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Selective crystal fractionation in a bubble-bearing magma body: implications from Kutsugata lava flow, Rishiri Volcano

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The issues of how chemical differentiation takes place in magma bodies have long been challenged in solid-earth science, because of the importance of, and interest in, the geochemical and dynamical phenomena associated with magmatic differentiation. Previous geological information of how magmatic differentiation takes place has been mainly extracted from large igneous complexes and sills, because they represent "fossil magma chambers" that we can directly access. It has been recognized that internal differentiation can also take place in solidifying lava flows, as represented by the presence of segregation sheets and cylinders. Such lava flows are expected to record information which is erased in relatively larger magma bodies by later processes like convection and reequilibration of crystals with melt. Previous studies on the mechanisms of internal differentiation in lava flows have suggested that some segregation products are likely to be produced by gas filter-pressing. However, from a geochemical viewpoint, there is a shortage of good field examples that can be used to elucidate internal differentiation in cooling magma bodies, because detailed studies on origin of compositional variations in lava flows are scarce.

In this study, we investigated the internal differentiation processes in the Kutsugata lava flows from Rishiri Volcano, Japan. The internal structure of the lava flows has been described in detail by Yoshida et al. (1981), and it is characterized by the presence of well-developed vesicle-rich segregation cylinders and sheets. The purpose of this paper is to understand the formation processes of geochemical features of the vesicle-rich segregation products, on the basis of detailed sampling and chemical analysis of rocks from the vertical section of one representative lava flow.

In the representative 6 m-thick lava flow, segregation products occur mainly as forms of pipe (vesicle cylinder) and layer (vesicle sheet). The vesicle cylinders and the vesicle sheets occur around 0.5-2.3 m and 2.0-4.0 m above the base, respectively. Both the cylinders and the sheets are significantly more enriched in incompatible elements and are more depleted in CaO and Al_2O_3than the host lavas, suggesting that these products essentially represent residual melt produced during solidification of the lava flow. However, the vesicle cylinders are remarkably higher in MgO content (up to 8 wt.%) than the host lava (< 6 wt.%), whereas the vesicle sheets are depleted in MgO (as low as 3.5 wt.%). The relatively high MgO content of the vesicle cylinders cannot be explained solely by mechanical mixing of olivine phenocrysts with residual melt. Mass balance modeling for major elements showed that the groundmass compositions for the vesicle sheets are consistent with fractionation of olivine, augite, and plagioclase from the initial interstitial melt composition, suggesting that the residual melt migrated from crystal network consisting of these phases in the host lava to form the vesicle sheets. On the other hand, the groundmass compositions for the vesicle cylinders can be accounted for by addition of olivine, in addition to fractionation of augite and plagioclase. Therefore, the vesicle cylinders were produced by extraction of olivine-bearing interstitial melt from augite-plagioclase network in the host lava. This selective crystal fractionation is inferred to have resulted from the processes that abundant vesicles, rejected from the upward-migrating floor solidification front, prevented olivine crystals from being incorporated

into crystal network in the host lava. Calculations for the thermal evolution of the lava flow showed that vesicle cylinders occurred in 1 day after the lava flow came to rest and continued to grow upward at about 9 cm/day, whereas relatively large vesicle sheets appeared after 9 days. Formation of the segregation products essentially finished by 20 days after the lava flow ceased its motion.

Keywords: Fractional crystallization, Melt segregation, Lava flow, Segregation body, Vesicle