Rare earth element inversion models for basalts associated with the Kerguelen mantle plume

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Introduction

McKenzie and O'Nions (1991, 1994) have shown that the composition of magmas generated by decompression melting of primitive or depleted mantle can be modelled by inverting rare earth element (*REE*) concentrations. The inversion technique assumes fractional, adiabatic melting (White *et al.*, 1992), with the composition of the melt and residue governed by the vertical extent and depth of melting. In this study, we present results for Cretaceous and Mid-Eocene basalts from the eastern Indian Ocean, believed to be products of the Kerguelen mantle plume (e.g., Royer and Sandwell, 1989). The age, chemistry, and isotopic characteristics of these lavas have been discussed in several recent papers (see Storey *et al.*, 1992 for references). The aim of our work is to constrain the melting history of the Kerguelen plume, and to relate this history to tectonic setting and the fluid dynamics of the plume. A more comprehensive discussion of the modelling results will be presented elsewhere (Kent *et al.*, in preparation).

Methodology

The rare earth element composition of the melt was calculated from the partition coefficients and source concentrations given by McKenzie and O'Nions (1991, 1994), using the expressions for adiabatic melting in White *et al.* (1992). Major element concentrations for the solutions were predicted from Watson and McKenzie's (1991) parameterization. The melt fraction as a function of depth was obtained from the mean of the observed *REE* abundances in the melt, using the inversion method described by McKenzie and O'Nions (1991). In order to minimise the effects of clinopyroxene and plagioclase fractionation, the inversions used samples with $\geqslant 6$ wt.% MgO, for which at least eight *REE* concentrations were available. The amount of fractionation undergone by the samples was calculated using equation 31 of McKenzie and O'Nions (1991).

Inversion results

The total melt thickness obtained from each inversion is shown in Fig. 1. The inversions for Kerguelen Plateau ODP sites and Kerguelen Island used only two to four samples, and may not represent a true average of the melting column. In each case, the best fit to the data was obtained by using primitive mantle for the normalisation. The calculated melt thicknesses agree well with estimates of crustal thickness obtained by seismic refraction studies, where available (see Storey *et al.*, 1992 for summary).

The Rajmahal basalts form the feather-edge of a seaward-dipping reflector sequence erupted on the margin of eastern India in Early Cretaceous times (Kent, 1992). Inversion of tholeiite samples from the Rajmahal Hills suggests that melting occurs between slightly thin lithosphere (melt top ~55 km), with the garnet-spinel transition zone

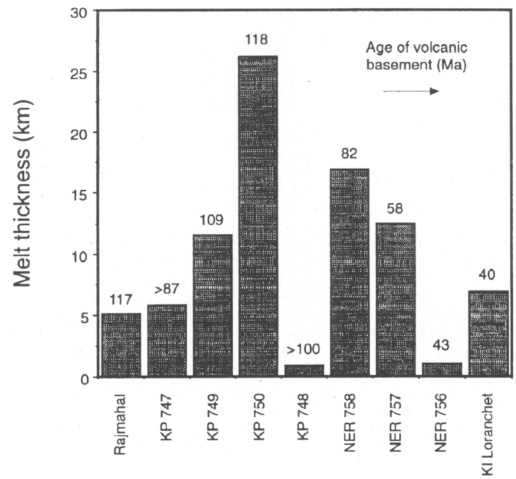

FIG. 1. Melt thickness at individual sites along the Kerguelen plume track, calculated from *REE* inversions. The approximate age of igneous basement is shown above each column. KI = Kerguelen Island, KP = Kerguelen Plateau, NER = Ninetyeast Ridge.

between 80 and 100 km. A maximum melt fraction of 8–9% and a melting column of 90 km is required to produce these basalts. Results for Kerguelen Plateau Site 747 are similar, with a maximum melt fraction of ~13%. Sites 749 and 750 (central Kerguelen Plateau) require slightly larger melt fractions of 16–21%, with melting extending to shallow levels (< 40 km). The results for these sites are consistent with melting of a hot plume (200–300°C hotter than ambient mantle) close to a ridge axis. Kerguelen Plateau Site 748, representing an alkali basalt flow some 150–200 m above seismic basement, is the only data set that requires metasomatic enrichment of the source region prior to melt generation. In this respect, it resembles the data sets from oceanic islands studied by McKenzie and O'Nions (1994).

Inversion of lavas from Ninetyeast Ridge ODP Sites 757 and 758 suggests that melting occurred over a large depth range (~100 km), with shallow melt tops (25 km and 10 km, respectively). The data are consistent with melting beneath a spreading centre, as predicted by the plate reconstructions of Royer and Sandwell (1989). Tholeiites from Site 756 on the southern part of the Ridge require a maximum melt fraction of 6–7%. Melt at this site is produced at depths between 110 and 70 km, suggesting an off-axis setting.

The Kerguelen Island data comprise three tholeiites from the Loranchet Peninsula, representing the shield-building stage of volcanism (Mid-Eocene). In this solution, melt is produced between 170 km and 60 km, with a maximum melt fraction of 16%.

Summary and conclusions

The *REE* inversion results provide useful information about melting associated with the Kerguelen mantle plume. Melt thicknesses obtained from the inversions are in good agreement with data from seismic refraction measurements of oceanic crustal thickness, and consistent with tectonic settings (e.g., plume-ridge intersections) predicted by plate reconstructions of the eastern Indian Ocean. Further progress in understanding the dynamics of melt generation in the Kerguelen plume will come from considering the inversion results in the context of thermodynamic models of plumes (e.g., Ribe and Smooke, 1987; Watson and McKenzie, 1991), and integrating this information with Pb-Nd-Sr isotopic data obtained on the basalts.

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