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Brittle to ductile transition in fragmentation of vesicular magma by decompression

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Fragmentation of vesicular magma due to rapid decompression in volcanic conduits is a key process to determine the style of volcanic eruption. Intensive researches have been conducted to find the conditions where the brittle fragmentation occurs. The magma is a viscoelastic material, not a solid. Thus, the characteristic time of decompression should be incorporated into the fragmentation condition.

The viscoelasticity of magma is modeled using the Maxwell relation, in which the relaxation time of solid to liquid state is defined as the ratio of viscosity to rigidity. The brittle fragmentation is expected when the characteristic decompression time is within the relaxation time (Martel et al. 2000). We examined the time dependence of the fragmentation of vesicular viscoelastic materials using a rapid decompression facility. We developed a novel analogous material of vesicular magma, which is maltose syrup with oxygen bubbles. The oxygen bubbles are generated from hydrogen peroxide with manganese dioxide as catalyst. The viscosity of syrup is controlled by dehydration and temperature.

The syrup is more suitable analogous material to simulate the fragmentation of vesicular magma than those previously used. The syrup has considerably large rigidity (1 GPa, Ichihara et al. 2004), which is close to the rigidity of natural magma (O(10 GPa)). The material with low rigidity like polymer exhibits rubber-like behavior. This rubber-like behavior is not expected in the fragmentation of the natural magma. The water content in the syrup alters its viscosity, while it does not affect the rigidity in its elastic limit. Thus we can control the Maxwell relaxation time by alternation of the viscosity.

The rapid decompression facility consists of a high-pressure vessel and a large vacuum chamber. Double diaphragms are installed to separate from each other. The bubbly syrup (specimen) is heaped up on the bottom of the vessel. No side-wall is attached to the specimen. The vessel is decompressed by rupturing the diaphragms. Occasionally an orifice is placed beneath the diaphragm to reduce the decompression rate. The response of the specimen is observed by high-speed photography.

In the present experiment, we choose a constant initial pressure (3 MPa) and a constant terminal pressure (0.05 MPa). The viscosity is varied from 10^4 Pa.s to 10^9 Pa.s, whose Maxwell relaxation time is from 10^{-5} s to 1 s. The decompression rate is from 0.1 MPa/s to 400 MPa/s, whose characteristic time is from 10 s to $5x10^{-3}$ s. The porosity of the specimen is 6% in most cases. The specimen with larger porosity (50%) is tested in the case where the viscosity is 10^5 Pa.s.

The experimental result shows that the style of deformation due to rapid decompression is classified into three modes: (A) brittle fragmentation without expansion, (B) fracutre after small ductile expansion, (C) ductile expansion without fracture. The mode A is observed when the ratio of characteristic decompression time to the relaxation time is smaller than unity. The mode B appears when the ratio is from several tens to unity. the porosity of the specimen also has influence on the classification criterion. The mode is changed from C to B as the porosity increases with a constant time ratio. On the other hand, in the mode B, the duration required to start the fracture is longer than the mode A fracture. This fact suggests that the fragmentation of the low viscous magma is delayed from the highly viscous ones. Further investigation is needed to understand the dynamic fracture mechanics of vesicular viscoelastic materials.