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Markov Chain Monte Carlo Inversion of Mantle Temperature and Composition, with Application to Iceland

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Basalts are formed by adiabatic decompression melting of the asthenosphere, and thus provide records of the thermal, chemical and dynamical state of the upper mantle. However, uniquely constraining the importance of these factors through the lens of melting is challenging given the inevitability that primary basalts are the product of variable mixing of melts derived from distinct lithologies having different melting behaviors (e.g. peridotite vs. pyroxenite). Forward mantle melting models, such as REEBOX PRO [1], are useful tools in this regard, because they can account for differences in melting behavior and melt pooling processes, and provide estimates of bulk crust composition and volume that can be compared with geochemical and geophysical constraints, respectively. Nevertheless, these models require critical assumptions regarding mantle temperature, and lithologic abundance(s)/composition(s), all of which are poorly constrained. To provide better constraints on these parameters and their uncertainties, we have coupled a Markov Chain Monte Carlo (MCMC) sampling technique with the REEBOX PRO melting model. The MCMC method systematically samples distributions of key REEBOX PRO input parameters (mantle potential temperature, and initial abundances and compositions of the source lithologies) based on a likelihood function that describes the 'fit' of the model outputs (bulk crust composition and volume and end-member peridotite and pyroxenite melts) relative to geochemical and geophysical constraints and their associated uncertainties. As a case study, we have tested and applied the model to magmatism along Reykjanes Peninsula in Iceland, where pyroxenite has been inferred to be present in the mantle source. This locale is ideal because there exist sufficient geochemical and geophysical data to estimate bulk crust compositions and volumes, as well as the range of near-parental melts derived from the mantle. We find that for the case of passive upwelling, the models that best fit the geochemical and geophysical observables require elevated mantle potential temperatures ($\sim$120 °C above ambient mantle), and $\sim$5% pyroxenite. The modeled peridotite source has a trace element composition similar to depleted MORB mantle, whereas the trace element composition of the pyroxenite is similar to enriched mid-ocean ridge basalt. These results highlight the promise of this method for efficiently exploring the range of mantle temperatures, lithologic abundances, and mantle source compositions that are most consistent with available observational constraints in individual volcanic systems.

1 Brown and Lesher (2016), G-cubed, 17, 3929-3968