Effects of magma fragmentation mechanisms on eruption rate

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Explosive volcanic eruptions are studied using a one-dimensional steady conduit flow model coupled with bubble growth. Spherical cell model is used for bubble growth, and the magma is treated as a Maxwell visco-elastic body. The flow is assumed to discontinuously change from bubbly-flow to gas-pyroclast flow at a fragmentation surface. We introduce two types of fragmentation condition; expansion fragmentation based on critical void fraction and stress fragmentation based on critical tensile strength of magma. The jump conditions at the discontinuous fragmentation surface are taken into account in the model.

Mitani et al. (2003) and Koyaguchi et al. (an accompanied paper in this session) showed that the condition whether expansion or stress fragmentation occurs is determined by a non-dimensional number, that is, the ratio of wall friction force in conduit flow to the tensile strength of magma. This means that the mode of fragmentation and the eruption style depend not only on magma viscosity, but also on other geological conditions such as conduit radius and eruption rate (Q); for a given viscosity the stress fragmentation is more likely to occur as conduit radius is smaller and Q is greater.

We investigate how fragmentation mode and Q change as a function of these parameters systematically. We calculate the lengths of bubbly flow region and gas-pyroclast flow region for various Q, chamber pressure (P), and magma viscosity. The required boundary condition for steady flow is that the total length of bubbly flow region and gas-pyroclast flow region is equal to the chamber depth. Results are summarized as follows.

The length of the bubbly-flow region is primarily governed by the pressure gradient within the bubbly-flow region; it simply decreases as the magma viscosity or Q increases and increases as P increases. On the other hand, the length of the gas-pyroclast flow region is determined by pressures at the vent and the fragmentation surface. It decreases with increasing Q, because the vent-pressure increases as Q increases. As a result, the total length of the two region decreases as Q increases for a given P. In other words, when the depth of the magma chamber is given, Q increases as the depth becomes small.

It should be noted that the length of gas-pyroclast flow region critically depends on the fragmentation mechanisms. When the expansion fragmentation occurs, the pressure at fragmentation surface is fixed. As a result the length of gas-pyroclast flow region is fixed regardless of P or other conditions of bubbly flow regions. On the other hand, when the stress fragmentation occurs, the length of gas-pyroclast flow region increases as P increases because the pressure at fragmentation surface depend on P.

For a given depth of magma chamber, the relationships between Q and P significantly depend on the fragmentation mechanism and hence the magma viscosity. We consider the cases where P decreases with time as an eruption proceeds. For low-viscosity magma, the expansion fragmentation occurs regardless of Q, and Q changes little as P decreases. For high-viscosity magma, the stress fragmentation occurs regardless of Q, and Q decreases by 1-3 orders of magnitude as P decreases. In the case of intermediate viscosity, Q significantly decreases as P decreases while Q is high enough for the stress fragmentation to occur. When Q reaches a critical value, the fragmentation mechanism changes from stress fragmentation to expansion fragmentation. As a result Q changes discontinuously. After that Q hardly changes with the decreasing P.