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Forecasting the transition of explosive volcanic eruptions using a combined model for conduit flow and eruption column

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We have developed a combined model for one-dimensional (1D) conduit flow and three-dimensional (3D) eruption column dynamics in order to forecast the transition of explosive volcanic eruptions.

During explosive eruptions, the ascending velocity of magma typically reaches the sound velocity of the gas-pyroclast mixture at the crater base. In this case, the motion of magma from the magma chamber to the eruption cloud is divided into the following three regions: conduit flow from the magma chamber to the crater base (Region 1), decompression and compression processes inside the crater (Region 2), and eruption column dynamics in the atmosphere (Region 3). According to the approximate solution of the 1D conduit flow model (Koyaguchi, 2005), the flow rate in Region 1 depends mainly on magma-chamber pressure, magmatic properties (e.g., temperature, water content and viscosity), conduit radius and conduit length from the magma chamber to the crater base. The decompression/compression process in Region 2 is essentially controlled by crater geometry; when the depth of crater and the ratio of the cross-sectional areas at the top and the base of the crater are given, exit pressure and exit velocity at the crater top are estimated as a function of flow rate (Koyaguchi et al., 2010). When the exit pressure differs from the atmospheric pressure just above the crater, the fluid dynamical features of the eruption column (i.e., Region 3) are significantly affected by the decompression and/or compression processes just above the crater; the ejected material accelerates or decelerates owing to decompression or compression into the atmosphere. According to 1D steady eruption column dynamics models (e.g., Woods, 1988), the column dynamics after the pressure of the eruption column balances the atmospheric pressure depends on magmatic properties, magma discharge rate, and ascent velocity at the time when the pressure of the eruption column balances the atmospheric pressure just above the crater top. The above consideration suggests that the evolution of conduit-crater geometry as well as that of chamber pressure plays a key role in the transition of explosive eruptions.

In this study, in order to evaluate the effects of conduit-crater geometry on the transition of explosive eruptions, we have derived an approximate solution to calculate the velocity and pressure at the crater top as a function of parameters on crater geometry, and systematically investigate the effects of over- and under-pressure at the crater top on the column dynamics using a 3D column dynamics model (Suzuki et al., 2005). The overall features of column dynamics such as column collapse condition in the 3D simulations are qualitatively consistent with the results based on the combination of the 1D column dynamics model and the 1D decompression/compression model (e.g., Woods and Bower, 1995; Koyaguchi et al., 2010). The 3D simulation results also show some distinct features that cannot be expressed in the 1D models; the over- or under-pressured jets are characterized by the highly accelerated annular supersonic flow with the central subsonic flow above the normal shock. Such velocity structure causes partial collapse and/or oscillation of the eruption column. We propose a regime map showing the diverse flow patterns of eruption columns in the parameter space of the flow rate and the crater geometry, and discuss how the flow patterns of eruption columns change as chamber pressure and conduit-crater geometry evolve in the course of typical explosive eruptions.

Keywords: conduit flow, eruption column, numerical model, transition of eruption style