Semi-analytical solution for magma fragmentation and Plinean eruptions

Noriko Mitani[1]; Takehiro Koyaguchi[1]

[1] ERI, Univ Tokyo

There is wide variety in gas volume fraction of pyroclastic fragments from Plinean eruptions. This variety is considered to result from the variety in the physical condition of eruption including magma fragmentation process. In order to clarify the relation between the condition of magma fragmentation and magma property like water content C and the geological condition such as conduit radius R, conduit length L, and the pressure in magma chamber P, the dynamics of explosive volcanic eruptions is numerically and semi-analytically studied. We apply a one-dimensional steady conduit flow model coupled with bubble growth. The spherical cell model is used for bubble growth, and liquid magma is treated as viscous fluid. We set the criterion that magma fragments when the stress at bubble walls exceeds the tensile strength of magma. The viscosity of magma depends on water content which varies according to the equilibrium exsolution law.

First, we numerically obtain fragmentation depth and physical quantities such as gas pressure or gas volume fraction at the fragmentation surface as a function of C, R, L, and P. For example, when C is small (2 weight %), the gas pressure increases and hence the gas volume fraction decreases as R, P, and L increase, and the fragmentation depth is deeper as R and P decrease and L increases. On the other hand, when C is large (5 weight %), the gas pressure decreases and the gas volume fraction increases as R increases, and the fragmentation depth becomes shallower as P decreases.

Next, we analytically investigate the factors that govern the physical quantities such as pressure and gas volume fraction at the fragmentation surface. We found that the physical quantities at the fragmentation surface are given as a universal function of C and a non-dimensional number N, and that the relationships are independent of the boundary conditions at the magma chamber and the vent. This non-dimensional number represents the wall friction force normalized by the tensile strength of magma. The gas pressure at the fragmentation surface monotonously decreases with C and increases with N and hence the gas volume fraction monotonously increases with C and decreases with N. Because N is related to the wall friction which depends on the eruption rate, the above relationship between gas volume fraction and N allows us to estimate the eruption rate from observed gas volume fraction of pyroclastic fragments.

Moreover, this relationship between C, N and the fragmentation condition enables us to derive semi-analytical solutions for Plinean eruptions. When conduit length and the boundary conditions at the magma chamber and the vent are given, we can determine the non-dimensional number N and the eruption rate as follows. The lengths of the liquid magma and the bubbly flow regions are related to the wall friction, while the length of the gas-pyroclastic flow is related to the exsolved gas content at the fragmentation surface and the eruption rate. This means that all of the lengths of these regions are functions of C and N. Therefore, we can determine N or the eruption rate such that the sum of the lengths of these regions coincides with the conduit length. The obtained semi-analytical solutions agree well with the numerical results. Thus the variety seen in the gas volume fraction in the fragmentation condition and the fragmentation depth can be accounted for by the variety of C and N.