Laboratory experiments on the whole process of magma chamber solidification

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How does the initially totally molten and thermally convecting magma chamber solidify ? How is the solidification process and solidification texture related ? There have been experimental (e.g., Brandeis & Marsh, *Nature*, 1989) and theoretical (e.g., Worster et al., *EPSL*, 1990) studies focusing on how the melt solidifies when it is cooled. These studies have showed a complex coupling between solidification and thermal, compositional convection, but detailed study on the whole process of solidification is still limited. Here we conduct laboratory experiments using a wax to model magma and study the whole process until complete solidification under different thermal boundary conditions.

We use a thin acrylic tank with a height 80 mm, width 80 mm and a thickness of 10 mm. We fill the tank with a wax (PEG 1000) which solidifies at 37 degrees C. We heat the tank from below using a heater at a temperature of 70 degrees C. The wax melts and thermal convection occurs. The Prandtl number of the liquid PEG is Pr = 700 and the Rayleigh number of thermal convection is $Ra=2.4\times10^7$. After a steady state convection is achieved, we turn off the heater and the wax solidifies. We record the cooling process using time-lapse photos and measure the temperature within the liquid and at the boundaries. We conducted experiments under the following 3 thermal boundary conditions : Case A (Cooled from above at a room temperature and insulated from below), Case B (Cooled from above by an ice water and insulated from below), Case C (Cooled from below at a room temperature and insulated from above). From these experiments, we find the following: (i) the time needed for the total solidification is the same for the 3 cases within 5 %, (ii) for cases A and B, convective pattern changed during cooling and transformed to a single upwelling at the center and two downwellings at the sides whereas for Case B, convective pattern remained unchanged during solidification and only changed immediately before total solidification, (iii) solidification texturing occurred with a pattern corresponding to the temperature field of the thermal convection immediately before the total solidification.

Our experimental results can be interpreted as follows. (i) In our experiments the time required for total solidification is comparable regardless of the thermal boundary condition. When the boundary temperature is low, solidification occurs earlier, but suppresses the heat transfer thereafter due to the thickening thermal boundary layer. This seems to be the reason for the comparable total solidification time. (ii) In our experiments, in Case B, solidification started within a time scale shorter than the turnover time and the convection pattern remained unchanged. This is consistent with the estimate that at least a convective turnover time is needed for a convection pattern to change. (iii) Our experiments show solidification texturing corresponding to the temperature field of thermal convection immediately before solidification. The thermal diffusion time for the temperature field originating from thermal convection to become homogenized can be estimated as 4 hours, assuming a convection cell size of 4 cm. On the other hand, the time needed for total solidification after the convection stops is only about 15-18 min, which is much shorter than the thermal diffusion time, which explains why solidification texturing occurred. Our experiments suggest that similar phenomena may occur in magma chambers if the same conditions describe above are satisfied.

Keywords: magma chamber, solidification process, thermal convection, solidification texturing

