A tree diagram for responses of bubbly magma on rapid decompression base on bubble dynamics

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When bubbly magma is subject to rapid decompression, it can show a variety of fragmentation and expansion behaviors. This study presents a tree diagram for various responses of the bubbly magma.

According to laboratory experiments using a shock-tube, and to theoretical models there are three types of fragmentations: (1) solid-like fragmentation before expansion, (2) fluid-like fragmentation after expansion, and (3) solid-like fragmentation after expansion. In laboratory experiments, (1) and (2) are mainly observed, while in the actual eruption, (3) is regarded to be the major mechanisms.

We propose bifurcations conditions between different processes toward the individual fragmentation mechanisms based on the expansion dynamics of a single bubble.

Characteristic times governing expansion of a bubble by rapid decompression are τ_{vis} associated with viscous expansion of a bubble, τ_{in} associated with inertia-controlled bubble expansion, τ_{dif} associated with diffusion-controlled bubble expansion, τ_{rlx} that is relaxation time of viscoelastic magma, τ_{dec} that represents the given decompression time, and τ_{ws} that is the characteristic time of stress accumulation at the bubble wall. Based on the results of laboratory experiments and theoretical analyses, it is found that the response of bubbly magma on rapid decompression is controlled by relations among these characteristic times.

A bubble expands before stress accumulation at the wall when τ_{vis} is larger than τ_{dec} and τ_{rlx} is larger than τ_{in} and τ_{vis} is larger than τ_{rlx} (Ichihara, 2008). Then solid-like fragmentation occurs when the stress at the bubble wall is large enough. Moreover, the solid-like fragmentation is classified to brittle fragmentation and brittle-like fragmentation, the latter of which occurs with a certain time delay, depending on the ration between τ_{dec} and τ_{rlx}. Generally, the critical stress for the fragmentation depends on τ_{ws}/τ_{rlx} and transition from brittle to brittle-like fragmentation occurs as τ_{ws}/τ_{rlx} exceeds unity.

It is assumed that the same criterion for the solid-like fragmentation is applicable to the solid-like fragmentation after expansion. The bubble expansion is controlled either by the viscosity or the inertia of the bubble wall. The former mechanism occurs when τ_{rlx} is smaller than τ_{vis} and larger than τ_{in}. In this case, the volatile diffusion from the magma to the bubble plays important roles in the stress accumulation and decreasing τ_{ws}/τ_{rlx} by keeping the overpressure of the bubble and increasing the magma viscosity. When this diffusion effect is large enough, the solid-like fragmentation criterion can be satisfied. On the other hand, when the inertia-controlled expansion occurs in magma, the stress cannot be accumulated. If fragmentation occurs in this case, it cannot be solid-like but fluid-like.