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Complex crystal zoning outcomes from simple dynamic processes

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Crystal chemical data have been used extensively to investigate magmatic processes such as assimilation, replenishment, degassing and decompression. In particular, experimental data is employed to connect physical changes of intensive variables with information stored in crystals by element zoning pattern. Most experimental data are limited by their equilibrium and therefore steady-state conditions. In real magmas crystals may experience transient chemical and thermal signals, in which e.g. gas-driven processes may have very short timescales whereas temperature-driven processes act on long timescales. Hence, the crystal cargo that reacts to the fluid flow may record transient changes that have timescales similar to crystal growth, while transient signals of short duration may be missed by the crystal recorder. Numerical simulations can address these unsteady conditions in crystal growth and make predictions for zoning pattern associated with magmatic processes.

We present a two-fold numerical approach that captures the interactions of the multiphase mixture (melt, crystals, and bubbles). Employing an Eulerian-Eulerian implementation the model calculates the flow field of each phase and its volume fractions as well as the corresponding intensive variables. Of particular interest are temperature and composition, because they mainly control phenocryst growth (e.g. plagioclase) in magmatic plumbing systems. In the second step up to 5000 example particles are introduced into the flow field and recover individual crystal information. Using a kinetic law as well as constitutive equations for the evolution of a boundary layer around single crystals we can generate synthetic crystal growth with an explicit zoning pattern. This technique enables us to investigate the formation of crystal zoning with respect to a variety of magmatic processes. We have focused on chamber overturn caused by degassing, chemical or thermal instabilities.

Fast gas-driven overturn mainly records the thermal and chemical environment after the chaotic rearrangement within the magmatic system. The result is a slowly settling zoned magma chamber. Hence, depending on the position within this chamber-wide zoning crystals may record vastly different local conditions. During further mixing or during eruption the crystals are redistributed and gathered from different environments of the system. Their chemical signature therefore can vary though they all record the same simple overturn process.