Effect of superheating on decompression-induced crystallization of hydrous rhyodacite magma: An experimental study

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Decompression experiments have been applied to determine decompression rates during magma ascent to the surface (e.g., Hammer and Rutherford, 2002). The texture of crystals in pyroclasts also records the pressure at magma fragmentation level during explosive eruption (e.g., Okumura et al., 2019). Comparison between the texture of crystals in natural pyroclasts and that in experimental products enables us to estimate the decompression rate and magma fragmentation pressure. This is a powerful method to estimate the processes of magma ascent; however, it has been thought that an experimentally reproduced texture of crystals depends on superheating before decompression. Indeed, two decompression experiments performed at the similar experimental condition but different superheating (Brugger and Hammer, 2010; Riker et al., 2015) show large difference in the number density of crystals.

In this study, we carried out a series of decompression experiments to investigate the effect of superheating on the number density and size of crystals and total crystallinity. We used powdered pumice sample of the 1977 sub-Plinian eruption of Usu volcano, Japan as a starting material. The liquidus temperature of this magma was estimated to be ~920˚C (Ohnishi and Tomiya, 2018). For the decompression experiments, we prepared four types of starting materials synthesized (annealed) at the same pressure (130 MPa) and temperature (900˚C), corresponding to the magma chamber condition (Ohnishi and Tomiya, 2018), but preheated at temperatures of 900, 940, 970, and 1300˚C (different degree of superheating) using a cold seal pressure vessel (CSPV) at Tohoku Univ and internally heated pressure vessel at GSJ/AIST. The durations of preheating and annealing are 2 to 48 h and 48 to 138 h, respectively. In the synthesized samples, no plagioclase was found when the sample was preheated at 1300˚C, and the number density of plagioclase increases with the decrease in preheating temperature although total crystallinity is not different. Decompression experiments were isothermally conducted at a temperature of 900˚C using CSPV, with continuous decompression from 130 to 30 MPa and decompression rates of 100, 20 and 5 MPa h^{-1}. After decompression, the sample was rapidly quenched, and the number density and size of crystals and total crystallinity were investigated.

Our results clearly indicate that the degree of superheating influences the number density and size of crystal. The number densities of plagioclase in the products preheated at 1300 and 970˚C are much lower than those at 940 and 900˚C . Under high decompression rate (100 MPa h^{-1}), no plagioclase was found in the product preheated at 1300˚C. The size of plagioclase is large in the products preheated at 1300 and 970˚C under decompression rate of 20 and 5 MPa h^{-1}.

We also observed the dependence of the number density on the decompression rates. The maximum number density of plagioclase was found at 20 MPa h^{-1} in the products preheated at 940 and 900℃. On the other hand, the number density in the product preheated at 970˚C shows only small variation with decompression rate. This indicates that the number density depends on decompression rate when crystallization is dominated by nucleation rather than growth.

On the basis of these results, we conclude that the degree of superheating controls the number density

and size of crystal as well as decompression rate. This is probably because the superheating determines the number density of clusters smaller than the critical nuclei size (Sato, 1995). When the number density of the cluster is high, the nucleation controls the relaxation of effective undercooling, while the undercooling is relaxed by the growth process under low number density of the cluster. Therefore, the effect of superheating must be considered when the decompression experiment and the resultant number density is applied to determine decompression rate and fragmentation pressure.

Keywords: volcanic eruption, Usu volcano, decompression expriments, decompression-induced crystallization, superheating, number density

