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A combined model of conduit flow and eruption cloud dynamics. Part 3. 3-D simulations of eruption column dynamics

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In order to predict the transition of eruption styles (e.g., plinian eruption to pyroclastic flow) during explosive volcanic eruptions on the basis of geophysical observations such as ground deformation around erupting volcanoes, we are developing a combined model for conduit flow and eruption cloud dynamics. We consider a conduit which flares with a certain opening angle at the vent, and systematically investigate the dynamics of conduit flow and eruption column. So far, we have obtained the relationship between the mass flow rate at the crater base and the magma chamber condition (depth and pressure) in Part 1, and the relationship between the quantities (radius, pressure and velocity) at the crater top and the mass flow rate at the crater base in Part 2. Here, we discuss the effects of crater shape on the condition of the generation of pyroclastic flow (column collapse condition) on the basis of 3-D numerical simulations of eruption column dynamics, in which the conditions at the crater top are given as boundary conditions.

When magma properties (e.g., water content and temperature) are fixed, the column collapse condition has been considered to depend primarily on magma discharge rate (e.g., Carazzo et al., 2008). When a crater is present, however, the radius, pressure and velocity at the crater top change depending on the crater shape, which, in turn, affects the column collapse condition. In this study, we investigate how the column collapse condition changes with crater shape in the parameter space of radius and pressure at the crater top (the r-p space). According to Koyaguchi et al. (2010), the flow in/above the crater is divided into 4 regimes in the r-p space: (1) sonic flow choked at crater top, (2) under-expanded supersonic flow, (3) over-expanded supersonic flow, and (4) subsonic flow. The boundary between (2) and (3) is defined as correctly expanded supersonic flow. For a given mass discharge rate, the flow regime changes from (1) to (4) as the radius increases and the pressure decreases at the crater top.

The results of 3-D simulations indicate that the eruption columns of the flow regimes (1) and (2) accelerate due to decompression just above the crater, whereas those of the flow regime (3) decelerate at a series of shock waves; as a result, the eruption columns of the flow regime (3) are more likely to collapse and generate pyroclastic flow for a given magma discharge rate. Combining these results and those of Part 2 leads to a conclusion that the generation of pyroclastic flow can be caused by an increase in opening angle of crater even for a constant magma discharge rate.

The column collapse condition obtained in the present study quasi-quantitatively agrees with that based on the 1-D steady decompression model at the crater (Woods and Bower ,1995; Koyaguchi et al., 2010) and the 1-D steady eruption column dynamics model (e.g., Bursik and Woods, 1991). We can observe additional features from the present 3-D simulation results. For example, the 3-D structure of jet around the transitional state between eruption column and pyroclastic flow is different between the flow regimes (2) and (3). In the flow regime (2), an annular unstable up-flow develops at the edge of jet, which enhances mixing between ejected materials and ambient air, and hence, stabilizes the eruption column. On the other hand, in the flow regime (3), the transitional state between eruption column and pyroclastic flow is characterized by an annular down-flow, which generates a small-scale pyroclastic flow, while the central part of the jet forms a stable buoyant eruption column.

Keywords: volcanic eruption, simulation, eruption column, pyroclastic flow, crater, fluid dynamics