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Effects of relative motion between liquid and gas phases on transition of eruption styles

Tomofumi Kozono[1], Takehiro Koyaguchi[2]

[1] Earth and Planetary Sci., Univ. of Tokyo, [2] Frontier Sciences, Univ Tokyo

In gas-liquid multiphase flows, relative motion between liquid and gas largely affects the global features of bulk flows. We investigated the effects of relative velocity between the two phases on the transition of eruption styles using a one-dimensional steady conduit flow model by Yoshida and Koyaguchi (1999) (YK model hereafter). In YK model, the vertical relative velocity between liquid and gas is allowed for and a new transitional zone ('fractured turbulent flow zone') is introduced between bubbly flow and gas-ash flow. In this zone, both the liquid and the gas are continuous phases. The gas flow through permeable liquid magma in this zone is regarded as an efficient degassing process in the vertical direction from gas-liquid mixture.

Our results show that the flow of gas-liquid mixture in a conduit is divided into five flow regimes as the magma ascends. Regime 1 is a bubbly flow which is characterized by a small relative velocity between the two phases due to large viscosity of magma. In Regime 2, gas phase can efficiently flow through the network structure of fractured turbulent zone as a permeable flow, so that the relative velocity between the two phases increases significantly. Regime 4 is a gas-ash flow where the relative velocity reaches a constant value which is determined by the terminal velocity of particles in the gas phase. In the transitional regime from Regime 2 to Regime 4 (Regime 3), pyroclasts accelerate due to drag force from flowing gas and the relative velocity decreases suddenly. As the flow approaches the choking condition in Regime 4, the gas velocity increases towards the sound velocity of the gas, whereas the increase of the liquid velocity is suppressed. As a result, the relative velocity increases again. We call this region as Regime 5. The force balance which determines the pressure gradient also changes as the magma ascends. In Regime 1 and Regime 2, the pressure gradient is mainly determined by the wall friction and mixture weight, whereas the pressure gradient is mainly balanced with the acceleration term in Regime 3 and with the mixture weight in Regime 4, respectively. The thickness of each regime varies depending on boundary conditions at the magma chamber and physical properties of magma (e.g. viscosity). We also analytically proved that the choking pressure in Regime 5 is determined by the mass flow rate of magma alone.

Solutions of steady flow must satisfy boundary conditions at the vent as follows. For subsonic flows the pressure is atmospheric, while for sonic flows the choking condition is satisfied. There are several different types of steady solutions. When the mass flow rate of magma is small, the increase of the gas volume fraction is suppressed due to a large relative velocity in Regime 2. As a result, the thickness of Regime 1 and Regime 2 increases and a flow of Regime 2 reaches the vent as a subsonic flow. On the other hand, when the mass flow rate is high, Regime 1 and Regime 2 become thinner, whereas the thickness of Regime 4 and Regime 5 increases. In this case, a flow of Regime 5 reaches the vent as a sonic flow. These flows of contrasting mass flow rates correspond to effusive and explosive eruptions respectively, and they are possible even under the same pressure condition at the magma chamber. It is suggested that the relative velocity between the liquid and the gas, in other words, vertical degassing process plays a significant role in the diversity of eruption styles.