A Hf Isotope Study of Lamproites: Implications for their Origins and Relationship to Kimberlites.

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Introduction

Lamproites are widely accepted to represent melts of enriched ancient lithospheric mantle (Mitchell and Bergman, 1991). However, the cause of the wide petrographic variability of lamproites and their relationship with Group II kimberlites remain matters of controversy. In particular, the influence of subduction zone processes on lamproite source regions and their occurrence in diverse tectonic settings remain problematic (Mitchell and Bergman, 1991). In order to place additional constraints on the source regions and genesis of lamproites, and to better understand the Hf isotopic variability of enriched lithospheric mantle, we have analysed a suite of 33 well characterised lamproites from N. America, including a new lamproite locality in Monatan (Irving and Kuehner, 1998) W. Australia and S. Spain.

Geographical coherence

Hf isotope data for the various lamproite localities are illustrated in Figures 1a&b. Given the accepted model for derivation of lamproites from enriched lithospheric mantle, and because lamproites are known to have negative εNd, it is logical to predict that they should have negative εHf values and simply plot on the established mantle-crust array in Hf-Nd isotope space. However, this is clearly not the case (Fig. 1a). In addition to their notable departure from the Hf-Nd mantle-crust array, the striking feature of the lamproites is their geographical coherence. Western Australian and Spanish lamproites are characterised by a very limited range in εHf, given the range in εNd, and define two distinct sub-horizontal linear arrays that trend off below the mantle-crust array (Figure 1a). North American lamproites are more complex, and this is not unexpected given the broad area from which they were collected. Even here, though, the data show good provincial coherence. Lamproites from Montana are similar to those of W. Australia and Spain and also define a sub-horizontal linear array trending off below the mantle-crust array. In complete contrast, the Madupite and Wyomingite/Orendite lamproite groups from Leucite Hills (Figure 1a) define two separate vertical arrays more akin to the kimberlite arrays (Nowell et al., 1998a). Using the ΔεHf notation of Johnson and Beard (1993), all the lamproites trend toward very negative ΔεHf values, irrespective of whether the arrays are vertical or sub-horizontal (Figure 1b), and in this respect are similar to kimberlites (Nowell et al., 1998a). The convergence of lamproite and Group II kimberlite arrays in HF-Nd isotope space confirm the similarities between these magmas (Mitchell and Bergman, 1991) and it may be argued that they share a common negative ΔεHf source component (Figure 1).

Implications for sources

The observed lamproite Hf-Nd isotope variations must reflect either source heterogeneity or mixing of distinct mantle components since the high field strength element (HFSE) and rare earth element (REE) contents of lamproites buffer them against the effects of crustal contamination. The Nd-Sr isotopic variations in lamproites of N. America and W. Australia have been attributed to mixing between enriched lithospheric mantle and depleted mantle (DM) as represented by Mid Ocean Ridge Basalt (McCulloch et al., 1983; Vollmer et al., 1984). Hf-Nd isotope systematics of lamproites, however, are inconsistent with such mixing models.

Lamproites from Montana and W. Australia are characterised by almost constant εHf and measured Hf/Nd ratios over the wide range in measured εNd. Unless the high εNd 'depleted' end-member has an extremely low Hf/Nd ratio (<0.03), its εHf must be similar to those observed in the lamproites (-35 and -25, respectively) to account for the sub-horizontal nature of the arrays. DM is characterised by a high Hf/Nd ratio of >0.27 and positive εHf (>10) so it cannot be called upon to generate the lamproite arrays in Figure 1a&b. The same applies to any magmas known to have come from the convecting mantle. We argue that the sub-horizontal Montana and W. Australia lamproite arrays can best be explained by mixing between enriched lithosphere and a 'depleted' or high εNd component that has by a very negative εHf and ΔεHf signature. Similarly, the only mixing model that can successfully reproduce the Leucite Hills array is one in which the 'depleted' endmember has very negative εHf (<-26) and ΔεHf values.

