

Statistical sampling of mantle heterogeneity

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The Earth's mantle is chemically, isotopically, and perhaps even lithologically, heterogeneous. This heterogeneity provides key information on Earth's evolution through time. Unfortunately much of this information is destroyed and overprinted by the melting and melt mixing processes that occur during the formation of basalt, which is then sampled at the Earth's surface.

The aim of this study is to better understand how mantle heterogeneity is filtered to produce the heterogeneity we observe in basalts. Since the physical processes of melting, melt mixing, and melt extraction are complex and still poorly understood, we focus here on developing simple statistical models of the sampling process. In these models we consider the melting of a two lithology source consisting of an enriched, more fusible, lithology (e.g. pyroxenite), and a more depleted, less fusible, lithology (e.g. peridotite). We fractionally melt these two lithologies, and then mix the resultant fractional melts together to form a sample, i.e. an erupted basalt.

There are many different ways in which the fractional melts can be mixed together to produce a sample, and we compare a number of different models for this mixing process. We focus in particular on the effects of biasing the mixing according to the different depths at which the fractional melts are generated. To constrain our models we compare the results with isotopic, major, and trace element observations of both whole rocks and melt inclusions from tightly constrained regions (e.g. Theistareykir, NE Iceland [1, 2]). Models in which deep melts mix more thoroughly than shallow melts can account for several key characteristics of these geochemical observations. We suggest that mixing of deep melts occurs during melt generation and migration in the mantle, prior to extensive mixing in lower crustal magma chambers.

[1] Stracke *et al.* (2003) *Geochem. Geophys. Geosyst.* **4**, 8507.

[2] MacleNNan *et al.* (2003) *Geochem. Geophys. Geosyst.* **4**, 8624.

A novel proxy links CAMP volcanism with end-Triassic mass extinction and early Jurassic evolution

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Phanerozoic mass extinctions are marked by global marine and terrestrial biodiversity loss and often linked to the formation of large igneous provinces (LIPs). Large-scale greenhouse gas release during these major volcanic events had a profound impact on the global exogenic carbon cycle, initiating strong perturbations in $\delta^{13}\text{C}$ records. Hence, they can be regarded as natural deep-time analogues of global environmental change. However, high resolution stratigraphic correlation between LIP formation, biotic crises and isotopic perturbations are poorly constrained. Here we present a novel proxy for volcanic activity, based on relative abundance changes of Lu, Hf, Y and Nb trace elements (ratio: $(\text{Lu}/\text{Hf})_{\text{Y/Nb}}$), in a marine sedimentary record across the Triassic-Jurassic boundary. We show that peak $(\text{Lu}/\text{Hf})_{\text{Y/Nb}}$ values exactly match up with consecutive continental flood basalt emplacements in the Central Atlantic Magmatic Province (CAMP). The observed $(\text{Lu}/\text{Hf})_{\text{Y/Nb}}$ -peaks also coincide with the end-Triassic mass extinction, one of the largest Phanerozoic extinctions (at ~201.38 Ma), and with early Jurassic recovery patterns, suggesting that volcanism also governs (the speed of) early Jurassic evolution. Hence, this proxy for the first time allows very detailed causality studies on increased volcanic activity, disruption of global geochemical cycles and global biodiversity/ ecosystem turnovers, in unprecedented stratigraphic resolution. We furthermore test this method on the end-Permian mass extinction, the largest extinction event in earth history. Furthermore, the abundance of these trace elements in different CAMP basalt units, suggests a transition in magmatic source for the flood basalts. Lu/Hf and Y/Nb values in the oldest CAMP units are similar to the upper crust and gradually change (within ~600 kyr) to MORB values in the youngest CAMP units. In addition, highly reactive iron and trace element (Mo, U etc.) data allow interpretation of water column conditions in terms of oxic vs. anoxic and ferruginous vs. euxinic conditions. Periods of ocean anoxia/ euxinia (based on increased Fe-HR/Fe-T, Fe (Py)/Fe-HR, Mo values) coincides with the CAMP volcanic phase, but a direct link to individual CAMP pulses is yet less clear.