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Crystal growth in ascending magmas: from individual crystals to crystal populations

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Ascent of magmas during extrusive volcanic eruptions involves large changes in - pressure-temperature conditions which result in non-equilibrium degassing-induced crystallization. Erupted rocks record magma ascent conditions through zonation in individual crystals and through size distributions in populations of crystals. We have developed a mathematical model of diffusive growth of an individual plagioclase crystal from an undercooled magma. The model considers diffusion of 3 components: anorthite (An), albite (Ab) and the rest of the melt. Diffusive fluxes contain cross-terms that account for the relative motion of the components. On the boundary of the growing crystal, mass conservation of An and Ab is satisfied. The growth rate of a crystal strongly depends on undercooling. Liquidus temperature depends on the An content and pressure. Crystal composition is a non-linear function of the An content of the melt. These features make the multi-component model of crystal growth highly non-linear. Numerical simulation of crystal growth in response to a linear drop in temperature with time shows complicated non-monotonic patterns. Crystal growth leads to depletion of a boundary layer in plagioclase components, meanwhile diffusion leads to re-equilibration of the melt with growing crystal. As a result, the crystal grows in pulses with sharp changes in composition due to changes in the melt composition in the boundary layer. As magma ascends, the competition between growth of preexisting crystals and nucleation of the new crystals determines the crystal size distribution (CSD). If nucleation dominates, the CSD will be shifted to smaller crystal sizes. In steady state, CSD evolution is described by a linear hyperbolic equation with coefficients that depend on ascent velocity, crystal growth and nucleation rates. If these coefficients are known as a function of temperature, pressure and crystal content, it is possible to reconstruct variations of these parameters along the conduit based on measures of the CSD of eruptive products. Obtained values of parameters from the CSD of volcanic dome samples are in good agreement with predictions of mechanical models of conduit flows.