Plinian and Ultra Plinian volcanos are the most explosive types of volcanoes.

Plinian plumes inevitably contain ice because of the height of the plume and the abundance of water. Other volcanic plumes topping out lower than the Plinian may also contain ice.

Figure 1 below. Plume heights typically exceed 25 km, some as high as 40 km.

Figure 2: Redoubt Volcano, Alaska – Alaska Volcano Observatory Photograph by R. Cluas April 21, 1990, U. S. Geological Survey

The Plume rises through several thin stable layers before broadly spreading out just above the tropopause. The top of the cloud penetrates into the stratosphere. This plume is free of cross winds enabling us to see the turbulence on the edges of the plume.

Figure 3: Erupting plume in Iceland Photograph by Marco Fulle – April 17, 2011

The photograph above is beautiful and also informative. In it we see both products present in volcanic clouds, discharges emerging near the vent and discharges extending from the volcanic cloud higher in the atmosphere. The upper discharges look exactly like negative cloud-ground lightning from thunderstorms. If this is the case then the lower plume is the product of the height extinction by which would be shifted positively. Many of the lower discharges of this lightning flash are also moving toward the lower plume.

The discharges in the lower plume appear quite different. They are short and reddish in color; the discharge has a very large optical thickness, so we only see the portions of the discharges that are close to the edge of the plume. The horizontal extent of the discharges is greater than the distance between the trigger plume for a short distance. The reddish emission extends beyond the discharge distance indicating that the discharge is heating the surrounding ash, which then radiates the reddish radiation.

Acknowledgment
This research supported through the Charles L. Corin Endowment Fund for Research

Pliny the Elder (Gaius Plinius Secundus, 23 AD – August 25, 79 AD) was a roman philosopher and the author of Naturalis Historia, which was the first book written in the format of an encyclopedia. He was also a military commander of roman and friend of roman emperors. During the eruption of Mount Vesuvius, which had already destroyed the cities of Pompeii and Herculaneum, Pliny commissioned a ship to take him across the Bay of Naples only to directly observe the volcanos but to rescue family friends. In his later years Pliny is reported that he was quite obsessed requiring the assistance of two servants to stand up from a seated position. He was physically unable to return to the ship and stood behind where he died. His body was hand covered in pumice. Pliny had no children; he adopted his nephew (Pliny the Younger), helped raise and educate him, and left him his fortune and legacy.

Pliny the Younger (Gaius Plinius Caecilius Secundus, AD 29 – 79) was correspondent and the emperor, the roman historian Tacitus. He was 18 when his uncle died during the Vesuvius eruption of 79 AD. He started writing at 14 and is recognized for his letters, although he was written to people they were meant for publication. Of special interest here are two letters written to the Roman Historian Tacitus. There are several English translations of the two letters (1) “a dreadful black cloud was torn by glowing flames and great tongues of fire like much-magnified letters: (1) “a dreadful black cloud was torn by glowing flames and great tongues of fire like much-magnified letters: (2) ‘In the other direction exposed a far greater number of recognizable phenomena (“saturating”) flashing and masses of flames, like lightning but much larger,” and (3) “the fire was a terrifying darkness...flaming to the horizon and barking, opening to reveal huge figures of flame. These were like lightning, but bigger.” This may be the first recorded description of lightning from “Plinian” volcanos.

Figure 4: The conditions in the magma chamber at depths 3 km to 30 km below the surface are, for hydrous magma, ~1200 °C and ~1000 °C. Voltiles are dissolved in the magma, principally water and CO2. As the magma moves slowly (up to 1 m/s) toward the surface the pressure decreases and as pressure decreases the volatiles exsolve from the magma initially forming small gas bubbles. Further decrease in pressure accelerates the exsolution and the bubbles grow in size. At the intermediate stage the magma most likely contains too much CO2 in the magma, but the magma continues to envelope the bubbles. The upward flow is faster than the increase of the bubble pressure. Upon reaching a pressure level of 10 atm, which is probably within ~1 km of the surface, the volcanic bubbles are large enough to break up the magma and become the dominant component of the fluid. Until this stage the magma and its entrained bubbles are in thermodynamic and dynamic equilibrium; from this stage the fluid component increases as a function of height and magma velocity is driven thermodynamically and thermally; the magma with its mass and heat capacity maintains a temperature ~700 °C and ~300 °C, respectively, as the explosive rise of the gas cools rapidly. The expansion can use the gas component to ~400 °C. The larger the plume takes out of the plume rapidly with the smallest lipid and ash move with the plume gas and come into thermodynamic equilibrium probably somewhat above 400 °C.

