A combined model of conduit flow and eruption cloud dynamics. Part 1. The effect of magma chamber pressure on the vent conditions

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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 must understand dynamics of magma from a magma chamber through a volcanic conduit to eruption cloud. For this purpose, we are developing a combined model for conduit flow and eruption cloud dynamics.

Generally, the condition of the generation of pyroclastic flow (column collapse condition) during explosive eruptions depends on magma properties, conduit radius, exit velocity and pressure at the vent. Woods and Bower (1994) have pointed out that the governing factors of the column collapse condition depend on whether the flow is sonic (i.e., the choking condition is satisfied) or subsonic at the vent. In the sonic case, the erupted materials (the mixture of pyroclasts and gas) have a higher pressure than the atmospheric pressure at the vent, and it is decompressed in the atmosphere. When the over-pressure at the vent exceeds 1 MPa, the ascending velocity after the decompression has a constant value that is determined by the magma property (e.g., water content). As a result, the critical magma discharge rate for column collapse can be predicted only from the water content in the magma. In the subsonic case, on the other hand, the pressure at the vent is equal to the atmospheric pressure, and hence the density of the erupted materials is fixed at the vent. In this case, the exit velocity (or the conduit radius) also controls the column collapse condition. These results imply that the condition for the exit velocity to be sonic in the conduit model is a key issue that controls the eruption column dynamics.

In this study, we focus on the following two problems: (1) to check the results by Woods and Bower (1994) on the basis of the 3-D eruption cloud model, and (2) to elucidate the relationship between the condition for the exit velocity to be sonic and the physical conditions (e.g., depth and pressure) at the magma chamber. This presentation will be specifically concerned with the second problem.

The condition for the exit velocity to be sonic can be obtained as a function of the depth and the pressure of magma chamber by means of the analytical method for the 1-D steady conduit model (Koyaguchi, 2005). The results show that the condition critically depends on whether the depth of magma chamber is greater than a depth scale where the static pressure of magma (gas and liquid mixture) increases from the atmospheric pressure to the pressure at the fragmentation surface (defined as D). The depth scale D depends on the magma properties (mainly on the water content) and it is typically a few to 10 km. When the chamber depth is less than D, the exit velocity is sonic and the exit pressure is greater than the atmospheric pressure regardless of the chamber pressure. When the chamber depth is greater than D, the exit pressure decreases and the flow becomes subsonic as the chamber pressure becomes substantially lower than the lithostatic pressure.

The above results imply that the column collapse condition as well as the evolution of the eruption styles depend on whether or not the chamber depth is greater than D. When the chamber depth is less than D, the dynamics of eruption cloud is insensitive to the chamber pressure; a high magma discharge rate is maintained even though the chamber pressure decreases due to the eruption. This situation explains the transition from a steady plinian eruption to a sudden caldera formation. When the chamber depth is much greater than D, as the chamber pressure decreases due to the eruption, the magma discharge rate and the exit velocity decrease. This causes another type of transition from plinian eruptions to pyroclastic flow eruption with relatively low magma discharge rates.