Kinetic delay of crystal growth controls plagioclase-basaltic melt apparent disequilibrium

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Plagioclase-melt compositional relations sensitively depend on temperature, T, and water content, X_W, of melt. Therefore, the relations are formulated as functions of T and X_W and used as geothermohygrometer (e.g., Putirka, 2008). Plagioclase-melt equilibrium is postulated for applying the thermohygrometer models. However, validity of the assumption is unobvious for microlite crystallization driven by degassing and/or cooling during eruption. Can we apply the thermohygrometers to the plagioclase-melt pairs formed by dynamic crystallization? To examine the issue, the cooling crystallization experiments of the high-Al basaltic melt were carried out and textural and chemical analyses were performed the run samples.

We used the high-Al basalt lava from Waianae, Hawaii Oahu as the starting material for the cooling crystallization experiments. This experiment was conducted using the 1atm fO_2-controlled furnace at University of Hawaii at Manoa. After 3 hours pre-heating at 1180℃, ~30K higher than the liquidus, the samples were cooled at cooling rates, R_c, of 0.1, 0.3, 1, 3, and 10K/min, and then quenched in water at four target temperatures, T_q, of 1150, 1120, 1090, and 1060℃. We used FE-EPMA (JEOL-JXA-8530FPlus) and EPMA (JEOL8800R) at Earthquake Research Institute, University of Tokyo, for textural and chemical analyses of the run samples.

As R_c and/or T_q increase, the abundance and size of plagioclase crystals decrease. As R_c increases, the shape of plagioclase changes from euhedral to dendritic. The R_c-dependent shape change is more obvious at lower T_q. Pyroxene crystallization was suppressed in the run samples coolied at higher R_c. In addition, melt boundary layers are observed around pyroxene in the samples cooled at 0.3-1K/min, quenched at 1090℃ and cooled at 0.3-3K/min, quenched at 1060℃, and around plagioclase in the samples cooled at >3K/min, quenched at <1120℃. Lower diffusivity of Al_2O_3 compared to those of FeO and MgO is responsible for lower threshold cooling rate of melt boundary layer formation around pyroxene.

The maximum An# [=100Ca/(Ca + Na)] of plagioclase was almost the same among all run samples. We applied both plagioclase liquidus and plagioclase-melt An-partitioning thermometers of Putirka (2008) to the pairs of plagioclase rim-boundary layer melt (BLM) and plagioclase rim-far field melt (FFM) to estimate temperatures recorded in their phase compositions. At T_q=1150℃, the estimated temperatures well represent T_q for both BLM and FFM. However, at lower T_q, both of the thermometers estimate temperatures higher than T_q; difference between estimated temperature and T_q, ΔT, increases as decreasing T_q. The two thermometers estimate similar temperatures for each sample, and the differences between the two estimated temperatures do not depend on R_c. These results suggest that the plagioclase-melt partition coefficient of An component does not depend on the R_c. Therefore, the increase of ΔT at lower T_q is not due to the R_c-dependence of the partition coefficient. It is attributed to the kinetic delay of the crystal growth at lower temperature. On the other hand, the coincidence between calculated temperatures and T_q at 1150℃ suggests that kinetic delay of plagioclase crystal growth is small at near liquidus temperature.

Present results show that plagioclase-melt thermometers can be applied regardless of the R_c at higher temperatures, while magmatic temperature tends to be overestimated due to kinetic delay of crystal growth at lower temperature.

Keywords: plagioclase, crystallization, kinetics, basalt, geothermometry

