SOURCE REGIONS OF KIMBERLITES AND LAMPROITES: CONSTRAINTS FROM RE-OS ISOTOPES

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Despite intensive research the nature of kimberlite and lamproite source regions remains controversial. Since the recognition of two isotopically distinct groups of southern African kimberlites (Smith, 1983) numerous "transitional" varieties have been found which may have originated either entirely within the lithosphere or as mixtures of asthenosphere- and lithosphere-derived melts. In addition, phase equilibria studies indicate that some kimberlites may originate from at least 300 km deep (Edgar and Charbonneau, 1993) while ultra-high pressure inclusions found in some diamonds allow an origin from 670 km or even the lower mantle-core/mantle boundary (Haggerty, 1994). To further constrain genetic models we have analysed a suite of well characterised southern African kimberlites and a varied suite of lamproites from the western U.S.A and Australia The highly distinctive Os isotope composition of lithospheric mantle (Carlson and Irving, 1994, Pearson et. al., in press;) and the tendency for Os to trace the major element evolution of magmas should make the Re-Os isotope system a powerful tracer of magma source regions.

Re (20-680 ppt; mean 287 ± 203 ppt) and Os (700 ppt to 3.1 ppb; mean 1.3 ± 0.8 ppb) contents of the kimberlites (n=16) are highly variable with no distinction between Group I, Group II or transitional variants. Lamproites and associated rocks (n=12) have systematically lower Re contents (15 to 398 ppt; mean 130 ± 120 ppt), and generally lower Os contents (113 ppt to 2.23 ppb; mean 570 ± 626 ppt) than either group of kimberlites but their ^{187}Re/^{188}Os values are the same within error (Kimb. 1.5±1.44; Lamp. 1.7 ± 1.5). Os shows a broad positive correlation with Ni, especially for the Group I kimberlites. Re is uncorrelated with Ni or incompatible elements such as Ba. The Re contents of kimberlites and lamproites are surprisingly low. Although it is tempting to speculate on the significance of this we are uncertain to what extent this may be the result of sulphide breakdown and oxidation during explosive eruption. Most of the samples studied here are young enough and of high enough Os content that more than a factor of 10 loss of Re would be needed to significantly change the conclusions regarding initial isotopic compositions.

^{187}Os/^{188}Os in the kimberlites vary from 0.11405 to 0.13918 in Mesozoic. Calculated initial Os isotopic compositions, expressed as γ_{Os} values (percent deviation from Bulk Earth at the time of eruption) for the Mesozoic kimberlites range from -10 to 6.7. There are no systematic differences between initial γ_{Os} values for Mesozoic Group I and Group II kimberlites (Fig. 1) and this is consistent with the broad similarities seen in their PGE patterns (McDonald et. al., 1994). The least radiogenic sample is from the Group II Bellsbank kimberlite which contains a very high abundance of olivine macrocrysts . This facies of the Bellsbank kimberlite is estimated to consist of up to 90% macrocrystic olivine in places, possibly derived from disrupted peridotite xenoliths. A further sample prepared by hand-picking macrocryst-free fragments of the kimberlite contained substantially lower Os (2.3 vs 3.1 ppb for the bulk sample) of more radiogenic isotopic composition (γ_{Os} -7 vs. -10). The γ_{Os} value of -10 for the bulk sample is remarkably close to the mean γ_{Os} value of -10.0 ± 4.7 for 21 Low-T Kaapvaal peridotite xenoliths (Pearson et. al., in press) suggesting that Os in this macrocryst-rich sample is dominated by comminuted, Os-rich (~3 ppb) peridotite. The possible influence of this process on the kimberlite suite as a whole can be seen from the general correlation between γ_{Os} and 1/Os (Fig. 2). It is therefore possible that the Os isotopic signature in some kimberlites is largely dominated by incorporation of >50% lithospheric peridotite into the kimberlite. This is compatible with the suggestion that the very high Ni contents in Finsch kimberlites are due to incorporation of over 50% lithospheric peridotite by comminution (Fraser and Hawkesworth, 1992). A further possibility is the contamination of kimberlite magma by siderophile element enriched "nuggets" within the lithospheric mantle (McDonald et. al., 1994).

The more radiogenic Os isotope compositions of *both* groups of kimberlites may be influenced by crustal contamination, the lower Os samples generally having higher γ_{Os} values (Fig. 2) although no strong trend is apparent. The samples studied are hypabyssal facies, selected for their lack of visible crustal contamination and the proportions of Archaean crust (up to 20%) required by simple mixing calculations (Fig. 2) seem unreasonably high. What then, is the nature of the kimberlite source ? Despite the probable influence of disaggregated peridotite on the Os isotope signatures of kimberlites few of them plot within the field for Kaapvaal peridotites (Low-T and High-T) in Nd-Os isotope space (Fig. 3). The Os isotope compositions of 5 metasomites from the Kimberley pipes (GPP-PKP-MARID's), γ_{Os} -13.1 to 9.4, overlap both the unradiogenic and radiogenic end of the Os isotope range for southern African kimberlites (Fig. 1) but none plot within the main compositional range. One MARID sample gives a Re-Os model age of 170 ± 30 Ma., within the range of ages for kimberlite activity in the region. This and other data indicate that the metasomites occurring in the Kimberley pipes are more likely products of kimberlite magmatism rather than its source. The data do not allow us to accurately constrain the Os isotope composition of kimberlite source regions but the clustering of compositions around the chondritic average ($\gamma_{Os} = 0$) for both Group I and Group II kimberlites do not require large volumes of ancient depleted lithosphere as the dominant *source* component in either group if Os traces the major elements. This does not preclude the highly incompatible elements in Group II kimberlites originating from highly enriched reservoirs such as those present in the lithosphere. A deep (300 km or more) origin from subducted oceanic lithosphere variably metasomatised by subducted sediments is also permitted by the data.