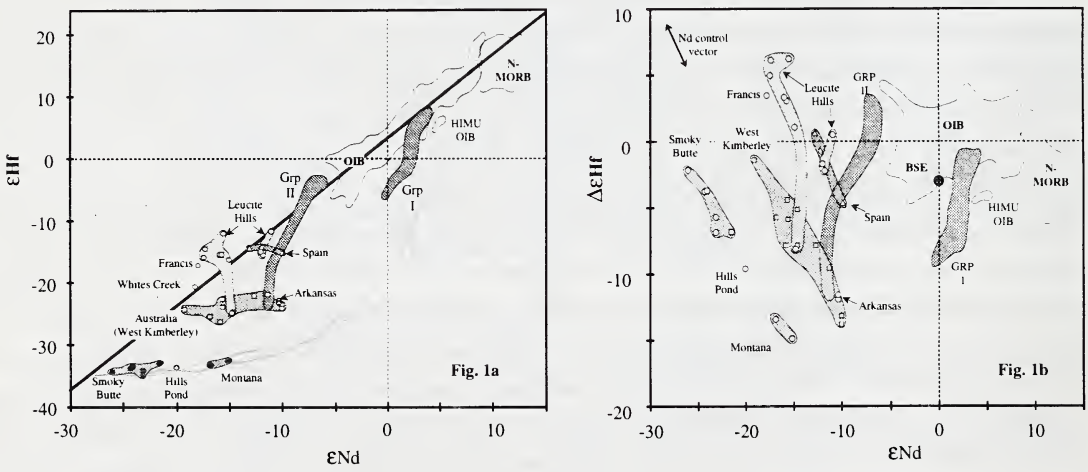

Figure 1a&b. (a) εHf versus εNd and (b) ΔεHf versus εNd for lamproites from N. America, W. Australia and Spain. Also shown are the fields for group I and II kimberlites (Nowell et al., 1998c). Hf isotope data normalised to a ^{176}Hf/^{177}Hf ratio for JMC 475 of 0.28216 (Nowell et al., in press). Nd Isotope data are normalised to a ^{143}Nd/^{144}Nd ratio for La Jolla of 0.511862. External reproducibility for the Hf standard JMC 475 was between 21 and 49ppm 2SD. Nd was determined various laboratories but external reproducibility is better than 60ppm 2SD.

Although it is not clear whether the lamproite arrays are due to mixing of distinct components or melting of a heterogeneous source, their genesis clearly requires a contribution from a reservoir characterised by very negative εHf and ΔεHf values, and it is this reservoir that is of particular interest. Development of negative εHf and ΔεHf values, such as those required for the lamproites, can only occur in ancient melts that were generated in the presence of residual garnet. Such a negative εHf and ΔεHf reservoir may develop in lithosphere that has been enriched by small degree melts derived from garnet-bearing asthenospheric mantle. Alternatively, given that lamproites are associated with fossil Benioff zones, such metasomatic melts might be derived from subducting oceanic crust. Another explanation, which cannot be ruled out at this time, is that the negative εHf and ΔεHf signature of lamproites is imposed on the lithospheric mantle by a metasomatic melt that inherited its negative εHf and ΔεHf signature from a much deeper mantle source. Nowell et al (1998a) argue that just such a negative εHf and ΔεHf reservoir could exist in the sub-lithospheric deep mantle as old subducted oceanic crust that was originally generated in the presence of residual garnet.

Conclusions

A contribution from an ancient melt generated in the presence of garnet is required to explain the trend toward very negative ΔεHf values shown by lamproites from three different regions. The Nd-Hf system appears to be a powerful tool in unravelling differing source components in lamproite magmas. Lamproites from specific locations show good coherence of Hf-Nd isotope systematics, and define distinct fields which may reflect lithospheric provinciality. It is not yet possible to determine whether the lamproite arrays represent variable degrees of melting of a composite lithospheric source or, mixing between enriched lithospheric mantle and a melt derived from a globally ubiquitous, possibly deep-seated, source (Haggerty, 1994; Ringwood et al., 1992) characterised by negative ΔεHf.

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