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Constraining the amount of recycled material in the mantle source from basalt chemistry

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As the primary flux of material from the mantle to the surface, the basalts erupted at mid-ocean ridges (MORB) are a key resource for investigating the mantle's chemical composition. However, despite the large volumes of oceanic crust returned to the mantle by subduction, it has proven difficult to estimate the abundance of this recycled material in the mantle source using the chemistry of MORB. This is a significant problem, as fundamental questions about the dynamics of our planet cannot be answered without quantifying the abundance and spatial distribution of the mantle's chemical heterogeneity: is Earth's convection layered, or does it involve the whole mantle? What is the eventual fate of recycled oceanic material? What are the fluxes of elements from the deep Earth to the surface? Here, we present a method to estimate the proportion of enriched material in mantle source regions by combining geochemical observations with simple bilithologic models of mantle melting.

Working backwards from the chemistry of an erupted basalt to the proportions of peridotite and basalt lithologies in the source requires a number of critical pieces of information. Firstly, the geochemical variability at a ridge segment needs to be used to identify the types of lithology melting. Secondly, the relative mass of the enriched and depleted melts needs to be determined. Finally, a bi-lithological melting model needs to be run in an attempt to account for the over-representation of fusible, productive lithologies in the final mixed melt (Hirschmann and Stolper, 1996; Shorttle and Maclennan, 2011). This last step involves a large number of secondary assumptions/inputs to make the melting problem tractable, such as the mantle flow field and mantle potential temperature.

We determine the abundance of recycled material in the mantle beneath Iceland and at other ridges and ocean island settings in three stages. (1) The lithologies contributing to melting are identified by quantitative comparison of the major element composition of erupted basalts to a database of experimental partial melts (Shorttle and Maclennan, 2011). (2) A mass balance is calculated between the endmember basalt compositions and the fully mixed melt to obtain the relative proportion of enriched and depleted melts. (3) A bilithologic melting model modified from Shorttle and Maclennan (2011) is then used with the appropriate lithological melting parametrisations to account for the differences in productivity.

Applying this method to Iceland demonstrates that $\sim 10\,\%$ of the source is recycled basaltic material. However there are large uncertainties on this number, and our results demonstrate that the ability to constrain the mass fraction of lithologies contributing to melting depends heavily on the dynamics of mantle flow, melting and melt transport/reaction.

References:
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