The Os isotope compositions of the lamproites are much more variable than those of kimberlites and most are more radiogenic than Bulk Earth (Fig. 3). These radiogenic values cannot realistically be explained by contamination with crust and appear to require highly heterogeneous sources. Samples from throughout the Wyoming Craton have consistently radiogenic Os isotope compositions although ε_{Nd} varies widely (Fig. 3). Websterite and a mica-dunite xenoliths from Montana (Carlson and Irving, 1994) are the only mantle samples thus far analysed that overlap the low ε_{Nd}-high γ_{Os} isotopic compositions of some lamproites. Lamproite sources may be quite different from those of kimberlites and the great isotopic variability of lamproites may be explained if they originated from complex sources consisting of veined lithospheric mantle (Foley, 1992). In terms of isotopes, a compositie source similar to mica-pyroxenite ± harzburgite wall rock could be a plausible lamproite source. The isotopic data indicate that Group II kimberlites and lamproites are unlikely to originate from similar sources.

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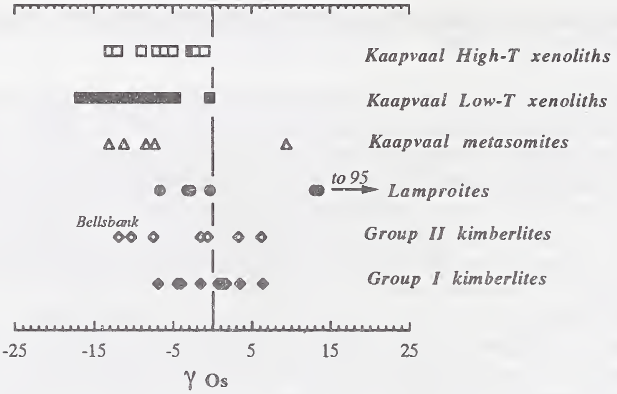
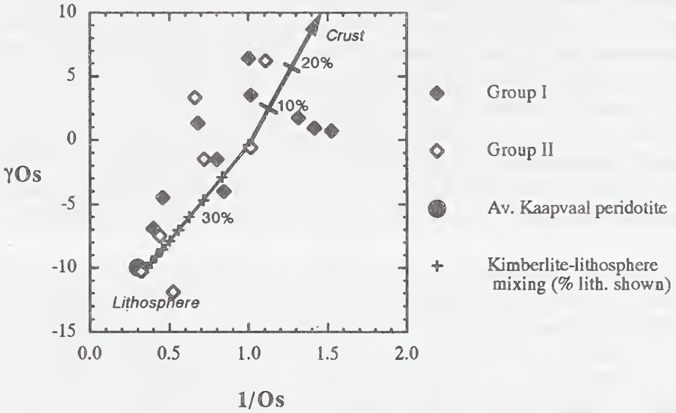
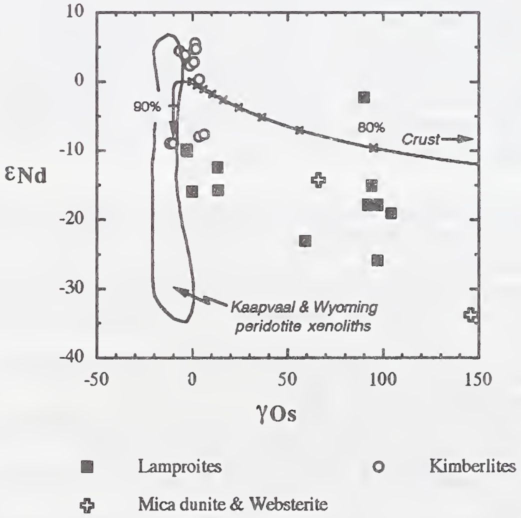

Kaapvaal High-T xenoliths
Kaapvaal Low-T xenoliths
Kaapvaal metasomites
to 95
Lamproites
Bellsbank
Group II kimberlites
Group I kimberlites
-25
-15
-5
5
15
25
γ Os


10
5
0
-5
-10
-15
γOs
Crust
20%
10%
30%
Lithosphere
0.0
0.5
1.0
1.5
2.0
1/Os
Group I
Group II
Av. Kaapvaal peridotite
Kimberlite-lithosphere mixing (% lith. shown)


10
0
-10
-20
-30
-40
εNd
90%
80%
Crust
Kaapvaal & Wyoming peridotite xenoliths
-50
0
50
100
150
γOs
Lamproites
Kimberlites
Mica dunite & Websterite