from a massive pyroclastic flow. It covers nearly 2,200 square kilometers. Pyroclastic flows of this magnitude are relatively uncommon, because it takes a super eruption to create them. Further yet the pyroclastic flow was hot enough to reach temperatures to weld its deposits together. Although compared to Yellowstone and other super eruptions, products like the Bishop Tuff are not uncommon, although differences in chemical composition will have changes of welding and erosion of the pyroclastic deposits. To find similar ignimbrites and pyroclastic deposits of this magnitude, it would be wise to look for similarly large eruptions. Super eruptions of this size will happen again, in time. And anyone who wants to survive such an eruption must clear out the area within at least a 100 km radius, to get away form the huge pyroclastic flows.

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Figure 1: The Bishop Ash Bed (Middle Pleistocene) and Some Older (Pliocene and Pleistocene) Chemically and Mineralogically Similar Ash Beds in California, Nevada, and Utah. Izett, Glen A. and John D. Obradovich, and Harald H. Mehnert. p.6.

Figure 2: Ash Flow Tuffs: The Bishop Tuff: Evidence for the origin of compositional zonation in silicic magma chambers, Wes Hildreth. p.45.

Figure 3: Fiamme Structures. Pamela Williams.

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