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A fragmentation criterion for highly viscous magmas estimated from shock tube experiments

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When a bubbly magma is decompressed during an explosive eruption, the magma fragments; the bubbly magma changes into a gas-pyroclast dispersion. This process is a key for understanding of explosive volcanisms, because it critically control the efficiency for the potential energy and thermal energy of an expanding magma (liquid and gas phases) to be converted to the kinetic energy of individual pyroclasts. For this reason a number of shock-tube experiments have been conducted using actual magmas or porous rock in order to investigate the physics of magma fragmentation. On the other hand, Koyaguchi and Mitani (2005) have recently extended the classical shock-tube theory for inviscid compressible fluid to the cases of viscous bubbly magmas. The new theory enables us to estimate the physical conditions (e.g., stress in the melt) during fragmentation of highly viscous bubbly magma in the shock tube experiments. Here, we apply an extended version of this theory to recent shock tube experiments, and determine the criterion of magma fragmentation.

In the shock tube experiments, initially a highly viscous bubbly magma at a high pressure is separated from air at the atmosphere by a diaphragm. As the diaphragm is ruptured, the bubbly magma is decompressed and layer-by-layer fracturing propagates through the magma. The new theory provides an analytical relationship between the difference between gas pressure inside bubbles and the mean pressure of the gas-liquid mixture (gas-overpressure) at the fragmentation surface and the downward propagation velocity of the fragmentation surface (fragmentation speed). Applying this relationship to the data of fragmentation speed in recent shock tube experiments using natural highly viscous magma and porous rocks (e.g., Spieler et al., 2004; Scheu et al., 2005), we found two tendencies; (1) the gas-overpressure at the fragmentation surface systematically increases as the initial pressure increases, and (2) the increasing rate of the gas-overpressure with the initial pressure systematically decreases as the initial porosity decreases. These two tendencies are accounted for by a criterion that magma fragments when the tangential stress around bubbles becomes tensile (or exceeds an effective tensile strength of a few MPa) even away from the bubbles. We propose a new formula of fragmentation criterion of highly viscous magmas on the basis of this interpretation.