

Modeling the chemical evolution of open-system magma chambers using the principles of heat and mass transfer and thermodynamics

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A model of the chemical evolution of open-system magma chambers has been developed using the principles of heat and mass transfer, and thermodynamics. Generally speaking, thermal Rayleigh numbers for high-temperature, crystal-poor magma chambers are very large, resulting in vigorous thermal convection (Martin et al., 1987). However, convection is suppressed following ~50% crystallization because of the formation of an interlocking framework of crystals. This study focuses on the earlier convection stage of sheet-like magma chambers, prior to significant crystallization.

The model incorporates the effects of concurrent magma influx (recharge or mixing), roof-rock assimilation, magma extraction, and fractional crystallization. Magma influx affects magma composition and temperature, while the rate of roof-rock assimilation is controlled by convective heat flux from the magma and the effective fusion temperature of the roof rock (Huppert and Sparks, 1988; Koyaguchi and Kaneko, 1999). Crystal settling occurs at the floor of the magma chamber (Martin and Nokes, 1988). Equilibrium phase relations and the partitioning of major elements between mineral phases and coexisting liquid are calculated thermodynamically using the rhyolite-MELTS algorithm (Gualda et al., 2012). Trace element and isotopic variations of the magma are calculated using open-system chemical mass balance equations (Nishimura, 2012).

The model quantifies the evolution paths of major and trace elements, and isotopes within crystals, liquid, magma, and crystal rims. Of note, it also shows that the rate of magma influx strongly affects crystal core-to-rim profiles of trace-element concentrations and isotopic ratios.

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