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Forward Modeling Crystal Growth in Recharge-Driven Magma Chambers Using the Magma Chamber Simulator

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Magma recharge and mixing are fundamental open-system processes that are hypothesized to catalyze volcanic eruptions. The record of magma recharge/mixing preserved within minerals typically manifests as core-to-rim chemical changes often associated with disequilibrium textures. Quantifying the conditions that generate particular mineral compositional change is critical for interpreting magmatic processes and assessing volcanic behavior; however, directly linking observed zoning patterns to specific recharge conditions remains a major challenge in igneous petrology.

The Magma Chamber Simulator (MCS) is a thermodynamic modeling tool that documents open-system magmatic processes. The output includes the composition and mass of stable phases for each computational step. This study presents the first systematic investigation of mineral compositional changes associated with variable magma recharge events within an isobaric magma chamber. Results are visualized to allow detailed comparison of mineral zoning patterns produced by different recharge scenarios, enabling petrologists to define best-fit model constraints by comparing modeled and observed zoning patterns.

More than 20 MCS recharge-fractional crystallization (RFC) simulations systematically varied recharge conditions. The *aggregate* recharge magma mass was equivalent to 1.5 times the resident (pre-existing) magma mass. Recharge frequency and masses included two pulses of 0.75, three of 0.50, five of 0.30, and ten of 0.15 times the initial resident magma mass. Resident magma–recharge magma compositional contrasts included mafic-into-felsic and mafic-into-mafic scenarios. Hydrous recharge conditions were tested by varying H_2O content between the resident and recharge magmas.

Zoning patterns of olivine, plagioclase, and clinopyroxene were documented using a Python-based workflow that isolates mineral-specific data at each temperature step of an MCS calculation, calculates key compositional parameters (plagioclase An, clinopyroxene Mg#, olivine Fo), and couples these values with normalized mineral mass.

This approach generates quantitative visualizations for core-to-rim crystal growth during RFC. Distinct zoning trajectories emerge in response to changes in recharge temperature, mass, event frequency, and resident melt and recharge magma compositions. Specific recharge conditions produce identifiable mineral growth signatures, providing an innovative computational framework for matching zoning patterns in natural volcanic rocks with computational results. By transforming raw thermodynamic simulations into crystal growth histories, this work introduces a novel methodological bridge between forward modeling and petrographic observation.