The source regions/components of kimberlites: constraints from Hf-Nd isotope systematics

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Introduction

Isotopes have played a key role in developing models for the genesis of Group I and II kimberlites. The most accepted model, based on Sr-Nd and Pb isotopes, is that Group I kimberlites have an origin within the asthenosphere, whereas isotopically enriched Group II kimberlites are derived from a time-integrated LIL and LRE element-enriched source located within the sub-continental lithospheric mantle.

In order to place further possible constraints on the genesis of Group I and II kimberlites we analysed a suite of well characterised fresh hyperbyssal South African kimberlites for Hf isotopes. Lu-Hf is similar to Sm-Nd in as much as the parent isotope is more compatible than the daughter isotope but has the added advantage that, unlike the latter, the fractionation of the Lu/Hf ratio during melting is sensitive to the presence or absence of garnet. Ancient melts generated in the presence of garnet should therefore generate distinct Hf-Nd isotopic variations.

Results and Discussion

Preliminary Hf isotope data for kimberlites analysed by conventional TIMS methods are summarised in Table 1 along with Nd isotope data. Data are shown in Figures 1a&b.

In Hf-Nd isotope space, both Group I and II kimberlites are characterised by a remarkably large variation in εHf given their restricted range in εNd (Table 1, Figure 1a). The linear fields defined by both kimberlite groups show a similar degree of obliqueness to, and trend well below, the array defined by other terrestrial magmas (Figure 1a). Using the ΔεHf notation of Johnson and Beard (1993), which defines the extent to which a sample plots above (+ve ΔεHf) or below (-ve ΔεHf) the ocean island basalt (OIB) array, both groups of kimberlites plot toward very -ve ΔεHf values (Figure 1b). Indeed, kimberlites have some of the most extreme -ve ΔεHf values of any terrestrial magmas yet analysed for Hf, except lamproites (Nowell et al.,1998b).

Given the Sr-Nd-Pb isotope-based petrogenetic models for Group I and II kimberlites, it was expected that kimberlites would simply plot on the mantle-crust array at positive and negative εHf values, respectively. The linear trends of Group I and II kimberlites towards low ΔεHf is unexpected, and is inconsistent genetic with models based on Sr-Nd-Pb isotope systematics. There are at least two possible explanations for this:

1] Contamination of a kimberlite magma by components with higher Hf/Nd ratios that lie on the mantle-crust array at lower εHf-εNd such that the negative ΔεHf values of kimberlites are merely an artifact of mixing

2] A source component that contributes to both kimberlite groups is itself characterised by negative ΔεHf values.

Parameter	Group I		Group II	
	max	min	max	min
εHf	7.4	-18.5	-3.6	-23.8
ΔεHf	-1.0	-16.5	2.9	-11.5
εNd	4.0	-3.7	-6.2	-11.8

Table 1. Summary of Hf-Nd isotope data Group I and II kimberlites from South Africa.

Although Archean/Proterozoic crust represents a potential low εHf-εNd component from which kimberlites might inherit a negative ΔεHf signature, prohibitively large degrees of contamination are required to reproduce the kimberlite arrays. The only sample which shows any evidence of crustal contamination, both in hand specimen and in trace element and isotope geochemistry, is Premier Grey. The negative ΔεHf signatures of kimberlites, therefore, do not appear to be an artifact of mixing in the crust. Likewise, contamination with some enriched lithospheric mantle melt, such as represented by lamproites, isn't able to fully explain both the kimberlite arrays. Indeed, the lamproite data itself requires the existence of a source component characterised by a negative ΔεHf signature (Nowell et al.,1998b).

A contribution from a negative ΔεHf reservoir, possibly located in the lithosphere, such as the one that contributes to lamproite magmas may explain the Group II kimberlite trend. Evidence presented by Nowell and Pearson (1998) suggests that for group I kimberlites the negative ΔεHf signature might already be established before they even interact with, or traverse, the lithosphere. This would, in turn, imply that a ΔεHf reservoir must exist in the sub-lithospheric mantle. By analogy is possible that a similar sub-lithospheric negative ΔεHf reservoir is responsible for the ΔεHf signature of group II kimberlites.

