博士論文

An experimental study on interfacial tension-driven relaxation of magma foam: Implications for pressurization of volcanic conduits

（表面張力による発泡マグマの形状緩和実験：
火道増圧過程における意義）

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要　約

Permeable outgassing through the connected bubbles or brittle fractures are thought to control the explosivity and style of volcanic eruptions. Since permeability of magma is determined by the microstructure of outgassing pathways, interfacial tension plays a fundamental role for microstructure of magma. The effect of interfacial tension has been researched in case of bubble coalescence and relaxation of deformed bubble. However, interfacial tension works is unknown for complex porous structures such as natural foamed magma. In this study, I experimentally investigated the interfacial tension-driven microstructural relaxation of foamed magma in order to understand of permeability evolution of magmas in a volcanic conduit.

As a starting material for the heating experiments, I used andesitic pumice clasts from the 1914 (Taisho) Plinian eruption of Sakurajima volcano, Kagoshima Prefecture, Kyusyu, Japan. I assumed that this pumice is similar to foamed magma in conduits, which were rapidly decompressed, deformed by shear, retained hundreds of ppm H_2O in the melt, and had lower groundmass crystallinity. Pumice samples were cut into cubes of ca. 1.5, 3, 5, and 9 mm on a side. The pumice cubes were vacuum-encapsulated in a silica glass tube. The tubes were heated in a muffle furnace, and quenched after the run. Time series experiments were conducted at temperatures of 800–1000°C under ≤1 MPa vapor pressure (lower vapor pressure; LVP) and 1000°C under 2–6 MPa (higher vapor pressure; HVP) for 3 minutes to 32 hours. I simulated magmas in inter-explosion periods of vulcanian activity, including magmatic clasts welding within a shallow conduit. Microstructures were observed using a scanning electron microscope (SEM) and micro-focus X-ray computed tomography (CT), and their digital images were quantitatively analyzed for area fraction (porosity), circularity, and size distribution of the pores.

In 3-mm pumice cubes experiments, there were no change in the run products at 800°C for 32 hours, while outlines and internal pore microstructures of run products relaxed significantly in 3–5 and 30 minutes at 1000°C (at both LVP and HVP) and 900°C (LVP), respectively. The porosity of 3 mm-side pumice cubes decreased from 72 to 15%, 20% and 38% in 8 hours at 900°C, in 2 hours at 1000°C under LVP and in 30 minutes

1000°C under HVP, respectively. The decrease in initial porosity was caused by the expulsion of pores connected to sample surfaces via relaxation, and not as result of gravitational compaction or pressurization by water vapor in glass tubes. In this study, I call this process as 'self-contraction'. The porosity of run products was lower in the LVP experiments than in the HVP experiments because the melt viscosity was two orders of magnitude lower in the HVP experiments and some pores were trapped inside the pumice during the relaxation of complex open channels. As a result of complex pore relaxations, many small (≤ 100 μm equivalent radius), isolated bubbles having a wide range of circularities formed within 3 minutes. With time, bubble coalescence proceeded with an oscillatory increase in circularity.

For larger starting materials (9-mm pumice cubes), multiple contraction units formed melt globs, which promoted the formation of connected pores with concave-outward shapes between globs within a few to 30 minutes. In contrast to the inter-bubble network, such pores are expected to maintain high permeability on a macroscopic scale. These inter-glob pores disappeared due to gravitational deformation and healing of the boundaries after 8–32 hours at 1000°C.

I estimate the Bond number (*Bo*) to discuss relative effects of interfacial tension driven relaxation and gravitational compaction on sample external form. The *Bo* became 0.04–1.32 for the of 1.5–9-mm samples. It is roughly consistent with the present experiments results that showed the smaller samples (1.5- and 3-mm pumice cubes) to be almost spherical after hating for 30 minutes. On the other hand, the external form of the 9-mm samples was deformed due to the gravity force with increasing run duration.

The rapid changes in pore microstructures via relaxation, contraction, and compaction processes may be responsible for pressurization of volcanic couduit during vulcanian explosion cycles. The vulcanian explosions are often repeated at short intervals (a few minutes to several hours). The geological observations suggest that conduit magma is high permeability just after explosions, but becomes low permeability by the formation of lava cap in the volcanic crater, which lead to over pressurization in shallow conduit. Here I consider the permeability evolution in the shallow conduit of vulcanian cycle. Upon explosion, the magma within a deeper conduit vesiculates and ascends, which becomes permeable due to increased vesicularity via decompression and shear-induced bubble coalescence. The microstructural relaxation starts immediately after the rapid decompression of magma. When the conduit magma ceases to ascend, interfacial tension-driven relaxation will overcome shear deformation, and the formation of spherical bubbles and the conglobation of melt globs will then proceed coincidently in short time (3 minutes to 2 hours in present experiments). In this stage, magma outgassing is facilitated through inter-glob pathways. For the conduit magmas, the gravitational force is much larger than the interfacial tension of the melt; thus, gravitational compaction follows the establishment of an inter-glob pore network and outgassing. The timescale of compaction is estimated to be 20 and 1400 minutes at 1000 and 900°C, respectively, for a thickness of 10 m. This means that the top of conduit magma columns become impermeable by disappearing inter-glob pore via compaction. The microstructural evolution and timescales of foamed magmas observed in present study were consistent with the geological observations of volcanic activity.