Pyrrhotite oxidation as a tool for reconstructing thermal structure of eruption columns

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Entrainment of ambient air is a key process in eruption cloud dynamics as it thermally expands and produces buoyancy. Because magma fragments (pyroclasts) are cooled and oxidized by air entrainment, petrological analysis may evaluate independently the entrainment process. To quantify the degree of interaction between fragmented magma and entrained air, we focused on oxidation of pyrrhotite (Po, $Fe_{1-x}S$) in the pyroclasts. In this study, we simulated cooling of pyroclasts to examine the coupling between degree of oxidation and eruption dynamics. Cooling of pyroclasts was simulated using a newly-developed routine for a three-dimensional (3-D) eruption column model, while oxidation kinetics of Po are already relatively well understood. By testing the parameter sensitivity of the degree of oxidation and comparing simulated and natural oxidation degrees for a Plinian eruption, we examined the usefulness of Po oxidation as a marker for magma-air interaction and an indicator of eruption-column thermal structure in the 3-D model.

Three simulations with different mass discharge rates and magma temperatures were performed based on the 3-D eruption column model. In the simulations, two types of thermal structures corresponding to jet flow and fountain flow (Suzuki and Koyaguchi 2012) were observed with magma discharge rates of 10^6–10^7 kg/s and ~10^9 kg/s, respectively. Both of the flow types included an "unmixed core" (or high mass fraction zone) in the column. The fountain-type maintained high temperature longer than the jet-type because the fountain-type unmixed core was not eroded until extensive air entrainment occurred at the top of the fountain.

The oxidation degree of pyroclasts was then calculated on the basis of predicted temperature change of particles in the eruption column. Po in volcanic rocks is often oxidized to form magnetite (Mt, Fe_3O_4) and then hematite (Hm, Fe_2O_3) (Matsumoto and Nakamura 2012). The growth rate of Hm from Mt can be applied to measure the oxidation degree of pyroclasts as it has been determined experimentally (Païdassi 1958). Calculations of Hm width were made for approximately 300 to 1000 oxidation markers in the eruption column for each simulation condition, and expressed as frequency distributions of oxidation degree. Our calculations showed that Hm-width distribution varied according to the mass discharge rate (i.e., flow type) and initial magma temperature. The distribution of oxidation degree was broad in the case of fountain-type, whereas it was narrow in the case of jet-type. In addition, an eruption column which has a high initial magma temperature and jet-like structure was characterized by a long-tailed distribution, which results from a presence of high oxidation degree markers. These results indicate that Po oxidation can be potentially used for characterizing the thermal structure of eruption columns.

We also compared calculated Hm widths with petrographic data from the Sakurajima 1914 Plinian eruption. The Hm widths based on the simulation were approximately one-third the thickness of those observed in natural pumices. Three potential explanations for this discrepancy are: (1) thermal conduction of the pumice clasts, which is neglected in the present 3-D model, affects the Po reaction degree; (2) Po reaction rate was underestimated; and/or (3) Po oxidation started in the volcanic conduit before magma fragmentation, possibly accompanying open-system outgassing of the magma.

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