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Effects of vertical and lateral gas escapes on volatile compositions, porosity and pressure in dome-forming eruptions

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As silicic volatile-rich magma ascends to the surface and decompresses in volcanic conduits, the magma vesiculates and its porosity (i.e., gas volume fraction) increases. When gas escapes from magma efficiently, the porosity decreases, which may lead to an effusion of a lava dome with a low porosity. Owing to the competition between the vesiculation and the gas escape, not only the porosity distribution inside the conduit but also the distributions of volatile compositions and pressure change in a complex way. In this study, we systematically investigated the relationship between the degree of the gas escape and the distributions of the volatile compositions, the porosity and the pressure inside the conduit on the basis of a 1-D steady conduit flow model.

During magma ascent in dome-forming eruptions, the gas phase escapes from magma in two different ways. One is vertical gas escape through the magma to the vent, and the other is lateral gas escape through the conduit wall. The relative importance of these two effects is expressed by a non-dimensional number E_w that is defined as the ratio of the effects of the lateral gas escape to the vertical gas escape. This parameter controls the partitioning of volatile components between gas and melt, and hence, the compositional variation of gas phase and volatile component during magma ascent. The compositional variation of volatiles is explained by the batch fractionation when $E_w=0$, and by Rayleigh fractionation when $E_w=1$. The characteristic of the compositional variation gradually changes from that of the batch fractionation to that of Rayleigh fractionation as E_w increases from 0 to 1. The value of E_w inside the conduit is constrained by conduit flow dynamics. In other words, the compositional variation of gas phase and volatile component during dome-forming eruptions are strongly affected by the physics of conduit flow.

We systematically investigated how the distributions of E_w (i.e., the volatile compositions), the magma porosity and the pressure inside the conduit depend on the permeability of vertical gas escape (k_v) and/or that of lateral gas escape (k_w) on the basis of a conduit flow model that considers both vertical and lateral gas escapes. The results show that these dependencies critically change depending on the parameter that represents the ratio of the effects of gravitational load to liquid-gas interaction force, B. When the effect of gravitational load exceeds that of liquid-gas interaction force (i.e., B>1), E_w is proportional to k_w and is inversely proportional to k_v. The porosity is kept low and the pressure distribution is close to lithostatic throughout the conduit regardless of k_w. On the other hand, when B<1, E_w is approximately proportional to k_w, whereas it is independent of k_v. The porosity increases from 0 to 0.8 and the pressure becomes larger than the lithostatic pressure with decreasing k_w, which leads to a high-overpressure region at a shallow level in the conduit. Our results give constraints on the relationship between the distributions of the volatile compositions, the porosity and the pressure estimated by field observations such as volcanic gas monitoring, muon radiography and tilt measurements.

Keywords: dome-forming eruptions, gas escape, volcanic conduit flow, volatile compositions, magma porosity, pressure distribution