Insights into crystal growth rates from a study of orbicular granitoids

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Growth of crystals in magmatic systems places constraints on the thermal and chemical evolution of magmas, and as well as provides surfaces on which bubbles can nucleate. A case study of orbicular granitoids from Western Australia has been conducted to explore the crystal growth rate in geologic systems. The orbicular granitoid has a leucocratic matrix where a huge amount of elliptical orbicules intersperse. Each orbicule has a core and generally two concentric layers where radiating hornblende and interspersed plagioclase with minor biotite, opaque oxide occur. Detailed image analysis shows that mineral modes and hence bulk composition at the scale of the band is homogeneous from rim to core. Crystals number density decreases and crystal size increases from rim to core. These observations suggest that the orbicules crystallized rapidly from rim to core. We propose that these granitoid samples may result from the inward rapid cooling of dioritic pockets which are probably formed by the underplating and following injection of a hot dioritic magma into a cold granitic magma. We estimated cooling timescales based on conductive cooling models, constraining crystal growth rates to be 10^{-6} to 10^{-5} m/s or 1-2 cm/hr. The oscillatory banding reflects disequilibrium crystallization, wherein hornblende preferentially crystallizes, resulting in the diffusive growth of a chemical chemical boundary layer enriched in plagioclase component, which in turns results in crystallization of plagioclase. We show that the correlation between the width of each crystallization band with distance from orbicule rim is linear, with the slope corresponding to the square root of the ratio between chemical diffusivity in the growth medium and thermal diffusivity. We estimate chemical diffusivities of 2×10^{-7} m^2/s, which is remarkably fast for silicate liquids but reasonable for diffusion in hot aqueous fluids, suggesting that crystallization occurred during water-saturated conditions. Combined with estimates of the boundary layer thickness, we use these diffusivities to estimate the diffusive flux, arriving at crystal growth rates similar to that constrained by thermal modeling. This work shows that water content of mixing magmas is crucial for controlling the textures of rocks, and implies that in the presence of fluids, crystal growth rates in magmatic systems may be under-estimated.