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3-D numerical simulations of eruption clouds: the critical condition for column collapse

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During an explosive volcanic eruption, an eruption cloud generates either a buoyant eruption column or a pyroclastic flow. The mixture of hot pyroclasts and volcanic gas is released from the volcanic vent into the atmosphere. The density of the mixture is several times larger than atmospheric density. As the ejected material entrains ambient air, the density of the mixture decreases because the entrained air expands by heating from the pyroclasts. If the density of the mixture becomes less than the atmospheric density before the eruption cloud loses its upward momentum, a buoyant plume rises to form a plinian eruption column (column regime). On the other hand, if the mixture loses its upward momentum before it becomes buoyant, the eruption column collapses to generate a pyroclastic flow (collapse regime). In order to understand and predict the critical condition that separates these two eruption styles (i.e. column collapse condition), we have performed a series of three-dimensional numerical simulations.

In this study, we identified two types of column collapse in the simulations: jet-type and fountain-type collapses. In general, the entrainment of ambient air by the ejected material is driven by shear between the cloud and air at the edge of the column; consequently, a concentric structure consisting of an inner flow (i.e. potential core) and an outer shear layer is developed. The potential core is eroded by the outer shear layer as the downstream distance from the source increases; the length of potential core increases as the vent radius increases. If the cloud does not become buoyant before the outer shear layer reaches the central axis of the flow, the cloud with a high concentration of the ejected material generates a fountain structure and collapses to the ground (i.e. fountain-type collapse). On the other hand, if the cloud does not become buoyant after the potential core disappears due to erosion by shear, the cloud which mixes well with the ambient air generates structure similar to the turbulent jet and collapses as a pyroclastic flow (i.e. jet-type collapse).

When the exit velocity is fixed, the transition from eruption column to pyroclatic flow occurs as the mass discharge rate (i.e. vent radius) increases. This transitional condition (i.e. the column collapse condition) is determined by a critical mass discharge rate (MDR_{CC}). In addition, whether the potential core disappears or not is also determined by another critical mass discharge rage (MDR_{JF}). According to the flow regime maps obtained from our simulations, which type of collapse (fountain-type or jet-type collapse) occurs in the transition depends on whether MDR_{CC} is larger or smaller than MDR_{JF}. When the magma temperature is low, MDR_{CC} is smaller than MDR_{JF}; the jet-type collapse occurs in the transition. In this case, the column collapse condition depends only on the Richardson number. When the magma temperature is high, on the other hand, MDR_{CC} is larger than MDR_{JF}; the fountain-type collapse occurs in the transition. In this case, the collapse condition depends not only on the Richardson number but also on the Mach number. When the flow is supersonic (the Mach number is larger than 1.0), the standing shock waves developing in a fountain inhibit the entrainment of ambient air, which enhances column collapse.

Keywords: volcano, eruption cloud, numerical simulation, pyroclastic flow