RECALESCENCE IN SILICATE MELTS: APPLICATIONS TO CIRCUMSTELLAR DUST GRAINS, LAVA FOUNTAINS AND LAVA FLOWS. A. G. Whittington¹, A. Sehlke² and A. K. Speck³, ¹Geological Sciences, The University of Texas at San Antonio, One UTSA Circle, San Antonio TX 78249, alan.whittington@utsa.edu, ²NASA Ames Research Center, Moffett Field CA 94035, alexander.sehlke@nasa.gov, ³Physics and Astronomy, The University of Texas at San Antonio, One UTSA Circle, San Antonio TX 78249, angela.speck@utsa.edu

Introduction:  Lava droplets, chondrules, and circumstellar dust grains are generally assumed to cool monotonically. Crystallization releases additional latent heat, which typically slows cooling. However, when crystallization occurs very rapidly, such as at high degrees of undercooling, this latent heat can be released faster than it can be lost to the surroundings, and the sample will heat up. This phenomenon is known as recalescence. Although better known in metallurgical literature, recalescence has been suggested to occur in basaltic lavas based on temperature measurements by thermocouples overrun by advancing lava [1]. We have studied recalescence using cameras recording the cooling of small batches of lava in platinum crucibles, in the laboratory.

Experiments:  Rapid cooling of silicate melts facilitates undercooling, where nucleation is delayed and crystal growth begins at temperatures below equilibrium. In depolymerized (~mafic) melt compositions, crystal growth can be very rapid, and recalescence can occur. We have documented recalescence in Fe-Mg pyroxene and komatiite melts, using a thermal imaging (FLIR) camera for melt volumes on the order of a few cm³, and using differential scanning calorimetry for melt volumes on the order of a few mm³. On cooling Fe₀.₆Mg₀.₄Si₂O₆ liquid from ~1600°C in air, at ~30°C/s, crystallization begins at ~1110°C. Averaging over the whole base of the crucible (~10cm²), the observed temperature increase is ~100°C and it takes ~2.5 seconds to attain the thermal peak. Crystallization and heating can be seen migrating across the melt volume together. When looking at a 3x3 pixel spot (~1mm² in our setup), reheating of >150°C occurred in ~1 s. About 30 mg of the same melt was cooled in a differential scanning calorimeter. Cooled at ~1°C/s, two distinct crystallization peaks were seen at ~1450 and ~1270°C. Cooled at ~2°C/s, the first peak was delayed to ~1315°C and merged with the second. Examination of recovered samples indicates crystallization of enstatite, followed by Fe-oxides and tridymite in a silica-rich glass matrix. On cooling of komatiite liquid from ~1600°C at ~50°C/s, crystallization begins at ~1080°C. The average temperature plateaus for ~2s and then continues cooling. When looking at a 3x3 pixel spot, heating of ~10°C could be detected only by comparing different video frames.

We determined the latent heat release by differential scanning calorimetry, at 440J/g for pyroxene and 275 J/g for komatiite, with a power output of ~100 Wg⁻¹ or ~300 MWm⁻³. Recalescence may be a widespread process in the solar system, on a range of scales, from ultramafic to mafic lava flows, lava lakes, and lava fountains, but also chondrules and circumstellar dust shells.

Implications For Crystallization In Circumstellar Dust Shells: Dust that coalesces to form planetary systems originates around dying stars, before passing into the interstellar medium (ISM). Historically, observations of broad smooth features in the 10-µm region suggested that dust in circumstellar regions, and in the ISM, was mostly amorphous rather than crystalline [2]. With improved space telescope capabilities, crystalline silicates were discovered in the circumstellar regions around both young and old stars [3-5], although they remain undetected in the ISM [6]. Despite intensive study the precise conditions that lead to the formation of crystalline silicates are still unknown, and their absence in the ISM remains problematic.

We have documented recalescence in rapidly crystallizing Mg-rich silicate melts, with local heating at the crystallization front exceeding 160°C in some cases. In circumstellar dust shells, amorphous grains with similar compositions condense at temperatures near their glass transition, and if they crystallize, they will recalesce. The higher temperature (T) of newly crystallized dust allows crystalline spectral features to

Figure 1: Crystallization in a Pt crucible, imaged with an iPhone. Crucible base is ~5cm diameter. Crystals are hotter than the melt from which they grew, and the crystallization front is the hottest part of the sample.
be seen, because flux emitted depends on $T^4$. After cooling to ambient temperature, crystalline spectral features in the ISM are concealed by volumetrically dominant amorphous dust. Our results explain the existence of crystalline silicate pre-solar grains, which are older than the solar system, and have implications for radiative transfer modeling and hydrodynamics of dusty environments, which are sensitive to small variations in optical properties.

**Implications for lava fountains on Io:** Lava droplets on Io are expected to be similar to glass spherules found on the Moon, ranging in size from 0.1 to 1 mm in diameter (e.g., [7]). Keszthelyi et al. (2007) modeled the thermal history of lava droplets on Io for 0.1 and 1.0 mm diameter (representing lava fountaining), and an infinite slab (representing a lava flow) [8]. These 0.1 and 1 mm droplets are predicted to cool at about ~650 and ~200 degrees per second. However, in the thermal modeling, the droplets were assumed to quench to glass, therefore unable to recrystallize and release heat during crystallization.

Droplets of ~0.5 to 2 mm diameter are predicted to cool at ~20-50 K/s [9], the range in our experiments where we observed recrystallization during rapid crystal growth, following delayed nucleation. In this case, the additional latent heat released will contribute to the overall thermal flux of the fountain [10], but will not be accompanied by higher peak temperatures, because recrystallization is limited to subliquidus temperatures (Figure 2).

![Diagram](image.png)

**Figure 2:** Schematic temperature-time diagram indicating cooling rates that result in quenching, recrystallization, and monotonic cooling. Note log scale on the x-axis.

**Implications for lava flow monitoring and modeling:** Our observations of mm-scale temperature differences up to ~100° C in cooling lava suggest that thermal imaging of basaltic lava flows needs to be conducted with mm-scale spatial resolution (see figure; crucible is ~5 mm diameter). Temperatures recorded with low spatial resolution, which average cooler melt and hotter crystals in a single pixel, will systematically overestimate the temperature of the liquid phase. Only the surface of a lava flow is likely to cool quickly enough for recrystallization to occur, but this is precisely the part of the lava that is monitored by thermal imaging.

Additionally, numerical models of thermal processes should incorporate latent heat of crystallization explicitly, and not as an “effective heat capacity” term, if recrystallization is a possibility. This will generally only apply to processes involving mafic to ultramafic lava cooling at tens of degrees per second.

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**References:**