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A combined model of conduit flow and eruption cloud dynamics. Part 4. Internal structure of eruption cloud

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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 using a 1-D steady conduit flow model (Koyaguchi, 2005; Koyaguchi et al., 2010) and 3-D eruption cloud model (Suzuki et al., 2005). We attempt to determine the condition of the generation of pyroclastic flow (column collapse condition) as a function of geological parameters such as pressure in magma chamber and crater shape on the basis of this combined model.

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). Koyaguchi et al. (2010) proposed that the column collapse condition also strongly depends on the crater shape. In Part 3, we confirmed this proposition using the 3-D numerical simulations, and showed that the column collapse condition can be roughly estimated from 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). In this presentation, we investigate internal structure of eruption cloud by means of 3-D numerical simulations in order to support this conclusion.

According to Koyaguchi et al. (2010), the flow in/above the crater is divided into 4 regimes in the parameter space of radius and pressure at the crater top (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 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 flow regime (3) are more likely to collapse and generate pyroclastic flow for a given magma discharge rate.

The 3-D simulation results show that the internal structure of eruption cloud has distinct features between under-expanded supersonic flow (regime (1) or (2)) and over-expanded supersonic flow (regime (3)). The under-expanded flow regime is characterized by barrel shocks and Mach disk shock. The axial part of the under-expanded supersonic flow decelerates at the Mach disk shock, whereas an annular supersonic up-flow develops at the edge of jet above the Mach disk shock. The instability in the annular supersonic up-flow enhances mixing between ejected material and ambient air, and hence, stabilizes the eruption column. The over-expanded flow regime, on the other hand, is characterized by oblique shocks; the supersonic flow from the crater decelerates at these oblique shocks, and a region of subsonic flow develops around the jet. In the transitional state between eruption column and pyroclastic flow, this annular subsonic flow partly collapses and generates a small-scale pyroclastic flow, while the central part of the jet forms a stable buoyant eruption column.

Keywords: eruption cloud, conduit flow, numerical simulation, compressible fluid dynamics