Role of thermal boundary layer on microlite crystallization: constraints from shear-deformation experiments

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Microlite crystallization in ascending hydrous magmas has been widely believed to be driven by decompression and resulting liquidus temperature increase, because thermal conductivity of magma is low and cooling is less effective for magmas ascending at a common velocity in a conduit. In the thermal boundary layer along conduit walls, however, effect of thermal conduction is imposed on the undercooling produced by decompression, thus microlite nucleation is supposed to be enhanced. The conduit walls may work also as a site for heterogeneous nucleation. In order to evaluate the potential role of thermal boundary layer on the microlite crystallization in ascending magmas, we have investigated experimentally the effect of temperature gradients and shear flow on the textural evolution and crystallization kinetics of trachyandesitic melt using an image furnace. The shear deformation was applied by twisting two rods, fixed to the upper and lower shafts. The rods of alumina were used in Series1 experiments. In Series2 experiments, dacite lava was used for the upper rod. The starting materials were initially heated at a temperature higher than the liquidus temperature for 60–120 minutes, then once quenched and reheated at a run temperature below the liquidus. The difference between the initial heating temperature and the liquidus was defined as superheating, -DT. The difference between the run temperature and the liquidus temperature, was defined as supercooling, DT. The experiments were performed at different degrees of superheating (-DT = 33, 98 and 233°C), supercooling (DT<138°C) and rotation rates (0, 0.08 and 0.8 rpm). In Series 1, run products had high crystal fraction only at low superheating (33°C), in which minute relict crystals worked as a nucleation sites. At higher superheating experiments (98 and 233°C) and static experiments without shear, no crystal was observed in the central part of the run products. On the other hand, the run products of Series2 had high crystal fractions even at a high superheating (-DT = 233°C) when the shear rate was high ($>10^{-1}$ s^{-1}: 0.8 rpm). The difference between Series1 and Series2 can be summarized as follows. The surface of the rods, both alumina and dacite, induced heterogeneous nucleation of plagioclase. However, the crystals formed on the alumina rod surface were spherite-like, whereas those on the dacite rod surface had a shape similar to natural microlites. The nucleated plagioclase crystals were removed from the rod surfaces by shear flow only from the dacite surface in Series2. The plagioclase crystals were brought to the inside of the samples, resulting in high crystal number density and volume fraction.

Assuming a simple plug flow with conductive cooling from the walls, the thermal boundary layer with DT=20°C can be formed from the conduit wall with a thickness of a few percentage of the conduit radius. The strain rate at which the crystal can be removed from the boundary layer, i.e., 10^{-1} s^{-1} , is achieved near the conduit wall if the ascent rate of magma is higher than 5.0×10^{-2} m s^{-1}. These rates were observed in some eruptions such as Mount St. Helens. Crystal number density of the eruptive materials may, therefore, include the crystals formed at the thermal boundary layer near the conduit wall as well as the crystals nucleated in the conduit center solely by decompression. The effect of thermal boundary layer crystallization should be considered for number density and morphology of microlites in volcanic rocks.

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