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Crystallization, latent heat release, and thermal history of magmas

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Crystallization of magma releases ~250-450 J g^{-1} of latent heat, equivalent to the sensible heat released during ~200-300K of cooling, and thereby effectively doubling the heat capacity of the magma over the region of partial melting or crystallization. Ordinarily, the effect is thermal buffering, slowing cooling rates. However, growth at high degrees of undercooling can occur very rapidly, forcing the release of large amounts of latent heat very quickly. We showed that recalescence, or spontaneous reheating of a cooling material due to rapid release of latent heat, can occur during disequilibrium crystallization of depolymerized Mg-rich melts [1]. This can only happen at fast cooling rates, where the melt becomes undercooled by tens to hundreds of degrees before crystallization begins. Using a forward-looking infrared (FLIR) camera, we documented recalescence in pyroxene $(Fe,Mg)SiO_3$ and komatiite lavas that initially cooled at 25–50 °C s^{-1}. Local heating at the crystallization front exceeds 150 °C for the pyroxene and 10 °C for komatiite and lasts for several seconds as the crystallization front migrates through.

Thermal diffusivity in melts is typically ~3-5x10^{-7} m^2s^{-1} [2] and crystal growth rates ~10^{-3} ms^{-1} observed in our experiments are consistent with growth into the cooler melt outpacing heat loss from the crystals. Both occur orders of magnitude faster than chemical diffusion in the melt, which is of the order of 10^{-10} m^2s^{-1} [3]. Using differential scanning calorimetry, we determined the latent heat release by to be 440 J g^{-1} for pyroxene and 275 J g^{-1} for komatiite, with a brief power output of ~100 W g^{-1} or ~300 MW m^{-3}. Recalescence may be a widespread process in the solar system, particularly in lava fountains and chondrules, and cooling histories of mafic pyroclasts should not be assumed a priori to be monotonic.

[1] Whittington & Sehlke (2021), *Geology* 49, 1457–1461.

[2] Hofmeister et al. (2016), *J. Volc. Geotherm. Res.* 327, 330-348.

[3] Ni, Hui, & Steinle-Neumann (2015), *Rev. Geophys* 53, 715–744.