

The Magma Chamber Simulator: Modeling the Impact of Assimilation-Fractional Crystallization in a Composite Magma-Wallrock System

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Elucidation of the spectrum of compositional and mineralogical characteristics that can be generated by assimilation-fractional crystallization (AFC) contributes to the goal of defining the thermal and mass characteristics required to develop and maintain magma transport and storage systems in a range of tectonic settings. The Magma Chamber Simulator (MCS) utilizes the thermodynamic functionality of MELTS (Ghiorso & Sack 1995) and the composite system approach of EC-AFC (Spera and Bohrsen 2001) to assess thermal, compositional and mass variations that develop in a composite magma wallrock (M-WR) system undergoing AFC; constraints of energy conservation are operative in the composite system. Wallrock of defined initial conditions (e.g., PTX) heats up and potentially melts as magma cools and crystallizes. Energy balance is maintained between magma and wallrock and informs the thermal condition of wallrock, which dictates the amount and composition of anatectic melt. When anatectic melt is incorporated into magma, the composition and temperature of solids and melt are assessed. As magma cools through a defined T path, model output includes thermal, mass, compositional, and physical parameters for melt and solids in magma and wallrock. The simulation is complete when thermal equilibrium between magma and wallrock is achieved. Key parameters, among others, that can impact the bulk composition and mineralogy of magma undergoing AFC include the wallrock to magma initial mass ratio, wallrock initial T, the initial compositions of magma and wallrock, and the abundances and composition of fractionating minerals.

Preliminary analysis of a case where basaltic magma assimilates a variety of wallrock melt compositions illustrates the impact that energy constraints place on AFC. MORB host magma at 0.1 GPa (~3 km) is contaminated by anatectic melts from lherzolite, andesite, dacite and rhyolite composition wallrock. To emphasize the impact of assimilation, for the illustrated simulations, the initial mass of magma is equal to the initial mass of wallrock. The magma liquidus (~1225°C) is determined by MELTS, and the initial wallrock temperature, which is user defined, is 900°C for lherzolite and 650°C for all other compositions. The lherzolite case runs to thermal equilibrium, whereas the other cases terminated at magma temperatures between 1150 and 1100°C and wallrock temperatures less than 950°C. As magma cools and crystallizes, wallrock heats up; enthalpy added to wallrock is tracked, and associated partial melting in wallrock occurs, producing variable amounts and compositions of anatectic melt. For example, lherzolite melts are generally basaltic, whereas initial melts from the other wallrock compositions are silicic, and have up to 75 wt. % SiO₂. Compositions of anatectic melts change as wallrock heat up, in response to the changing residual mineral assemblage and the amount of enthalpy delivered to wallrock. In the case of lherzolite, the cumulative mass of anatectic melt incorporated at thermal equilibrium between magma and wallrock is relatively small, ~5%. In contrast, the other cases yield between ~30 and 50% addition of melt. Because of the pseudo-invariant type melting behavior of the more silicic wallrock compositions, substantial anatectic melt is produced over small wallrock and magma temperature intervals. Thus, compared to a case of fractional crystallization (FC), contaminated melts (except lherzolite) have much higher SiO₂ at the same

magma temperature. One consequence of addition of highly silicic melts is suppression of crystallization in the magma. For FC only, the dominant minerals in the crystallizing assemblage include plagioclase, clinopyroxene, olivine and spinel. In the andesite, dacite and rhyolite cases, early in the assimilation process, crystallization of plagioclase, clinopyroxene, and olivine is suspended, and spinel does not become stable in the simulations. Additional work is required to fully understand this phenomenon. Major element impacts of the small amount of lherzolite assimilation are not profound; comparison with the FC only case shows that little difference is evident in the major oxides. In contrast, the more silicic cases show distinct differences compared to the FC only case. Using magma SiO_2 as the progress variable, contaminated magmas have more MgO , Al_2O_3 , and CaO than the FC case; these differences are most likely related to removal of those oxides by the fractionating phases. FeO and Na_2O are depleted relative to FC only, perhaps because added anatectic melts dilute magma abundances.

While additional analysis of these cases and trace element and isotopic modeling are pending, key preliminary observations from these simulations include: (1) the composition of anatectic melt changes during the partial melting process. Models that titrate constant composition assimilant into magma to evaluate compositional impact are therefore inappropriate; (2) basaltic magma composition varies, in some cases significantly, in response to assimilation of intermediate and evolved wallrock melts. Because oxide values can vary compared to FC only, even when SiO_2 is still in the basaltic range, and the response to assimilation by the crystallizing mineral assemblage may be subtle, interpretation of the origin of major element variations in basalts needs to be assessed in the context of the potential for AFC; and (3) the consequences of assimilation on the phase equilibria and composition of magma can be complex, and thus, a tool such as the Magma Chamber Simulator provides critical modeling capability that will enhance our ability to assess the origins of compositional evolution in magmas.