Decoding the pre-eruptive process by crystal clots: A case study of Unzen 1991-95 eruption

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1. Introduction

Magma mixing is one of the major triggers of volcanic eruption. So, mixing process of end member magmas can control magnitude and style of eruptive activities. There are some factors that control magma mixing processes. Among them, viscosities of mixing end member magmas are the most important one. It is well known that the viscosity of magma depends on crystal abundance, melt composition, and temperature of magma. Although we can determine the compositions of crystals and melt of erupted magma, it is not easy to know these properties before magma mixing because magma mixing causes temperature increase and results in changing to the composition and crystallinity of magma different from those of initial pre mixing magma.

In this study, we use crystal clots to reveal the conditions of magmas before magma mixing. Crystal clots are assemblage of crystals. Because mushy magma reservoir contains >50 vol. % crystals, crystals can be closely assembled in the reservoir. From this consideration, crystal clots can be part of the mushy magma reservoir. In addition, between crystals, there are interstitial melts. So, these crystal clots are likely to possess information about condition of magma before magma mixing.

We use samples of Unzen 1991-95 eruption to deal with these questions. Unzen 1991-95 eruption is characterized by the growth and collapse of lava domes, leading to repeated pyroclastic flows. Pre-eruptive magma mixing is thought to have occurred in the magma reservoir (e.g., Nakamura, 1995).

2. Samples and analytical methods

During the 1991–1995 eruption, two peaks were observed in the eruption rate. So, we used 13 samples erupted at different period of the 1991–1995 eruption in this study to cover the two peaks. We call an assemblage of multiple minerals as crystal clots in this study. Crystal clots in products of Unzen 1991-95 eruption are mainly composed of plagioclases, amphiboles, pyroxenes and Fe-Ti oxides. Between crystals, interstitial melts exist.

We analyzed the interstitial melts, amphiboles and plagioclases in crystal clots. We also analyzed the rims of plagioclases to apply a plagioclase-liquid hygrometer. Compositional analysis was performed by EPMA (JEOL JXA-8800R) at Earthquake Research Institute, University of Tokyo. For quantifying the modal abundances in crystal clots, we used X-ray mapping using above-mentioned EPMA.

3. Results

Two temperature conditions are identified based on amphibole composition; LT (low temperature, 770-830℃) and MT (middle temperature, 870-950℃). Amphiboles in crystal clots are classified into A-type, B-type, C-type and D-type. A-type is characterized by zonal texture, B-type has breakdown rim and C-type has both zonal texture and breakdown rim. D-type is almost homogenous. Modal abundance of each type of amphiboles in crystal clots had changed during the 1991-1995 eruption. Changes in the amount of B-type and C-type amphiboles are obviously related to the effusion rate. Growth conditions estimated by methods of Putirka (2016) show that almost all amphiboles are grown in condition of LT magma reservoir and only 3% of amphiboles show condition of MT magma. On the other hands, SiO_2 contents of interstitial melts show similar with that of LT end member melt. Water content of LT magma is estimated to be ˜7-10 wt.% by means of plagioclase-liquid hygrometer (Waters and Lange, 2015).

Accordingly, assembled depth of crystal clots are calculated as 6-9 km, provided that the magma was saturated in water.

4. Discussion

Assembled depth of crystal clots are similar to the depth of main magma reservoir of Unzen 1991-95 eruption estimated by geophysical observations. Occurrences of crystal clots imply that they were part of LT magma reservoir, and was caught by injected magma. So, we estimate crystal ratio of LT and MT magma from that of crystal clots and their mixing ratio. Moreover, we calculated viscosity of each endmember magma by using estimated crystal content to consider magma mixing process. We also constrained this process by considering the timescale of formation of reaction rims surrounding amphiboles. Finally, we propose model of pre-eruptive process of Unzen 1991-95 eruption based on these results and consideration.

Keywords: crystal clots, pre-eruptive process, mushy magma reservoir