# Volcanologists discover how bubbles accumulate in magma

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Tambora on the Indonesian island of Sumbawa: the explosive eruption of this volcano 200 years ago cooled the climate and lead to a year without a summer. Credit: Jialiang Gao / Wikimedia Commons CC BY-SA 3.0

In 1816, summer failed to make an appearance in central Europe and people were starving. Just a year earlier, the Tambora volcano had erupted in Indonesia, spewing huge amounts of ash and sulphur into the atmosphere. As these particles partly blocked sunlight, cooling the climate, it had a serious impact on the land and the people, even in Switzerland.

Since then, volcanologists have developed more precise ideas of why super-volcanoes such as Tambora are not only highly explosive but also why they release so much sulphur into the atmosphere.

Gas bubbles tend to accumulate in the upper layers of magma reservoirs, which are only a few kilometres beneath the earth's surface, building up pressure that can then be abruptly liberated by eruption. These bubbles mainly contain water vapour but also sulphur.

## Sulphur-rich eruptions

"Such volcanic eruptions can be extremely powerful and spew an enormous amount of ash and sulphur to the surface," says Andrea Parmigiani, a post-doc in the Institute of Geochemistry and Petrology at ETH Zurich. "We've known for some time that gas bubbles play a major role in such events, but we had only been able to speculate on how they accumulate in magma reservoirs."

Together with other scientists from ETH Zurich and Georgia Institute of Technology (Georgia Tech), the researchers studied the behaviour of bubbles with a computer model.

The scientists used theoretical calculations and laboratory experiments to examine in particular how bubbles in crystal-rich and crystal-poor layers of magma reservoirs move buoyantly upward. In many volcanic systems, the magma reservoir consists mainly of two zones: an upper layer consisting of viscous melt with almost no crystals, and a lower layer rich in crystals, but still containing pore space.

**Super bubbles meander through a maze**

When Andrea Parmigiani, Christian Huber and Olivier Bachmann started this project, they thought that the bubbles, as they moved upwards through crystal-rich areas of the magma reservoirs, would dramatically slow down, while they would go faster in the crystal-poor zones.

"Instead, we found that, under volatile-rich conditions, they would ascend much faster in the crystal-rich zones, and accumulate in the melt-rich portions above" says Parmigiani.

Parmigiani explains this as follows: when the proportion of bubbles in the pore space of the crystal-rich layers increases, small individual bubbles coalesce into finger-like channels, displacing the existing highly viscous melt. These finger-like channels allow for a higher vertical gas velocity. The bubbles, however, have to fill at least 10 to 15 % of the pore space.

"If the vapour phase cannot form these channels, individual bubbles are mechanically trapped," says the earth scientist. As these finger-like channels reach the boundary of the crystal-poor melt, individual, more spherical bubbles detach, and continue their ascent towards the surface. However, the more bubble, the more reduce their migration velocity is.

This is because each bubble creates a return flow of viscous melt around it. When an adjacent bubble feels this return flow, it is slowed down. This process was demonstrated in a laboratory experiment conducted by Parmigiani's colleagues Salah Faroughi and Christian Huber at Georgia Tech, using water bubbles in a viscous silicone solution.

"Through this mechanism, a large number of gas bubbles can accumulate in the crystal-poor melt under the roof of the magma reservoir. This eventually leads to overpressurization of the reservoir," says lead author Parmigiani. And because the bubbles also contain sulphur, this also accumulates, explaining why such a volcano might emit more sulphur than expected based on its composition.

What this means for the explosivity of a given volcano is still unclear. "This study focuses primarily on understanding the basic principles of gas flow in magma reservoirs; a direct application to prediction of volcanic behaviour remains a question for the future," says the researcher, adding that existing computer models do not depict the entire magma reservoir, but only a tiny part of it: roughly a square of a few cubic centimeter with a clear boundary between the crystal-poor and crystal-rich layers.

To calculate this small volume, Parmigiani used high-performance computers such as the Euler Cluster at ETH Zurich and a supercomputer at the Swiss National Supercomputing Centre in Lugano.

For the software, the researcher had access to the open-source library Palabos, which he continues to develop in collaboration with researchers from University of Geneva. "This software is particularly suitable for this type of simulation," says the physicist.

**More information:** A. Parmigiani et al. Bubble accumulation and its role in the evolution of magma reservoirs in the upper crust, *Nature* (2016). DOI: 10.1038/nature17401

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