V160-007 **Room: 201A** **Time: May 18 10:45-11:00**

A combined model of conduit flow and eruption cloud dynamics (Part 2) The effect of crater shape on the column collapse condition

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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 exit velocity and the eruption column dynamics for various magma chamber conditions.

The condition of the generation of pyroclastic flow (column collapse condition) during explosive eruptions is estimated from the radius and the velocity of an eruption column at the time when the pressure of the eruption column balances with the atmospheric pressure just above the vent on the basis of the 1-D eruption column dynamics model (e.g., Bursik and Woods, 1991). Woods and Bower (1995) have pointed out that the radius and the velocity at the atmospheric pressure depend on the dynamics of the conduit flow and the flow inside the crater; however, the quantitative features of the dependence have not been fully understood. In Part 1 we discussed the relationship between the mass flow rate through a conduit and the magma chamber condition (depth and pressure): the mass flow rate sensitively depends on the chamber depth for a high-viscosity magma ascending through a narrow conduit, whereas it mainly depends on the chamber pressure for a low-viscosity magma ascending through a wide conduit. In this presentation (Part 2) we discuss the relationship between the radius and the velocity of an eruption column at the atmospheric pressure and the mass flow rate at the base of the crater, and quantitatively evaluate the effect of the crater shape on the column collapse condition.

For an explosive eruption, we can estimate the magma discharge rate from the total mass of ejecta divided by the duration of the eruption, or from the column height. We can also estimate the geometry of the crater from the field survey. We, therefore, attempt to determine the column collapse condition in the space of the magma discharge rate versus the conduit radius (i.e., the radius at the base of the crater). According to the dynamics model of compressible multiphase flow, the flow inside the crater is divided into 4 types in the above parameter space: (1) the sonic flow choked at the top of the crater, (2) the subsonic flow, (3) the over-expanded supersonic flow, and (4) the under-expanded supersonic flow. The boundary between (3) and (4) is defined as the correctly expanded supersonic flow. We can estimate the radius and the velocity of an eruption column at the atmospheric pressure for each of the flow type on the basis of a simple consideration on the momentum conservation just above the vent. By comparing the velocity at the atmospheric pressure with the critical velocity for the column collapse based on the 1-D eruption column dynamics model, we can draw the column collapse condition in the space of the magma discharge rate versus the conduit radius.

Combining the above result and the relationship between the mass flow rate through a conduit and the magma chamber condition (i.e., the results of Part 1) enables us to discuss how the column collapse condition depends on the magma chamber condition. Previously it is considered that the column collapse is accompanied by widening of vent during the waxing stage of the eruption. The present results indicate that, in addition to this previously known scenario, the decrease of the magma chamber pressure during the waning stage of the eruption can cause the column collapse in a wide range of geological parameters. It is also suggested that the critical magma discharge rate for the column collapse condition during the waning stage sensitively depends on the depth and/or the opening angle of the crater as well as the water content of the magma.