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Thermodynamic constraints on assimilation of silicic crust by primitive magmas

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Some studies on basaltic and more primitive rocks suggest that their parental magmas have assimilated more than 50 wt.% (relative to the initial uncontaminated magma) of crustal silicate wallrock. But what are the thermodynamic limits for assimilation by primitive magmas? This question has been considered for over a century, first by N.L. Bowen and many others since then. Here we pursue this question quantitatively using a freely available thermodynamic tool for phase equilibria modeling of open magmatic systems — the Magma Chamber Simulator (MCS; https://mcs.geol.ucsb.edu).

In the models, komatiitic, picritic, and basaltic magmas of various ages and from different tectonic settings assimilate progressive partial melts of average lower, middle, and upper crust. In order to pursue the maximum limits of assimilation constrained by phase equilibria and energetics, the mass of wallrock in the simulations was set at twice that of the initially pristine primitive magmas. In addition, the initial temperature of wallrock was set close to its solidus at a given pressure. Such conditions would approximate a rift setting with tabular chambers and high magma input causing concomitant crustal heating and steep geotherms.

Our results indicate that it is difficult for any primitive magma to assimilate more than 20−30 wt.% of upper crust before evolving to intermediate/felsic compositions. However, if assimilant is lower crust, typical komatiitic magmas can assimilate more than their own weight (range of 59−102 wt.%) and retain a basaltic composition. Even picritic magmas, more relevant to modern intraplate settings, have a thermodynamic potential to assimilate 28−49 wt.% of lower crust before evolving into intermediate/felsic compositions.

These findings have important implications for petrogenesis of magmas. The parental melt composition and the assimilant heavily influence both how much assimilation is energetically possible in primitive magmas and the final magma composition. The fact that primitive mantle melts have potential to partially melt and assimilate significant fractions of (lower) crust may have fundamental importance for how trans-Moho magmatic systems evolve and how crustal growth is accomplished. Examples include generation of siliceous high-magnesium basalts in the Precambrian and anorogenic anorthosite-mangerite-charnockite-granite complexes with

geochemical evidence of considerable geochemical overprint from (lower) crustal sources.