Modeling of fluid dynamical phenomena accompanied by volcanic eruptions

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During the project of Dynamics of Explosive Volcanisms, our group (Group A03) has developed basic numerical models of fluid dynamical phenomena accompanied by volcanic eruptions. Those are composed of models of magma ascent through volcanic conduits and those of eruption cloud dynamics. We have also studied physics of some elementary processes related to these numerical models. Here, I review representative results of our group, and discuss future perspective.

Conduit model:.As magma ascends and decompresses, volatiles exsolve and gas volume fraction increases. As a result, the flow changes from bubbly flow to gas-pyroclast flow (i.e., magma fragmentation). The features of the conduit flow are determined by the balance of viscous effects of the bubbly flow and expansion of the gas-pyroclast flow. On the basis of conduit flow models, it is suggested that gas escape from magma and magma fragmentation are the key processes to determine the features of the conduit flow. Kozono and Koyaguchi analytically determined the number and the type of steady solutions for a 1-D conduit model where the effects of relative motion between gas and liquid phases are taken into account and have explained the diversity of the eruption styles (e.g., non-explosive lava dome eruption and explosive Plinian eruption). Ida also developed a 1-D time-dependent model where the effects of horizontal gas escape is taken into account and reproduced the transition from non-explosive to explosive eruptions.

The physics of the key processes that govern the conduit flow have been investigated from experimental and/or theoretical point of view. Niimura et al. theoretically studied gas percolation through the bubbly magma where bubbles are elongated because of shear flow. Koyaguchi et al. developed a theory for shock tube problems of viscous bubbly magma and determined a fragmentation criterion on the basis of previous shock tube experiments. Kameda et al. performed a series of experiments which show the viscoelasticity plays an essential role in fragmentation. The nucleation and the growth of bubbles in volatile rich magma have been reproduced experimentally (Abe et al.) and numerically (Tsuda and Takagi; Yukawa and Ito). Some numerical techniques to calculate the bubble deformation are also developed (Ohnishi and Ohashi). These basic studies on the elementary processes have contributed to the development of the conduit flow models.

Eruption cloud model:The dynamics of eruption cloud (eruption column and/or pyroclastic flow) critically depends on efficiency of turbulent mixing between the eruption cloud and the ambient air. Previous one-dimensional (1-D) models of steady eruption clouds are based on the entrainment hypothesis for turbulent mixing, which is supported by laboratory experiments. Over the past 20 years, the development of two-dimensional (2-D), time-dependent, and multi-phase numerical models for eruption clouds have provided new explanations for many features of explosive volcanism; however, the predictions of column-collapse condition and column height by the 2-D models were not always quantitatively consistent with those of the steady 1-D models. Suzuki et al. (2005) pointed out that the turbulent mixing correctly reproduced in numerical models only by employing three-dimensional coordinates, a third-order accuracy scheme, and a fine grid-size, and have developed a new numerical pseudo-gas model which successfully reproduced the quantitative features of entrainment observed in the laboratory experiments as well as fundamental features of the dynamics of eruption clouds. In order to apply the 3-D eruption cloud model to the problem of the dynamics of pyroclastic flow, the physics at the base of pyroclastic flow should be rigorously taken into consideration. Tanaka et al. have developed a numerical model of the fluidization process driven by hot gas flow using the discrete element method for this purpose.