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Crystal fractionation by crystal-driven convection

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In the last two decades, improved fine scale analysis in crystalline profiles has improved our understanding of igneous processes, while opening our sight to more complexities. As an example, plagioclase crystal profiles in Holyoke flood-basalt flow revealed that the crystals got exposured to different melt environments as the layer underwent fractional crystallization. Fractional crystallization is an essential process for determining the compositional evolution of magmatic systems. The process requires a reactive segregation process, where crystals precipitate from the melt and segregate from their residual melt. In this study, we are motivated by the subtleties in the crystalline record to model the segregation component of fractional crystallization, or crystal fractionation.

We build a numerical model with individually resolved, denser-than-melt crystals in a convective flow. We test the low to intermediate crystallinity regime, where the physical processes leading to efficient fractionation are less clear than at high crystallinity. We simulate the physical segregation of crystals from their residual melt at the scale of individual crystals using a direct numerical method. By resolving each of the crystals, we do not require a priori parameterization of crystal-melt interactions. We use tracers in the melt to track the different melts around the crystals.

We find that collective sinking of crystal-rich clusters dominate settling at low particle Reynolds numbers. The relatively rapid motion of this cluster strips away the residual melt around the cluster. Compared to individual settling, the resulting crystal fractionation is efficient but heterogeneous at the crystalline scale. Similar to the Holyoke flood-basalt plagioclase profiles, the crystals in our analysis show exposure to different melt environments as they drive crystal fractionation. Our results suggest that cluster driven fractional crystallization will vary in efficiency. At the system scale, this result would suggest a bell curve compositional abundance distribution in volcanic systems.