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Porosity change of an ascending magma in volcanic conduits during dome-forming eruptions

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As silicic volatile-rich magma ascends to the surface and decompresses in volcanic conduits, volatiles exsolve and volume fraction of gas (i.e., porosity) increases. It has been recognized that in dome-forming eruptions, the increase in the porosity is suppressed by efficient escape of gas from magma, leading to effusion of lava domes with low porosity. However, the mechanism of the porosity change during magma ascent and that of the formation of the low-porosity lava domes are not fully understood. We study the porosity change of an ascending magma during dome-forming eruptions on the basis of a model for 1-dimensional steady flow in volcanic conduits. In our model, vertical relative motion between gas and liquid phases is taken into account. In addition, we introduce a flow region where both the gas and the liquid are continuous phases ('permeable flow region'), allowing the efficient vertical escape of gas through the permeable structure.

We specified a mechanical balance which controls the porosity change during magma ascent. On the basis of this balance, we found two essential effects that suppress the increase in the porosity during magma ascent: (1) gas escape promoted by the suppression of the ascent of the liquid due to the increase in the effect of wall friction force, and (2) gas escape leaving the dense liquid due to the decrease in the effect of liquid-gas interaction force. These effects are expressed by non-dimensional numbers A and B, respectively. The parameter A is defined as the ratio of effects of wall friction force to liquid-gas interaction force, and the parameter B is defined as the ratio of effects of gravitational load to liquid-gas interaction force. Gas escape is promoted and the increase in the magma porosity is suppressed with increasing A or B.

According to the analyses with typical magmatic and geological parameters in dome-forming eruptions, the most essential effect which suppresses the increase in the magma porosity is the increase in A accompanied by the increase in wall friction force due to the increase in magma viscosity during magma ascent. The magma viscosity increases rapidly at a shallow level in conduits because of volatile exsolution and crystallization. Generally, in dome-forming eruptions, the magma porosity increases during magma ascent from magma chamber to a shallow level. We found that at a shallow level the magma porosity decreases rapidly by the effect of the increase in A due to the rapid increase in the magma viscosity. In addition, we described how the porosity at the surface, as a consequence of the rapid decrease, depends on magma properties (e.g., viscosity and permeability), geological conditions (e.g., conduit radius) and magma flow rate. The result shows that the low porosity at the surface observed in dome-forming eruptions (about 0-0.4) is possible if viscosity/(conduit radius)^2 is larger than about 10^8 Pa s m^{-2}, or if permeability of magma is higher than about 10^{-10} m^2. Our results give constraints on shallow conduit system which is observed from various geophysical measurements, and the magma porosity at the surface which is estimated from lava dome sample.