Although the negative ΔεHf signatures of Group I and II kimberlites may be inherited from different sources within the mantle, in both cases such signatures must be indicative of ancient melts generated in the presence of residual garnet. In the case of Group II kimberlites, and possibly lamproites, this signature may represent old lithosphere enriched by small degree melts derived from garnet-bearing asthenospheric mantle, perhaps even 'protokimberlite' melts that failed to erupt. It is also conceivable that this signature may develop near the base of the lithosphere in eclogites that 'represent ancient recrystallised subducted underplated oceanic crust' (Mitchell, 1995). The very negative ΔεHf signatures of Group I kimberlites have not been observed in magmas known to have originated from the convecting mantle. Thus, to explain the Group I kimberlite data requires a component that has been isolated from the convecting upper mantle for long periods that is not obviously lithospheric mantle. If not old enriched lithosphere, the only plausible candidate for this very negative ΔεHf component in the deep mantle is old subducted oceanic crust±oceanic lithosphere/sediments. This is compatible with those models which invoke a very deep mantle origin for kimberlites, incorporating crust±oceanic lithosphere/sediments from the D" prime layer (Haggerty, 1994) or 670km discontinuity (Ringwood et al, 1992).

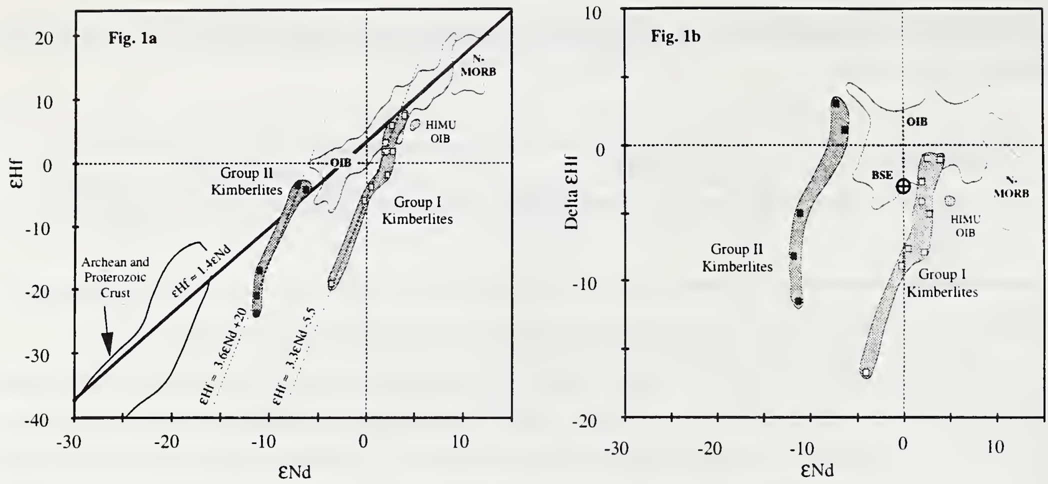

Figure 1a&b. (a) εHf versus εNd and (b) ΔεHf versus εNd for Group I and II kimberlites. Hf isotope data are normalised to a ^{176}Hf/^{177}Hf ratio for JMC 475 of 0.28216 (Nowell et al., 1998c) while Nd Isotope data are normalised to a ^{143}Nd/^{144}Nd ratio for La Jolla of 0.511862. During analysis of the kimberlites the external reproducibility for the Hf standard JMC 475 was between 32 and 63ppm 2SD and for Nd was 35ppm 2SD.

Conclusion

The ΔεHf signature of group I and II kimberlites implies that an ancient melt, necessarily generated in the presence of residual garnet, must exist within their source regions. For Group II kimberlites this old melt component it may reside as ancient subducted oceanic crust in the lithsopheric mantle but for Group I kimberlites may reside in the deeper mantle, perhaps at the 650km discontinuiy or D" prime layer (Ringwood et a., 1992; Haggerty, 1994).

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