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Bubble Expansion and Magma Fragmentation: the Importance of Decompression Rate

Atsuko Namiki[1]; Michael Manga[1]

[1] UC Berkeley

http://seismo.berkeley.edu/˜namiki/

The occurrence of explosive and effusive volcanic eruptions is often attributed to fragmentation and gas escape by permeable flow, respectively. In Namiki and Manga [EPSL vol.236, page 269-284 (2005)], we presented decompression experiments of bubbly fluid and found that for sufficiently large pressure reduction DP and initial vesicularity Phi, the fluid can fragment and make a highly permeable structure caused by rupture of bubble walls. In our previous study, however, the decompression was always instantaneous. In this study, we perform another series of decompression experiments using the same shock-tube apparatus to investigate the effect of decompression rate on the expansion and eruption style of bubbly, viscoelastic fluids. For fast decompression, we again observe fragmentation and rupture of bubble walls for large DP and large Phi. For slow decompression, however, bubbles maintain a spherical shape as the bubbly fluid expands irrespective of DP and Phi. In order to explain the effect of decompression rate on the style of eruption, we compare theoretical models for the expansion of the bubbly fluid with the observed expansion. We consider two theoretical limits for the expansion of bubbles which we refer to as ‘equilibrium‘ and ‘disequilibrium‘ expansion. During equilibrium expansion, the pressures inside and outside the bubbles are assumed to be equal throughout the decompression. The height of the expanding bubbly fluid can be calculated using the ideal gas law assuming isothermal expansion of the bubbles is caused by the pressure reduction. For disequilibrium expansion, we calculate the velocity of the expanding bubbly fluid assuming that the enthalpy change caused by the pressure reduction is converted into kinetic energy. When the decompression is fast enough, the calculated expansion rate under the equilibrium assumption is greater than that for disequilibrium expansion, and vice versa for sufficiently slow decompression. In the latter limit, where bubbles expand while maintaining their spherical shape, the measured expansion is well-explained by equilibrium expansion. On the other hand, for fast decompression cases in which we observe the rupture of bubble walls and fragmentation, the expansion follows disequilibrium expansion. We thus conclude that fragmentation and the rupture of bubble walls require disequilibrium expansion so that there is a pressure difference between the gas inside the bubbles and surrounding fluid.