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Differentiation mechanism of frontal-arc basalt magmas

T. Kuritani (1), T. Yoshida (2), J. Kimura (3), Y. Hirahara (3), and T. Takahashi (3)

(1) Graduate School of Science, Osaka City University, Osaka, Japan (kuritani@sci.osaka-cu.ac.jp), (2) Graduate School of Science, Tohoku University, Sendai, Japan, (3) Institute for Research on Earth Evolution, Japan Agency for Marine-Earth Science and Technology, Yokosuka, Japan

In a cooling magma chamber, magmatic differentiation can proceed both by fractionation of crystals from the main molten part of the magma body (homogeneous fractionation) and by mixing of the main magma with fractionated melt derived from low-temperature mush zones (boundary layer fractionation) (Jaupart and Tait, 1995, and references therein). The geochemical path caused by boundary layer fractionation can be fairly different from a path resulting from homogeneous fractionation (e.g., Langmuir, 1989). Therefore, it is important to understand the relative contributions of these fractionation mechanisms in magma chambers. Kuritani (2009) examined the relative roles of the two fractionation mechanisms in cooling basaltic magma chambers using a thermodynamics-based mass balance model. However, the basaltic magmas examined in the work were alkali-rich (Na2O+K2O > 4 wt.%). In this study, to explore differentiation mechanisms of frontal-arc basalt magmas that are volumetrically much more important than rear-arc alkali basalt magmas, the relative roles of the two fractionation mechanisms are examined for low-K tholetiitic basalt magma from Iwate Volcano, NE Japan arc, using the same mass balance model.

First, the water content and the temperature of the Iwate magma were estimated. The Iwate lavas are moderately porphyritic, consisting of ∼8 vol.% olivine and ∼20 vol.% plagioclase phenocrysts. The olivine and plagioclase phenocrysts show significant compositional variations, and the Mg# of olivine phenocrysts (Mg#78–81) correlates positively with the An content of coexisting plagioclase phenocrysts (An85–92). The olivine phenocrysts with Mg# > ∼82 do not form crystal aggregates with plagioclase. It is inferred from these observations that the phenocrysts with variable compositions were derived from a common magma with variable temperature in a magma chamber, and the plagioclase phenocrysts were all derived from mushy boundary layers along the walls of the magma chamber. By using thermodynamic calculations with the observed petrological features of the lavas, the water content and liquidus temperature of the Iwate magma were estimated to be 4–5 wt.% and ∼1180°C at 200 MPa. Then, the model of Kuritani (2009) was applied to the Iwate magma. Model calculations suggest that, in relatively deep (>∼200 MPa) magma chambers, magmatic differentiation proceeds primarily through boundary layer fractionation. In this case, the crystallinity of the magma remains low over long periods of magmatic differentiation, because mush-melt mixing causes a depression of the liquidus temperature in the main magma. On the other hand, in magma chambers at relatively shallow levels (<∼100 MPa), magmatic differentiation proceeds essentially through homogeneous fractionation. In this case, the magma can become rich in crystals in early stages of magmatic differentiation.