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Mechanism of delayed fragmentation of vesicular magma by decompression

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The fragmentation of vesicular magma is a key phenomenon to determine the style of volcanic eruption. To understand the magma fragmentation, we performed a rapid decompression experiment using bubbly syrup as an analogous material of vesicular magma. We classify the onset of fragmentation using a measure of brittleness (critical brittleness) at the bubble surface at the time when the differential stress at the surface reaches the critical fracture stress. In our case, the brittleness is unity when the response of material is brittle. It is 0.5 when the material response is completely ductile. The results are summarized as follows: (a) Brittle fragmentation occurs when the critical brittleness close to unity when the differential stress reaches the critical stress; (b) No fragmentation occurs when the critical brittleness is close to 0.5 if the differential stress is slightly larger than the critical stress. In addition to the classifications (a) and (b), we find the other class: (c) Delayed fragmentation occurs even if the critical brittleness indicates the ductile response of the material when the differential stress sufficiently exceeds the critical stress.

The delayed fragmentation occurs within the characteristic time of bubble expansion in viscous liquid, while its onset is after the relaxation time of viscoelastic material. This means that the delayed fragmentation is brittle-like (solid-like) fragmentation. Magma fragmentation may be viewed as sequential brittle-like fragmentation (Kameda et al. JVGR (2012), submitted).

To understand the cause of the delayed fragmentation, we tested the response of a large number of samples, which vary in brittleness, volume, bubble diameter, void fraction, and porosity distribution. The volume of samples is selected from 25 ml (small) or 100 ml (large). The void fraction is in the range of 3 to 28%.

From the experiments with small volume of samples, we observed some of samples exhibit no fragmentation even if their critical brittleness was about 0.9. All the samples with large volumes fragment when the brittleness was 0.9. The pore distribution of the small samples is more uniform than that of large samples. Therefore, stress concentration in the small samples is weaker than that in the large samples.

Next, we evaluated the influence of bubble diameter to the response of the sample. We generated the oxygen bubbles in the sample using hydrogen peroxide and manganese dioxide as a catalyst. We controlled the bubble diameter by changing the temperature of the syrup when we added the manganese dioxide. The response of two samples with different bubble was observed diameters simultaneously placed in the decompression facility. The observation indicates the response of two samples is identical. Therefore, average bubble diameter does not affect the onset of fragmentation.

We find that fragmentation does not occur in the sample with the void fraction less than 8% whose critical brittleness is about 0.9. Then, we observed the response of the sample with low void fraction but in which a large volume of cavity was artificially created. This sample fragments.

The critical brittleness was calculated using the differential stress on the bubble surface under the assumption of uniform pore distribution. Our experiments indicate that this calculated value may inadequate to evaluate the fragmentation. The true value of brittleness required to the onset of brittle fragmentation should be close to unity. Our experiments also suggest that the delayed fragmentation observed with lower value of the critical brittleness is caused by non-uniform pore distribution, which leads to increase the local differential stress and brittleness in the sample.

Keywords: fragmentation, viscoelasticity, analogous experiment, brittleness