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Compaction of silicic gas-rich magma during lava dome eruptions

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During lava dome eruptions, as silicic volatile-rich magma ascends to the surface and decompresses in volcanic conduits, the magma vesiculates and the exsolved gas expands. The porosity of the magma changes with depth owing to the competition between vesiculation and escape of gas from the magma. The processes of gas escape are controlled by viscous deformation of the gas-liquid mixture. Recently, Michaut et al. (2009) have applied the theory of magma compaction and melt segregation to the problem of viscous deformation of the gas-liquid mixture during degassing of gas-rich magma. Their mathematical analyses are based on the assumptions that the densities of both gas and liquid phases are constant and that the effect of viscous wall friction can be neglected. We have extended their compaction theory to cases in which these two assumptions are relaxed.

We apply a 1-dimensional steady conduit flow model where vertical relative motion and difference in pressure between gas and liquid phases are taken into account. The gas-liquid mixture inflates when the gas pressure exceeds the liquid pressure, whereas it is compacted when the liquid pressure exceeds the gas pressure. The vertical relative motion is assumed to follow Darcy's law. Distributions of gas velocity, liquid velocity, gas pressure, liquid pressure, and porosity of magma in a conduit are determined by solving the ordinary differential equation as a two-point boundary value problem. The boundary condition at the bottom of the conduit is that the mean pressure of the gas and liquid phases is equal to the pressure at the magma chamber, and the boundary condition at the vent is that both the gas and liquid pressures are equal to atmospheric pressure. It is generally difficult to find a steady solution for this two-point boundary value problem with a naive shooting method, because the differential equation involves a very small parameter (square of compaction length divided by total length of conduit) multiplying the highest derivative (the term representing the resistance against compaction). We resolve this difficulty with a new numerical method based on the boundary layer theory.

Our results show that porosity of effused magma during lava dome eruptions is largely controlled by the compaction process at shallow depths (within "the compaction length" from the surface). Within the boundary layer near the surface, complex porosity distribution develops such that the competition between vesiculation and gas escape accommodates to the boundary condition at the vent. The results also suggest that an increase in magma viscosity near the surface plays an important role in the formation of low porosities observed in lava domes. Generally, magma viscosity drastically increases near the surface because of volatile exsolution and crystallization. As a result, the ascent of liquid is suppressed owing to large wall friction force, whereas the gas ascends easily. These effects result in an efficient gas escape and, hence, in a compaction of the gas-liquid mixture.