Permission from Marco Fulle – www.smirnov.net

Endowment Fund for Research

Figure 5: Several curves are plotted in Figure 6 above in linear Altitude versus Temperature diagram. On the left side are schematic representations of the environmental profiles for tropical, mid-latitude and polar atmospheres. As long as there is a volcanic plume/cloud reaches to the right of the appropriate profile it will remain buoyant. The “Saturnian Airshroud” curve is an extension of the conditions computed above to the top of the troposphere of the jet of the vent; a thermodynamic diagram was used to plot this curve. This curve labeled “Heikkinen et. al. Model” is derived from their Figure 5. Their model is a cloud physics model including microphysics that is placed in a moist tropical environment. Among their conclusions is that for conditions of maximum entrainment and latent release to the cloud exists. Finally, the right most curve “Nakamura and Vesper Pressure” used was computed using the Clausius-Clapeyron equation. This curve represents the upper boundary for clouds because it assumes that the vapor is providing the total pressure in the cloud.

Figure 6: The curves in Figure 5 are useful to understanding the consequences of the entraining of water in volcanic plumes. In summary, ice nucleation in thunderstorm clouds, there are no ice particles but they can grow large on the available vapor. In contrast volcanic clouds contain numerous ice nuclei particularly, and they can develop as many small ice particles. This great difference in ice behavior between the thunderstorm clouds and the volcanic clouds can have significant impact on electrification, cloud evolution and chemical transport into the stratosphere.

To produce Figure 6, I took 1 m² of water and distributed it into “1” hexagonal ice crystals each having a side dimension “a” and length “na”. I then computed for each value of the total surface area of the whole collection of crystals. The results are displayed in the figure. We easily see that as the number of crystals increases the total surface and the cross-sectional areas of the system even when the volume is constant.

1. Electric charge resides on the surface of ice particles; hence, the more numerous but smaller ice particles have a greater electric capacity.

2. The adsorption capability of ice particles for chemicals in the volcanic plumes is also proportional to total surface area.

3. The smaller ice particles are more easily lifted into the stratosphere transporting the volcanic chemicals.

4. Ice contact is a source of electrical charging and the frequency of particle collisions is increased with increased cross-sectional area.

Credit: Sakurajima Volcanological Observatory


In summary, ice nucleation in thunderstorm clouds, there are no ice particles but they can grow large on the available vapor. In contrast volcanic clouds contain numerous ice nuclei particularly, and they can develop as many small ice particles. This great difference in ice behavior between the thunderstorm clouds and the volcanic clouds can have significant impact on electrification, cloud evolution and chemical transport into the stratosphere.

To produce Figure 6, I took 1 m² of water and distributed it into “1” hexagonal ice crystals each having a side dimension “a” and length “na”. I then computed for each value of the total surface area of the whole collection of crystals. The results are displayed in the figure. We easily see that as the number of crystals increases the total surface and the cross-sectional areas of the system even when the volume is constant.

1. Electric charge resides on the surface of ice particles; hence, the more numerous but smaller ice particles have a greater electric capacity.

2. The adsorption capability of ice particles for chemicals in the volcanic plumes is also proportional to total surface area.

3. The smaller ice particles are more easily lifted into the stratosphere transporting the volcanic chemicals.

4. Ice contact is a source of electrical charging and the frequency of particle collisions is increased with increased cross-sectional area.